WATER TREATMENT 404

CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE



Technical Learning College

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Professional Engineers: Most states will accept our courses for credit but we do not officially list the States or Agencies acceptance or approvals.

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We have taught this course to over 5,000 students in a conventional classroom setting. Call and schedule a class at your facility or utilize the distance learning course to obtain your CEUs.

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Technical Learning College's Scope and Function

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds approximately eighty different governmental approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. Most TLC's distance based or independent study courses are offered in a print based format and you are welcome to examine this material on your computer with no obligation. Our courses are designed to be flexible and for you do finish the material on your leisure. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and assignments. Most CEU courses allow students to submit lessons using e-mail or fax; however some courses require students to submit lessons by postal mail. (See the course description for more information.) Students have direct contact with their instructor—primarily by e-mail. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling, i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored exams depending upon your state requirements.

Flexible Learning
At TLC, there are no scheduled online sessions you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

We will beat any other training competitor's price for the same CEU material or classroom training. Student satisfaction is guaranteed.

Course Structure
TLC's online courses combine the best of online delivery and traditional university textbooks. Online you will find the course syllabus, course content, assignments, and online open book exams. This student friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One
TLC Online offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members are assigned at the beginning of each course providing the academic support you need to successfully complete each course.

Satisfaction Guaranteed
Our Iron-Clad, Risk-Free Guarantee ensures you will be another satisfied TLC student.

We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.

Our administrative staff is trained to provide the best customer service in town. Part of that training is knowing how to solve most problems on the spot with an exchange or refund.

TLC Continuing Education Course Material Development
Technical Learning College's (TLC's) continuing education course material development was based upon several factors; extensive academic research, advice from subject matter experts, data analysis, task analysis and training needs assessment process information gathered from other states.



Rush Grading Service

If you need this assignment graded and the results mailed to you within a 48-hour period, prepare to pay an additional rush service handling fee of $50.00. This fee may not cover postage costs. If you need this service, simply write RUSH on the top of your Registration Form. We will place you in the front of the grading and processing line.

For security purposes, please fax or e-mail a copy of your driver's license and always call us to confirm we've received your assignment and to confirm your identity.

Thank you…

Please fax or e-mail the answer key to TLC
Western Campus Fax (928) 272-0747 Back-up Fax (928) 468-0675.

Water Treatment 404 CEU Training Course Description

This distance learning training CEU course will cover conventional water treatment methods, sampling procedures, chlorine and disinfection and the Safe Drinking Water Act. This course will also cover modern water treatment methods and pumps and motors. We as professional Operators need to make sure that our finished water meets federal compliance and minimum standards.

Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators, Water Treatment Specialists and Customer Service Personnel are welcomed to take this course. The target audience for this course is the person interested in working in a water treatment or distribution facility and/or wishing to maintain CEUs for a certification license or to learn how to do the job safely and effectively and/or to meet education needs for promotion.

Task Analysis and Training Needs Assessments have been conducted to determine or set Needs-To-Know for this CEU course. The following is a listing of some of those who have conducted extensive valid studies from which TLC has based this program upon: the Environmental Protection Agency (EPA), the Arizona Department of Environmental Quality (ADEQ), the Texas Commission of Environmental Quality (TCEQ) and the American Boards of Certification (ABC).

Final Examination for Credit
Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

Course Procedures for Registration and Support
All of TLC's correspondence courses have complete registration and support service offered. Delivery of service will include, e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service. When a student registers for a distance or correspondence course, he or she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique assigned number.

Instructions for Written Assignments
The Water Treatment 404 CEU training course uses a multiple-choice and fill-in-the-blank answer key. You can find the Microsoft Word version on the Assignment page. We would prefer the answers are typed and faxed or e-mailed to info@tlch2o.com. If you are unable to do so, please write inside the assignment booklet, make a copy for yourself and mail us the completed manual. Please feel free to call us if you need assistance.

Other Student Information
Feedback Mechanism (Examination procedures)
Each student will receive a feedback form as part of their study packet. You will be able to find this form in the rear of the course or lesson. By completing this form, you can help us improve our course and serve your need better in the future.

Security and Integrity
All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit will result in the student forfeiting all fees, and the appropriate agency will be notified.

Grading Criteria
TLC offers the student either pass/fail or a standard letter grading assignment if we are notified by the student. If we are not notified, you will only receive a certificate for passing the test.

Recordkeeping and Reporting Practices
TLC will keep all student records for a minimum of seven years. It is the student's responsibility to give the completion certificate to the appropriate agencies. TLC will not release any records to any party, except to the student self.

ADA Compliance
TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group.

Note to Students
Keep a copy of everything that you submit! If your work is lost, you can submit your copy for grading. If you do not receive your certificate of completion or other results within two to three weeks after submitting it, please contact your instructor.

Educational Mission
The educational mission of TLC is:
To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the pesticide application field,

To provide TLC students with opportunities to understand and apply the theory and skills needed for pesticide application certification,

To provide opportunities for TLC students *to* learn and practice pesticide application skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to pesticide application education,

To provide a forum for the collection and dissemination of current information related to pesticide application education, and

To maintain an environment that nurtures academic and personal growth.

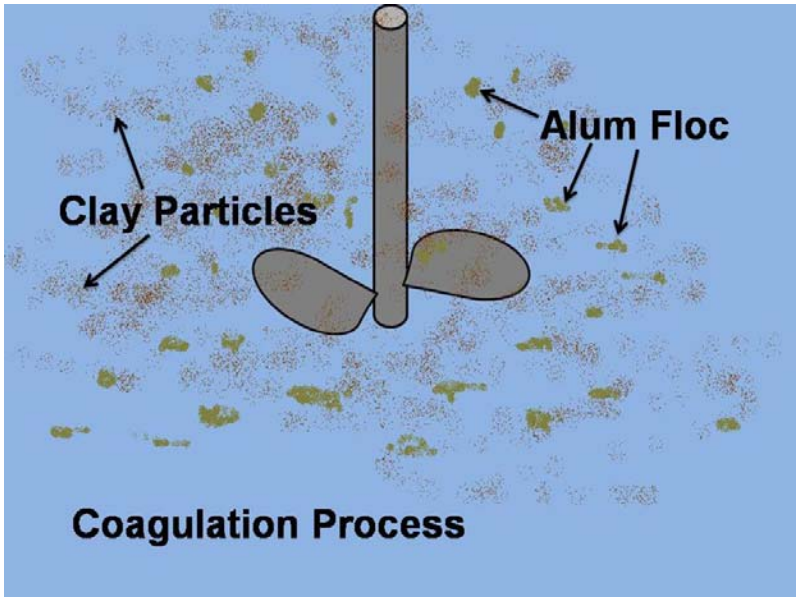
Mission Statement
Our only product is educational service. Our goal is to provide you with the best education service possible. TLC attempts to make your learning experience an enjoyable educational opportunity.

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Common Water Treatment Acronyms

AA Activated alumina
AC Activated carbon
ASR Annual Status Report
As(III) Trivalent arsenic, common inorganic form in water is arsenite, H_3AsO_3
As(V) Pentavalent arsenic, common inorganic form in water is arsenate, H_2AsO_4
BDAT best demonstrated available technology
BTEX Benzene, toluene, ethylbenzene, and xylene
CCA Chromated copper arsenate
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS 3 CERCLA Information System
CLU-IN EPA's CLeanUp INformation system
CWS Community Water System
cy Cubic yard
DDT Dichloro-diphenyl-trichloroethane
DI De-ionized
DOC Dissolved organic carbon
DoD Department of Defense
DOE Department of Energy
EDTA Ethylenediaminetetraacetic acid
EPA U.S. Environmental Protection Agency
EPT Extraction Procedure Toxicity Test
FRTR Federal Remediation Technologies Roundtable
ft feet
GJO DOE's Grand Junction Office
gpd gallons per day
gpm gallons per minute
HTMR High temperature metals recovery
MCL Maximum Contaminant Level (enforceable drinking water standard)
MF Microfiltration
MHO Metallurgie-Hoboken-Overpelt
mgd million gallons per day
mg/kg milligrams per kilogram
mg/L milligrams per Liter
NF Nanofiltration
NPL National Priorities List
OCLC Online Computer Library Center
ORD EPA Office of Research and Development
OU Operable Unit
PAH Polycyclic aromatic hydrocarbons
PCB Polychlorinated biphenyls
POTW Publicly owned treatment works
PRB Permeable reactive barrier
RCRA Resource Conservation and Recovery Act
Redox Reduction/oxidation
RO Reverse osmosis
ROD Record of Decision
SDWA Safe Drinking Water Act



SMZ surfactant modified zeolite
SNAP Superfund NPL Assessment Program
S/S Solidification/Stabilization
SVOC Semi-volatile organic compounds
TCLP Toxicity Characteristic Leaching Procedure
TNT 2,3,6-trinitrotoluene
TWA Total Waste Analysis
UF Ultrafiltration
VOC Volatile organic compounds
WET Waste Extraction Test
ZVI Zero valent iron



Ozone generator

Water Treatment Terms

Community Water System (CWS). A public water system that serves at least 15 service connections used by year-round residents of the area served by the system or regularly serves at least 25 year-round residents.

Class V Underground Injection Control (UIC). Rule A rule under development covering wells not included in Class I, II, III or IV in which nonhazardous fluids are injected into or above underground sources of drinking water.

Contamination Source Inventory. The process of identifying and inventorying contaminant sources within delineated source water protection areas through recording existing data, describing sources within the source water protection area, targeting likely sources for further investigation, collecting and interpreting new information on existing or potential sources through surveys, and verifying accuracy and reliability of the information gathered.

Cryptosporidium. A protozoan associated with the disease cryptosporidiosis in humans. The disease can be transmitted through ingestion of drinking water, person-to-person contact, or other exposure routes. Cryptosporidiosis may cause acute diarrhea, abdominal pain, vomiting, and fever that last 1-2 weeks in healthy adults, but may be chronic or fatal in immuno-compromised people.

Drinking Water State Revolving Fund (DWSRF). Under section 1452 of the SDWA, the EPA awards capitalization grants to states to develop drinking water revolving loan funds to help finance drinking water system infrastructure improvements, source water protection, to enhance operations and management of drinking water systems, and other activities to encourage public water system compliance and protection of public health.

Exposure. Contact between a person and a chemical. Exposures are calculated as the amount of chemical available for absorption by a person.

Giardia lamblia. A protozoan, which can survive in water for 1 to 3 months, associated with the disease giardiasis. Ingestion of this protozoan in contaminated drinking water, exposure from person-to-person contact, and other exposure routes may cause giardiasis. The symptoms of this gastrointestinal disease may persist for weeks or months and include diarrhea, fatigue, and cramps.

Ground Water Disinfection Rule (GWDR). Under section 107 of the SDWA Amendments of 1996, the statute reads, ". . . the Administrator shall also promulgate national primary drinking water regulations requiring disinfection as a treatment technique for all public water systems, including surface water systems, and as necessary, ground water systems."

Maximum Contaminant Level (MCL). In the SDWA, an MCL is defined as **"*the maximum permissible level of a contaminant in water which is delivered to any user of a public water system*."** MCLs are enforceable standards.

Maximum Contaminant Level Goal (MCLG). The maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health effect of persons would occr, and which allows for an adequate margin of safety. MCLGs are non-enforceable public health goals.

Nephelolometric Turbidity Units (NTU). A unit of measure used to describe the turbidity of water. Turbidity is the cloudiness in water.

Nitrates. Inorganic compounds that can enter water supplies from fertilizer runoff and sanitary wastewater discharges. Nitrates in drinking water are associated with methemoglobanemia, or blue baby syndrome, which results from interferences in the blood's ability to carry oxygen.

Non-Community Water System (NCWS). A public water system that is not a community water system. There are two types of NCWSs: transient and non-transient.

Organics. Chemical molecules contain carbon and other elements such as hydrogen. Organic contaminants of concern to drinking water include chlorohydrocarbons, pesticides, and others.

Phase I Contaminants. The Phase I Rule became effective on January 9, 1989. This rule, also called the Volatile Organic Chemical Rule, or VOC Rule, set water quality standards for 8 VOCs and required all community and Non-Transient, Non-Community water systems to monitor for, and if necessary, treat their supplies for these chemicals. The 8 VOCs regulated under this rule are: Benzene, Carbon Tetrachloride, para-dichlorobenzene, trichloroethylene, vinyl chloride, 1,1,2-trichlorethane, 1,1-dichloroethylene, and 1,2-dichlorothane.

Per capita. Per person; generally used in expressions of water use, gallons per capita per day (gpcd).

Point-of-Use Water Treatment. Refers to devices used in the home or office on a specific tap to provide additional drinking water treatment.

Point-of-Entry Water Treatment. Refers to devices used in the home where water pipes enter to provide additional treatment of drinking water used throughout the home.

Primacy State State that has the responsibility for ensuring a law is implemented, and has the authority to enforce the law and related regulations. State has adopted rules at least as stringent as federal regulations and has been granted primary enforcement responsibility.

Radionuclides. Elements that undergo a process of natural decay. As radionuclides decay, they emit radiation in the form of alpha or beta particles and gamma photons. Radiation can cause adverse health effects, such as cancer, so limits are placed on radionuclide concentrations in drinking water.

Risk. The potential for harm to people exposed to chemicals. In order for there to be risk, there must be hazard and there must be exposure.

SDWA - The Safe Drinking Water Act. The Safe Drinking Water Act was first passed in 1974 and established the basic requirements under which the nation's public water supplies were regulated. The US Environmental Protection Agency (**EPA**) is responsible for setting the national drinking water regulations, while individual states are responsible for ensuring that public water systems under their jurisdiction are complying with the regulations. The SDWA was amended in 1986 and again in 1996.

Significant Potential Source of Contamination. A facility or activity that stores, uses, or produces chemicals or elements, and that has the potential to release contaminants identified in a state program (contaminants with MCLs plus any others a state considers a health threat) within a source water protection area in an amount which could contribute significantly to the concentration of the contaminants in the source waters of the public water supply.

Sole Source Aquifer (SSA) Designation. The surface area above a sole source aquifer and its recharge area.

Source Water Protection Area (SWPA). The area delineated by the state for a PWS or including numerous PWSs, whether the source is ground water or surface water or both, as part of the state SWAP approved by the EPA under section 1453 of the SDWA.

Sub-watershed. A topographic boundary that is the perimeter of the catchment area of a tributary of a stream.

State Source Water Petition Program. A state program implemented in accordance with the statutory language at section 1454 of the SDWA to establish local voluntary incentive-based partnerships for SWP and remediation.

State Management Plan (SMP) Program. A state management plan under FIFRA required by the EPA to allow states (e.g. states, tribes and U.S. territories) the flexibility to design and implement approaches to manage the use of certain pesticides to protect ground water.

Surface Water Treatment Rule (SWTR). The rule specifies maximum contaminant level goals for ***Giardia lamblia***, viruses and ***Legionella,*** and promulgated filtration and disinfection requirements for public water systems using surface water sources, or by ground water sources under the direct influence of surface water. The regulations also specify water quality, treatment, and watershed protection criteria under which filtration may be avoided.

Susceptibility Analysis. An analysis to determine, with a clear understanding of where the significant potential sources of contamination are located, the susceptibility of the public water systems in the source water protection area to contamination from these sources. This analysis will assist the state in determining which potential sources of contamination are "**significant**."

To the Extent Practical. States must inventory sources of contamination to the extent they have the technology and resources to complete an inventory for a Source Water Protection Area delineated as described in the guidance. All information sources may be used, particularly previous Federal and state inventories of sources.

Transient/Non-Transient, Non-Community Water Systems (T/NT, NCWS). Water systems that are non-community systems: transient systems serve 25 non-resident persons per day for 6 months or less per year. Transient non-community systems typically are restaurants, hotels, large stores, etc. Non-transient systems regularly serve at least 25 of the same non-resident persons per day for more than 6 months per year. These systems typically are schools, offices, churches, factories, etc.

Treatment Technique. A specific treatment method required by the EPA to be used to control the level of a contaminant in drinking water. In specific cases where the EPA has determined it is not technically or economically feasible to establish an MCL, the EPA can

instead specify a treatment technique. A treatment technique is an enforceable procedure or level of technical performance which public water systems must follow to ensure control of a contaminant.

Total Coliform. Bacteria that are used as indicators of fecal contaminants in drinking water.

Toxicity. The property of a chemical to harm people who come into contact with it.

Underground Injection Control (UIC) Program. The program is designed to prevent underground injection which endangers drinking water sources. The program applies to injection well owners and operators on Federal facilities, Native American lands, and on all U.S. land and territories.

Watershed. A topographic boundary area that is the perimeter of the catchment area of a stream.

Watershed Approach. A watershed approach is a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, taking into consideration both ground and surface water flow.

Watershed Area. A topographic area that is within a line drawn connecting the highest points uphill of a drinking water intake, from which overland flow drains to the intake.

Wellhead Protection Area (WHPA). The surface and subsurface area surrounding a well or well field, supplying a PWS, through which contaminants are reasonably likely to move toward and reach such water well or well field.

More SDWA Information

Any federal agency having jurisdiction over federally owned and maintained public water systems must comply with all federal, state, and local drinking water requirements as well as any underground injection control programs (Section 1447). The Act provides for waivers in the interest of national security.

Procedures for judicial review are outlined (Section 1448), and provision for citizens' civil actions is made (Section 1449). Citizen suits may be brought against any person or agency allegedly in violation of provisions of the Act, or against the Administrator for alleged failure to perform any action or duty which is not discretionary.

EPA may use the new estrogenic substances screening program created in the Food Quality Protection Act of 1996 (P .L. 104-170) to provide for testing of substances that may be found in drinking water if the Administrator determines that a substantial population may be exposed to such substances (Section 1457).

EPA is directed to conduct drinking water studies involving subpopulations at greater risk and biological mechanisms, and studies to support several rules including those addressing D/DBPs and ***Cryptosporidium***. The Centers for Disease Control and Prevention and EPA must conduct pilot waterborne disease occurrence studies by August 1998. (Section 1458).

The Act includes a provision amending the Federal Food, Drug, and Cosmetic Act, generally requiring the Secretary of Health and Human Services to issue bottled drinking water standards for contaminants regulated under the Safe Drinking Water Act.

Other provisions of P.L. 104-182 authorize water and wastewater grants for *colonias* and Alaska rural and native villages, and authorize the transfer of the Washington (D.C.) Aqueduct to a regional authority.

The 1996 Amendments also authorize a $50 million per year grant program for additional infrastructure and watershed protection projects; the conference report lists, and directs EPA to give priority consideration to, 24 such projects.



IDEXX's SimPlate for HPC method is used for the quantification of heterotrophic plate count (HPC) in water. It is based on the Multiple Enzyme Technology which detects viable bacteria in water by testing for the presence of key enzymes known to be present in these little organisms. This technique uses enzyme substrates that produce a blue fluorescence when metabolized by waterborne bacteria. The sample and media are added to a SimPlate Plate, incubated and then examined for fluorescing wells. The number of wells corresponds to a Most Probable Number (MPN) of total bacteria in the original sample. The MPN values generated by the SimPlate for HPC method correlate with the Pour Plate method using the Total Plate Count Agar, incubated at 35^{o}C for 48 hours as described in *Standard Methods for the Examination of Water and Wastewater, 19th Edition.*

We will be more into detail in the Water Monitoring Section.

Sampling Plan

A written sampling plan must be developed by the water system. These plans will be reviewed by the Health Department or State Drinking Water agency during routine field visits for sanitary surveys or technical assistance visits. This plan should include:

1. The location of routine sampling sites on a system distribution map. You will need to locate more routine sampling sites than the number of samples required per month or quarter. A minimum of three sites is advised and the sites should be rotated on a regular basis.
2. Map the location of repeat sampling sites for the routine sampling sites. Remember that repeat samples must be collected within five (5) connections upstream and downstream from the routine sample sites.
3. Establish a sampling frequency of the routine sites.
4. Sampling technique, establish a minimum flushing time and requirements for free chlorine residuals at the sites (if you chlorinate continuously).

The sampling sites should be representative of the distribution network and pressure zones. If someone else, e.g., the lab, collects samples for you, you should provide them with a copy of your sampling plan and make sure they have access to all sample sites.



Grabbing a sample from a stream.

Understanding Water Quality

What's that Stuff in the Tap Water?

by Jameel Rahman and Gary A. Burlingame

Jameel Rahman is a retired analytical chemist supervisor for the Materials Testing Laboratory at the Philadelphia Water Department, where Gary A. Burlingame is the supervisor of water quality and research. Contact Burlingame at gary.burlingame@phila.gov or (215) 685-1417.

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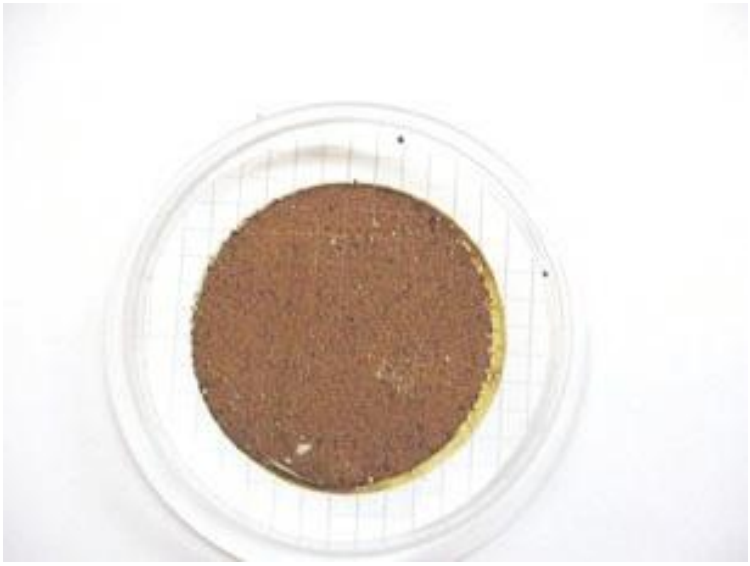
Almost every water utility employee responsible for solving customer problems has fielded a complaint about particles in a bathtub or faucet aerator. Although particles can come from cold or hot water systems, household plumbing, water distribution systems, and water treatment, the water supplier—at least in customers' eyes—is usually "*guilty until proven innocent*."

The Philadelphia Water Department has standardized procedures in place that can identify offending materials and help pinpoint their source.

Collecting and Identifying Particulates

Typically, the suspended matter customers complain about is particulate in form. The most important step in solving a particulate complaint is to collect as much suspect material as possible; making sure it represents the customer's actual concern. Sometimes enough material for analysis can be collected from faucet aerators. A container may be left with the customer for sample collection during normal tap use. Particulates can also accumulate in the toilet tank.

Particulate matter can be extracted from water samples by using nitrocellulose membrane filters. A 0.45 µm filter can be used if the water's colloidal matter doesn't clog the filter before enough particulate material is collected for analysis. Enough particulate matter can usually be captured with a water sample of approximately 250 mL. When samples have low turbidity, larger volumes will need to be filtered.



Granular Rust→

Under a microscope, examine the particulate matter captured on a filter.

Use a zoom microscope with at least 40×, preferably 75×, magnification to identify matter on the membrane filter disk, which can be stored in a Plexiglas Petri dish. For optimum observation, illuminate the particulates from above with a fiber-optic light.

Some particulates can be identified by their appearance and, sometimes, by touching them with a sharp needle and observing their physical properties, such as softness, stickiness, or solubility in a solvent. Particulates can be quantified as few, several, or numerous. If particulates cannot be identified by their appearance, perform simple chemical tests on the filter.

A characteristic evolution of a gas, such as carbon dioxide from scale particulates or marble, can be observed under the microscope. Color formed by chemical reactions can be seen by the unaided eye. If these tests still fail to identify the debris, or further delineation is required, use infrared spectroscopy (**IR**).

Visual Identification

Sand particulates have a characteristic vitreous appearance and irregular shape with smooth facets. They can be colorful but usually appear translucent to whitish.

Mica particulates have a characteristic platelet shape and shine under reflected light. You will need to understand the common soil minerals in your area to identify them.

Man-made fibers, found in all colors and with a characteristic wrinkled strip shape, are present in single strands, have significant length, and often are visible to the unaided eye. Usually, fibers are not present in large numbers — at most, 10 per filter. Fibers used in apparel are round, but fibers found in water typically have a strip shape, indicating a common source, such as pump packing.

Glass chips are transparent, may have smooth facets with sharp edges, and may be colorful. Relatively large amounts of similar particulates often indicate a problem within a plumbing system. Usually the source of such particulates is disintegrating plastic, a rubber gasket, or a corroding component of the plumbing system.

Heat Identification

Activated carbon particulates are black and usually coated with debris. They can show porosity, but appear dull compared to anthracite particulates, which display a shiny luster under reflected light. Pick up a few particulates on the tip of a wetted platinum wire and burn them in the blue part of a Bunsen burner flame. AC particulates will burn instantaneously with a glitter and no visible smoke or residue.

Disintegrated plastic particulates are usually white, large, and may be present in large numbers. Pick up a few particulates and burn them in a Bunsen burner flame. Plastic burns with a smoke. With fine-tipped tweezers, remove sufficient particulates from the disk and further identify them by IR. Most often they are polypropylene plastic. Disintegrated rubber gasket particulates are usually black, relatively large, and do not smear the filter disk with black when a drop of toluene is applied. If pressed with a needle, they flex. Remove a few particulates and burn them; rubber burns with a black smoke. Identify them further by IR. Often these particulates are ethylene-propylene-diene monomer, used in gaskets.

Acid Identification

Rust particulates are usually abundant and are easy to identify with their typically brown and rough irregular shapes. Large particulates may have yellow and black streaks or inclusions, while fine rust particulates form a uniform brown film on the filter disk. To confirm rust, add a drop of (1+1) hydrochloric acid (500 mL of 11.5N hydrochloric acid [**HC**l] solution plus 500 mL of distilled water) to the filter. Yellow staining indicates the presence of ferric chloride.

Add a drop of 2 percent solution of potassium thiocyanate on the yellow area where HCl was added. Brick-red staining confirms the presence of potassium ferrithiocyanate.



Large Rust Particles

Lead solder particulates are gray and may have a whitish coating, are usually brittle, and can be easily pulverized. Often, they are relatively large in size compared to most other particulates on the filter disk. If lead particulates are suspected, add a drop of pH 2.8 tartrate-buffer solution followed by a drop of 0.2 percent solution of freshly prepared sodium rhodizonate. If the particulates turn scarlet red, lead solder is present.

Prepare a pH 2.8 buffer solution by dissolving 1.9 g of sodium bitartrate and 1.5 g of tartaric acid in 100 mL of distilled water. To prepare the sodium rhodizonate reagent, dissolve 0.2 g of rhodizonic acid disodium salt in 100 mL of distilled water.

Patina is hydrated basic copper carbonate and has a greenish color. These irregularly shaped particulates result from corrosion of copper and copper alloys. To confirm their presence, add a drop of (1+1) HCl from a Pasture pipette. If tiny bubbles of carbon dioxide form under the microscope, the presence of patina is indicated. Remove a few particulates and place them in the cavity of a spot-test plate. Add a drop of (1+1) HCl followed by a drop of ammonia. Appearance of a blue precipitate or blue color confirms the presence of patina particulates. Rust particulates will interfere with this test if it is performed on the rust-coated filter. Calcium carbonate can develop as a white scale through evaporation of hard water or can occur as a particulate of limestone or calcite. Scales can form in water heaters.

Limestone can come from water treatment processes. Add a drop of HCl (1+1) on the particulates and observe the evolution of carbon dioxide under the microscope. The brisk evolution of gas confirms the presence of carbonates.

Solvent Identification

Asphalt pipe-coating compounds are black. To differentiate between various black particulates, add a drop of toluene or chloroform to the filter disk under the microscope. If the disk becomes smeared with black around the particulates, the particulates are classified as pipe-coating of an asphaltic nature. Anthracite, activated carbon, and rubber particulates are insoluble in the solvents used.

Anthracite particulates appear shiny compared with other black particulates and do not smear the filter disk if a drop of toluene is applied. These particulates can be removed from the filter disk and burned in a crucible; they will leave a solid residue.

Grease particulates are black and may be shiny. They are usually present as tiny heaps on the filter disk because of their softness and hydrophobic nature. They are soft and sticky when touched with a needle and can be smeared easily on the disk. Add a drop of toluene; grease will dissolve and a black color will spread around the particulates.

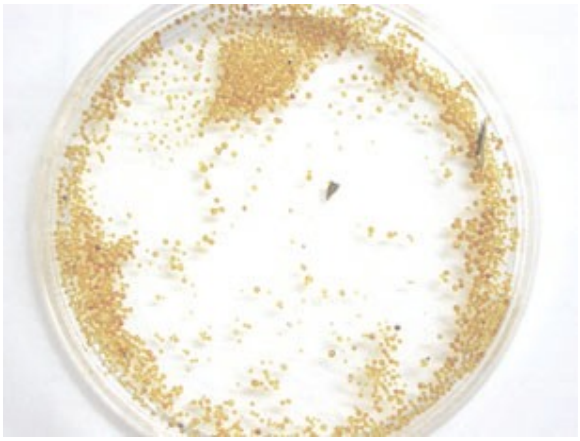
Let the toluene evaporate or use an oven to expedite drying. Touch the particulates with a needle in the area where toluene was added; they should no longer be sticky and may behave like a black powder. All greases may not behave this way, but their stickiness and extreme softness differentiates them from other black particulates.

Infrared Spectroscopy

When particulates cannot be completely identified by the above means, use IR to identify organic and inorganic materials. Inorganic compounds include calcium carbonate, calcium sulfate, barium sulfate, lead carbonate, metal oxides, silicates, or phosphates. Visually, and with the aid of heat, you might suspect a particulate is plastic in nature, but various types of plastics can occur in water systems, including polypropylene, polyvinyl chloride, and polyethylene. IR can differentiate between plastic materials.

Atoms in a molecule are in constant motion, changing bond angles by bending and bond lengths by stretching. Among these motions only certain vibrations absorb infrared radiation of specific energy. When portions of electromagnetic radiation are absorbed by such vibrations, an IR absorption band spectrum appears, which an infrared spectrometer records. Each compound has a unique infrared absorption spectrum, and various compounds can be identified by comparing absorption band positions in the IR spectrum of an unknown compound to band positions of known compounds.

Particulates are removed with fine-tipped tweezers one by one from the filter disk and transferred to a small vial for dissolving in a solvent, or to a small agate mortar for grinding and mixing with KBr for making a potassium bromide (KBr) pellet. The usually brittle plastic fragments can be powdered easily, and 10 mg of sample is all that is commonly needed to produce a good infrared absorption spectrum. Inorganic materials are identified by IR scanning of the KBr pellet of the sample alone; organic materials are identified by scanning a pellet or a film of the sample cast on a KBr plate.



Zeolite particles from a household water softener.

Most plastics are readily soluble in hot o-dichlorobenzene; try dissolving the sample in this solvent first. If soluble, cast a film of the sample on a KBr plate and scan it. If the sample is insoluble, evaporate the solvent completely and transfer the particulates to an agate mortar, make a KBr pellet, and scan the pellet. After obtaining a reasonably strong infrared spectrogram, the sample is identified by manual means or a computer search of a commercially available online IR library.

Standard Chemical Analyses

Chemical analyses available in most full-service water testing laboratories can be used to identify particulates when sufficient material is available. For example, hydrated aluminum oxide can occur as white slurry and be analyzed by inductively coupled plasma emission spectrometry after dissolving in mineral acids.

Similarly, granules of lead solder can also be analyzed by wet chemical or instrumental methods. After a sample is dissolved in a mineral acid, it can be analyzed for various elements by atomic absorption spectrophotometry. A variety of materials, including iron oxides, manganese dioxides, aluminum oxides, calcium carbonates, and copper and silicate particulates, can be identified by common chemical analyses.

During the late 1990s, customers in Philadelphia and across the country complained about white particulates clogging faucet aerators. Infrared spectroscopy revealed the particulates to be polypropylene, a plastic not used in the distribution system. The only common source for this plastic was found to be the dip tubes in residential gas hot-water heaters (see Opflow, December 1998).

Eventually, the dip-tube manufacturer admitted to changing materials to a less-durable plastic, prompting water heater manufacturers to give rebates to customers for dip-tube replacements. When this issue made the TV news, Philadelphia was in a good position to explain the situation to customers because our procedure was already in place for testing and characterizing particulates.



Dip Tube Particles

Table 1. Potential sources for particulate matter found in tap water

Particulate	From Customer Plumbing	From Water Supplier Piping
Activated carbon fines		X
Asphaltic lining fragments		X
Backfill sand		X
Calcium carbonate scale	X	X
Cast iron rust		X
Cement lining fragments		X
Copper fragments	X	
Glass chips		X
Greases and lubricants	X	X
Lead fragments	X	
Manganese dioxide deposits		X
Man-made fibers		X
On-site treatment device media		X
Plastic fragments	X	
Rubber gasket fragments	X	X
Soil minerals, mica		X

Table 2. Suspended matter classified by size

Soluble	< 0.45 µm
Colloidal	< 1.0 µm but > 0.45 µm
Particulate	> 1.0 µm

End of Article *by Jameel Rahman and Gary A. Burlingame*

Types of Algae

The simplest algae are single cells (e.g., the **diatoms**); the more complex forms consist of many cells grouped in a spherical colony (e.g., *Volvox*), in a ribbon like filament (e.g., *Spirogyra*), or in a branching thallus form (e.g., *Fucus*).

The cells of the colonies are generally similar, but some are differentiated for reproduction and for other functions.

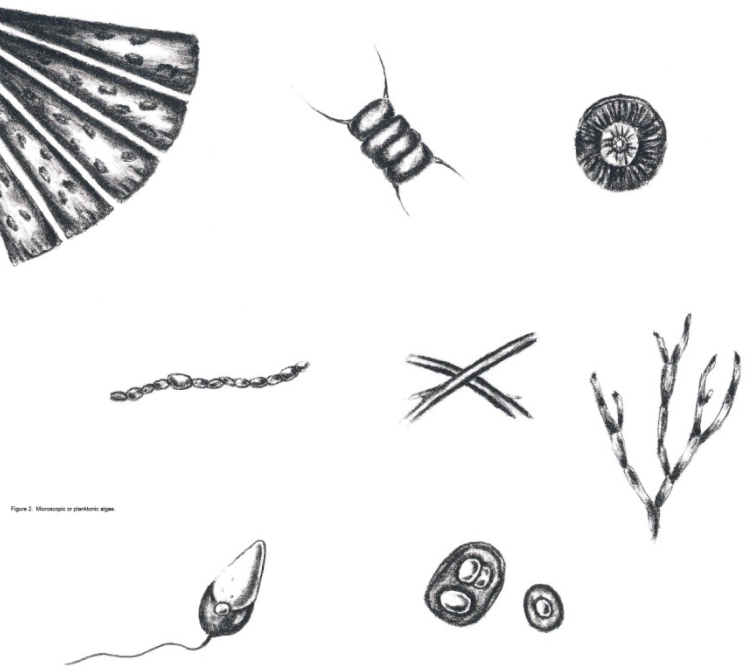
Kelps, the largest algae, may attain a length of more than 200 ft (61 m). *Euglena* and similar genera are free-swimming one-celled forms that contain chlorophyll but that are also able, under certain conditions, to ingest food in an animal like manner.

The green algae include most of the freshwater forms. The **pond scum**, a green slime found in stagnant water, is a green alga, as is the green film found on the bark of trees. The more complex brown algae and red algae are chiefly saltwater forms; the green color of the chlorophyll is masked by the presence of other pigments. Blue-green algae have been grouped with other prokaryotes in the kingdom **Monera** and renamed **cyanobacteria**.

Pond scum is an accumulation of floating green **algae** on the surface of stagnant or slowly moving waters, such as ponds and reservoirs. One of the most common forms is *Spirogyra.*

With the exception of the larger Algae -- seaweeds and kelp -- Protoctista are pretty much all microscopic organisms.

Green Algae (*Gamophyta* & *Chlorophyta*)
7000 species
Red Algae (*Rhodophyta*)
4000 species such as this Coralline Alga (*Calliarthron tuberculosum*)



Other species include Diatoms (Bacillariophyta, 10,000 species) and various Plankton

Major Algae Groups



Blue-green algae are the slimy stuff. Its cells lack nuclei and its pigment is scattered. Blue-green algae are not actually algae, they are bacteria.



Green algae cells have nuclei and the pigment is distinct. Green algae are the most common algae in ponds and can be multicellular.



Euglenoids are green or brown and swim with their flagellum, too. They are easy to spot because of their red eye. Euglenoids are microscopic and single celled.



Dinoflagellates have a flagella and can swim in open waters. They are microscopic and single celled.



Diatoms look like two shells that fit together. They are microscopic and single celled.

Bacteriological Monitoring Section





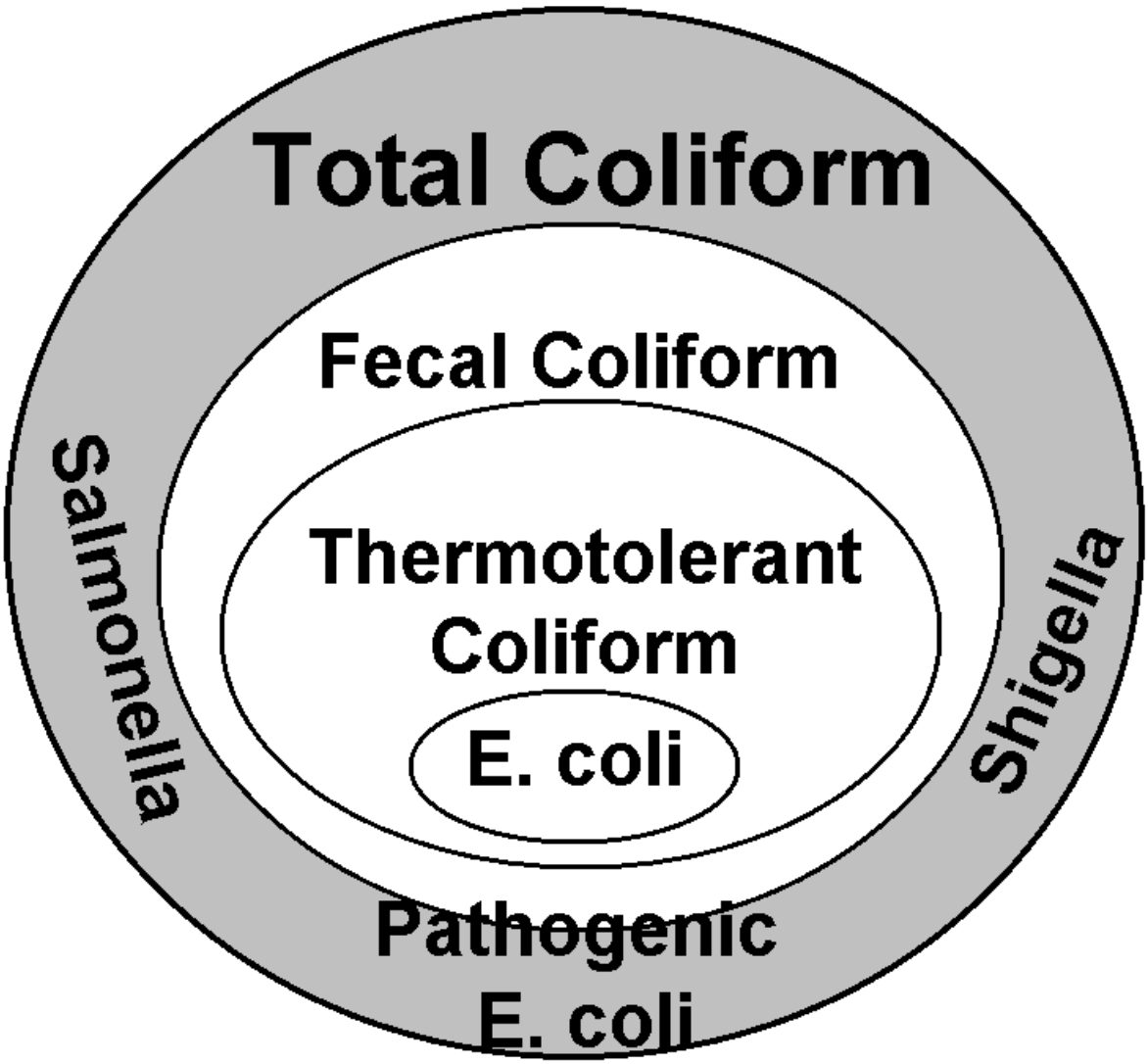


Looking under a black light to identify the presence of E. coli.

Colilert tests simultaneously detect and confirms coliform and E. coli in water samples in 24 hours or less.

Simply add the Colilert reagent to the sample, incubate for 24 hours, and read results.

Colilert is easy to read, as positive coliform samples turn yellow or blue, and when E. coli is present, samples fluoresce under UV light.


Total Coliform
Fecal Coliform
Thermotolerant Coliform
E. coli
Salmonella
Shigella
Pathogenic E. coli

Bacteriological Monitoring Section

Most waterborne diseases and illnesses have been related to the microbiological quality of drinking water. The routine microbiological analysis of your water is for coliform bacteria. The coliform bacteria group is used as an indicator organism to determine the biological quality of your water. The presence of an indicator or pathogenic bacteria in your drinking water is an important health concern. Indicator bacteria signal possible fecal contamination, and therefore, the potential presence of pathogens. They are used to monitor for pathogens because of the difficulties in determining the presence of specific disease-causing microorganisms.



Indicator bacteria are usually harmless, occur in high densities in their natural environment, and are easily cultured in relatively simple bacteriological media. Indicators in common use today for routine monitoring of drinking water include total coliforms, fecal coliforms, and *Escherichia coli (E. coli).*

Bacteria Sampling
Water samples for bacteria tests must always be collected in a sterile container. Take the sample from an inside faucet with the aerator removed. Sterilize by spraying a 5% Household beach or alcohol solution or flaming the end of the tap with a propane torch. Run the water for five minutes to clear the water lines and bring in fresh water. Do not touch or contaminate the inside of the bottle or cap. Carefully open the sample container and hold the outside of the cap. Fill the container and replace the top. Refrigerate the sample and transport it to the testing laboratory within six hours (in an ice chest). Many labs will not accept bacteria samples on Friday so check the lab's schedule. Mailing bacteria samples is not recommended because laboratory analysis results are not as reliable. Iron bacteria forms an obvious slime on the inside of pipes and fixtures. A water test is not needed for identification. Check for a reddish-brown slime inside a toilet tank or where water stands for several days.

Bac-T Sample Bottle Often referred to as a Standard Sample, 100 mls, notice the white powder inside the bottle. That is Sodium Thiosulfate, a de-chlorination agent. Be careful not to wash-out this chemical while sampling. Notice the custody seal on the bottle.

Coliform bacteria are common in the environment and are generally not harmful. However, the presence of these bacteria in drinking water is usually a result of a problem with the treatment system or the pipes which distribute water, and indicates that the water may be contaminated with germs that can cause disease.

Laboratory Procedures
The laboratory may perform the total coliform analysis in one of four methods approved by the U.S. EPA and your local environmental or health division:

Methods

The MMO-MUG test, a product marketed as Colilert, is the most common. The sample results will be reported by the laboratories as simply coliforms present or absent. If coliforms are present, the laboratory will analyze the sample further to determine if these are fecal coliforms or E. coli and report their presence or absence.

Types of Water Samples
It is important to properly identify the type of sample you are collecting. Please indicate in the space provided on the laboratory form the type of sample.

The three (3) types of samples are:
1. **Routine:** Samples collected on a routine basis to monitor for contamination. Collection should be in accordance with an approved sampling plan.

2. **Repeat:** Samples collected following a '***coliform present'*** routine sample. The number of repeat samples to be collected is based on the number of routine samples you normally collect.

3. **Special:** Samples collected for other reasons.
Examples would be a sample collected after repairs to the system and before it is placed back into operation or a sample collected at a wellhead prior to a disinfection injection point.

Routine Coliform Sampling
The number of routine samples and frequency of collection for community public water systems is shown in Table 3-1 below.

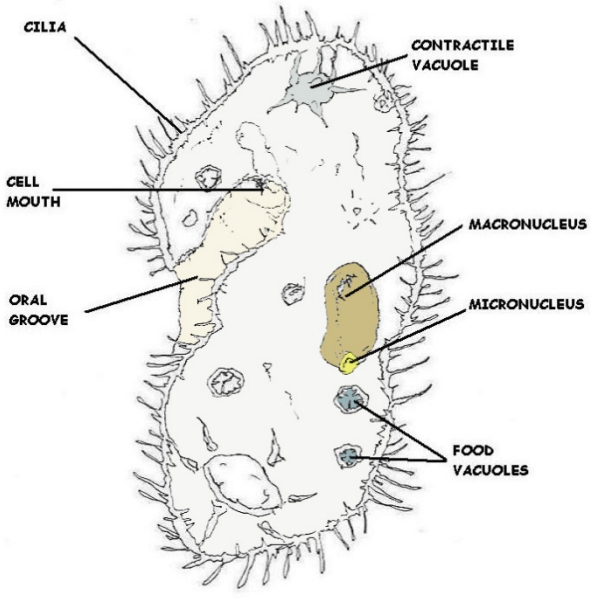
Noncommunity and nontransient noncommunity public water systems will sample at the same frequency as a like sized community public water system if:

1. It has more than 1,000 daily population and has ground water as a source, or
2. It serves 25 or more daily population and utilizes surface water as a source or ground water under the direct influence of surface water as its source.

Noncommunity and nontransient, noncommunity water systems with less than 1,000 daily population and groundwater as a source will sample on a quarterly basis.

Water Quality Review Statements

- ✓ What are disease causing organisms such as bacteria and viruses called? Pathogens
- ✓ Name the 4 broad categories of water quality. Physical, chemical, biological, radiological.
- ✓ What does a positive bacteriological sample indicate? The presence of bacteriological contamination.
- ✓ When must source water monitoring for lead and copper be performed? When a public water system exceeds an action level for lead of copper.



PARAMECIUM

No. of Samples per System Population

Persons served - Samples per month

up to 1,000	1
1,001-2,500	2
2,501-3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 12,900	10
12,901 to 17,200	15
17,201 to 21,500	20
21,501 to 25,000	25
25,001 to 33,000	30
33,001 to 41,000	40
41,001 to 50,000	50
50,001 to 59,000	60
59,001 to 70,000	70
70,001 to 83,000	80
83,001 to 96,000	90
96,001 to 130,000	100
130,001 to 220,000	120
220,001 to 320,000	150
320,001 to 450,000	180
450,001 to 600,000	210
600,001 to 780,000	240



Repeat Sampling

Repeat sampling replaces the old check sampling with a more comprehensive procedure to try to identify problem areas in the system. Whenever a routine sample has total coliform or fecal coliform present, a set of repeat samples must be collected within 24 hours after being notified by the laboratory. The follow-up for repeat sampling is:

1. If only one routine sample per month or quarter is required, four (4) repeat samples must be collected.
2. For systems collecting two (2) or more routine samples per month, three (3) repeat samples must be collected.
3. Repeat samples must be collected from:

a. The original sampling location of the coliform present sample.
b. Within five (5) service connections upstream from the original sampling location.
c. Within five (5) service connections downstream from the original sampling location.
d. Elsewhere in the distribution system or at the wellhead, if necessary.

4. If the system has only one service connection, the repeat samples must be collected from the same sampling location over a four-day period or on the same day.
5. All repeat samples are included in the MCL compliance calculation.
6. If a system which normally collects fewer than five (5) routine samples per month has a coliform present sample, it must collect five (5) routine samples the following month or quarter regardless of whether an MCL violation occurred or if repeat sampling was coliform absent.

Positive or Coliform Present Results

What do you do when your sample is positive or coliform present?

When you are notified of a positive test result you need to contact either the Drinking Water Program or your local county health department within 24 hours, or by the next business day after the results are reported to you. The Drinking Water Program contracts with many of the local health departments to provide assistance to water systems.



After you have contacted an agency for assistance, you will be instructed as to the proper repeat sampling procedures and possible corrective measures for solving the problem. It is very important to initiate the repeat sampling immediately as the corrective measures will be based on those results.

Some examples of typical corrective measures to coliform problems are:

1. Shock chlorination of a ground water well. The recommended dose of 5% household bleach is 2 cups per 100 gallons of water in the well. This should be done anytime the bell is opened for repair (pump replacement, etc.). If you plan to shock the entire system, calculate the total gallonage of storage and distribution.
2. Conduct routine distribution line flushing. Install blowoffs on all dead end lines.
3. Conduct a cross connection program to identify all connections with non-potable water sources. Eliminate all of these connections or provide approved backflow prevention devices.
4. Upgrade the wellhead area to meet current construction standards as set by your state environmental or health agency.
5. If you continuously chlorinate, review your operation and be sure to maintain a detectable residual (0.2 mg/l free chlorine) at all times in the distribution system.
6. Perform routine cleaning of the storage system.

This list provides some basic operation and maintenance procedures that could help eliminate potential bacteriological problems, check with your state drinking water section or health department for further instructions.

Maximum Contaminant Levels (MCLs)

State and federal laws establish standards for drinking water quality. Under normal circumstances when these standards are being met, the water is safe to drink with no threat to human health. These standards are known as maximum contaminant levels (**MCL**). When a particular contaminant exceeds its MCL a potential health threat may occur.

The MCLs are based on extensive research on toxicological properties of the contaminants, risk assessments and factors, short term (**acute**) exposure, and long term (**chronic**) exposure. You conduct the monitoring to make sure your water is in compliance with the MCL.

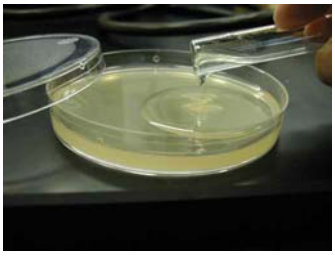
There are two types of MCL violations for coliform bacteria. The first is for total coliform; the second is an acute risk to health violation characterized by the confirmed presence of fecal coliform or E. coli.

Heterotrophic Plate Count

Heterotrophic Plate Count (**HPC**) --- formerly known as the standard plate count, is a procedure for estimating the number of live heterotrophic bacteria and measuring changes during water treatment and distribution in water or in swimming pools. Colonies may arise from pairs, chains, clusters, or single cells, all of which are included in the term "***colony-forming units***" (**CFU**).

Method:

There are three methods for standard plate count:

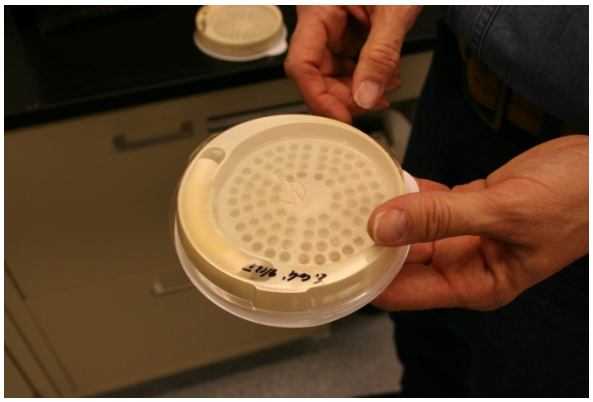


1. **Pour Plate Method**
The colonies produced are relatively small and compact, showing less tendency to encroach on each other than those produced by surface growth. On the other hand, submerged colonies often are slower growing and are difficult to transfer.
2. **Spread Plate Method**
All colonies are on the agar surface where they can be distinguished readily from particles and bubbles. Colonies can be transferred quickly, and colony morphology can be easily discerned and compared to published descriptions.
3. **Membrane Filter Method**
This method permits testing large volumes of low-turbidity water and is the method of choice for low-count waters.

Material

i) Apparatus
- Glass rod
- Erlenmeyer flask
- Graduated Cylinder
- Pipette
- Petri dish
- Incubator

ii) Reagent and sample
- Reagent-grade water
- Nutrient agar
- Sample



Procedure*

1. Boil mixture of nutrient agar and nutrient broth for 15 minutes, then cool for about 20 minutes.
2. Pour approximately 15 ml of medium in each Petri dish, let medium solidify.
3. Pipette 0.1 ml of each dilution onto surface of pre-dried plate, starting with the highest dilution.
4. Distribute inoculum over surface of the medium using a sterile bent glass rod.
5. Incubate plates at 35^{o}C for 48h.
6. Count all colonies on selected plates promptly after incubation, consider only plates having 30 to 300 colonies in determining the plate count.

*Duplicate samples

Computing and Reporting:

Compute bacterial count per milliliter by the following equation:

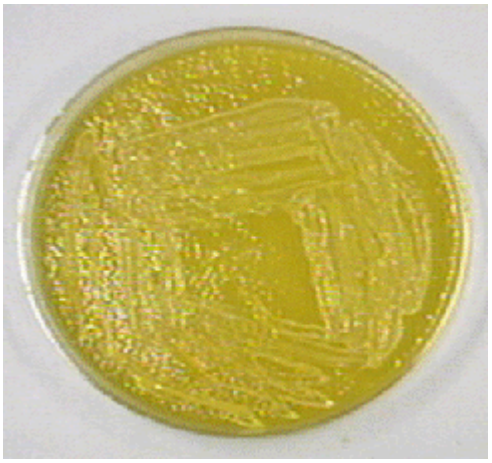
CFU/ml = colonies counted / actual volume of sample in dish a)If there is no plate with 30 to 300 colonies, and one or more plates have more than 300 colonies, use the plate(s) having a count nearest 300 colonies.

b) If plates from all dilutions of any sample have no colony, report the count as less than 1/actual volume of sample in dish estimated CFU/ml.
c) Avoid creating fictitious precision and accuracy when computing CFU by recording only the first two left-hand digits.

Heterotrophic Plate Count
(Spread Plate Method)

Heterotrophic organisms utilize organic compounds as their carbon source (food or substrate). In contrast, autotrophic organisms use inorganic carbon sources. The Heterotrophic Plate Count provides a technique to quantify the bacteriological activity of a sample. The R2A agar provides a medium that will support a large variety of heterotrophic bacteria. After an incubation period, a bacteriological colony count provides an estimate of the concentration of heterotrophs in the sample of interest.

Laboratory Equipment Needed
100 x 15 Petri Dishes
Turntable
Glass Rods: Bend fire polished glass rod 45 degrees about 40 mm from one end. Sterilize before using.
Pipette: Glass, 1.1 mL. Sterilize before using.
Quebec Colony Counter
Hand Tally Counter



Reagents
1) R2A Agar: Dissolve and dilute 0.5 g of yeast extract, 0.5 g of proteose peptone No. 3, 0.5 g of casamino acids, 0.5 g of glucose, 0.5 g of soluble starch, 0.3 g of dipotassium hydrogen phosphate, 0.05 g of magnesium sulfate heptahydrate, 0.3 g of sodium pyruvate, 15.0 g of agar to 1 L. Adjust pH to 7.2 with dipotassium hydrogen phosphate **before adding agar.** Heat to dissolve agar and sterilize at 121 C for 15 minutes.

2) Ethanol: As needed for flame sterilization.

Preparation of Spread Plates
Immediately after agar sterilization, pour 15 mL of R2A agar into sterile 100 x 15 Petri dishes; let agar solidify. Pre-dry plates inverted so that there is a 2 to 3 g water loss overnight with the lids on. Use pre-dried plates immediately or store up to two weeks in sealed plastic bags at 4°C.



Sample Preparation
Mark each plate with sample type, dilution, date, and any other information before sample application.

Prepare at least duplicate plates for each volume of sample or dilution examined. Thoroughly mix all samples by rapidly making about 25 complete up-and-down movements.

Sample Application
Uncover pre-dried agar plate. Minimize time plate remains uncovered. Pipette 0.1 or 0.5 mL sample onto surface of pre-dried agar plate.

Record Volume of Sample Used.
Using a sterile bent glass rod, distribute the sample over surface of the medium by rotating the dish by hand on a turntable. Let the sample be absorbed completely into the medium before incubating. Put cover back on Petri dish and invert for duration of incubation time. Incubate at 28°C for 7 days. Remove Petri dishes from incubator for counting.

Counting and Recording
After incubation period, promptly count all colonies on the plates. To count, uncover plate and place on Quebec colony counter. Use a hand tally counter to maintain count. Count all colonies on the plate, regardless of size. Compute bacterial count per milliliter by the following equation:

$$\text{CFU}/\text{mL} = \frac{\text{colonies counted}}{\text{actual volume of sample in dish, mL}}$$

To report counts on a plate with no colonies, report the count as less than one (<1) divided by the sample volume put on that plate (remember to account for any dilution of that sample).

If plates of all dilutions for a sample have no colonies, report the count as less than one (<1) divided by the largest sample volume used. Example: if 0.1 mL of a 100:1 and 10000:1 dilution of a sample both turned up with no colonies formed, the reported result would be <1 divided by the largest sample volume 0.001 mL (0.1 mL divided by 100). The final reported result for the sample is <1000 CFU per mL.

Assignment
1. Report the number of colony forming units (**CFU**) found on each plate.

2. Calculate the **CFU** per mL for each plate.

3. The aim of diluting samples is to produce a plate having 30 to 300 colonies, which plates meet these criteria. If no sample produces a plate with a count in this range, use the plate(s) with a count closest to 300. Based on these criteria, use your calculated results to report the CFU per mL for each sample.

In the conclusion of your lab report, comment on your final results for each sample type as well as the quality of your application of this analysis technique. Feel free to justify your comments using statistical analysis. Also, comment on the general accuracy of this analytical technique and the factors that affect its accuracy and or applicability.

Data Table for Samples

Sample ID	Volume of Sample, mL	Colonies Counted per plate

Total Coliforms

This MCL is based on the presence of total coliforms, and compliance is on a monthly or quarterly basis, depending on your water system type and state rule. For systems which collect *fewer* than 40 samples per month, no more than one sample per month may be positive. In other words, the second positive result (repeat or routine) in a month or quarter results in an MCL violation.

For systems which collect 40 or more samples per month, no more than five (5) percent may be positive. Check with your state drinking water section or health department for further instructions.

Acute Risk to Health (Fecal Coliforms and E. coli)

An acute risk to human health violation occurs if either one of the following happen:

1. A routine analysis shows total coliform present and is followed by a repeat analysis which indicates fecal coliform or E. coli present.

2. A routine analysis shows total and fecal coliform or E. coli present and is followed by a repeat analysis which indicates total coliform present. An acute health risk violation requires the water system to provide public notice via radio and television stations in the area. This type of contamination can pose an immediate threat to human health and notice must be given as soon as possible, but no later than 72 hours after notification from your laboratory of the test results.

Certain language may be mandatory for both these violations and is included in your state drinking water rule.

Public Notice

A public notice is required to be issued by a water system whenever it fails to comply with an applicable MCL or treatment technique, or fails to comply with the requirements of any scheduled variance or permit. This will inform users when there is a problem with the system and give them information.

A public notice is also required whenever a water system fails to comply with its monitoring and/or reporting requirements or testing procedure. Each public notice must contain certain information, be issued properly and in a timely manner and contain certain mandatory language. The timing and place of posting of the public notice depends on whether an acute risk is present to users. Check with your state drinking water section or health department for further instructions.

The following are Acute Violations

1. Violation of the MCL for nitrate.
2. Any violation of the MCL for total coliforms, when fecal coliforms or E. coli are present in the distribution system.
3. Any outbreak of waterborne disease, as defined by the rules.

Pathogen Section

Bacteria, viruses, and protozoans that cause disease are known as pathogens. Most pathogens are generally associated with diseases that cause intestinal illness and affect people in a relatively short amount of time, generally a few days to two weeks. They can cause illness through exposure to small quantities of contaminated water or food or from direct contact with infected people or animals.

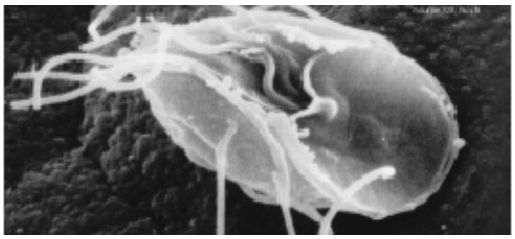
Pathogens that may cause waterborne outbreaks through drinking water have one thing in common: they are spread by the fecal-oral (or feces-to-mouth) route. Pathogens may get into water and spread when infected humans or animals pass the bacteria, viruses, and protozoa in their stool. For another person to become infected, he or she must take that pathogen in through the mouth.

Waterborne pathogens are different from other types of pathogens such as the viruses that cause influenza (the flu) or the bacteria that cause tuberculosis. Influenza virus and tuberculosis bacteria are spread by secretions that are coughed or sneezed into the air by an infected person.

Human or animal wastes in watersheds, failing septic systems, failing sewage treatment plants or cross-connections of water lines with sewage lines provide the potential for contaminating water with pathogens. The water may not appear to be contaminated because feces has been broken up, dispersed and diluted into microscopic particles. These particles, containing pathogens, may remain in the water and be passed to humans or animals unless adequately treated.

Only proper treatment will ensure eliminating the spread of disease. In addition to water, other methods exist for spreading pathogens by the fecal-oral route. The foodborne route is one of the more common methods. A frequent source is a food handler who does not wash his hands after a bowel movement and then handles food with “unclean” hands. The individual who eats feces-contaminated food may become infected and ill. It is interesting to note the majority of foodborne diseases occur in the home, not restaurants.

Day care centers are another common source for spreading pathogens by the fecal-oral route. Here, infected children in diapers may get feces on their fingers, then put their fingers in a friend’s mouth or handle toys that other children put into their mouths. You will usually be asked to sample for **Giardia** at these facilities.



The general public and some of the medical community usually refer to diarrhea symptoms as “**stomach flu**.” Technically, influenza is an upper respiratory illness and rarely has diarrhea associated with it; therefore, stomach flu is a misleading description for foodborne or waterborne illnesses, yet is accepted by the general public. So the next time you get the stomach flu, you may want to think twice about what you’ve digested within the past few days.

More on this subject in the Microorganism Appendix.

Chain of Transmission
Water is contaminated with feces. This contamination may be of human or animal origin. The feces must contain pathogens (disease-causing bacteria, viruses or protozoa). If the human or animal source is not infected with a pathogen, no disease will result. The pathogens must survive in the water. This depends on the temperature of the water and the length of time the pathogens are in the water. Some pathogens will survive for only a short time in water, others, such as Giardia or Cryptosporidium, may survive for months.

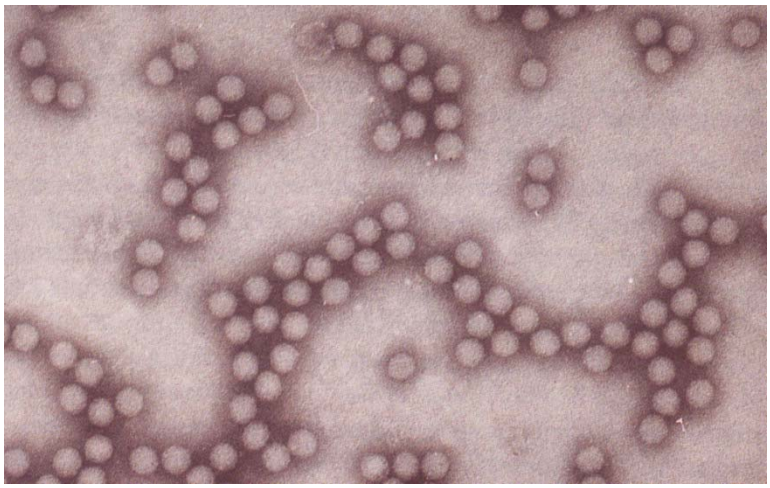
The pathogens in the water must enter the water system's intake in numbers sufficient to infect people. The water is either not treated or inadequately treated for the pathogens present. A susceptible person must drink the water that contains the pathogen; then illness (disease) will occur. This chain lists the events that must occur for the transmission of disease via drinking water. By breaking the chain at any point, the transmission of disease will be prevented.

Bacterial Diseases

Campylobacteriosis is the most common diarrheal illness caused by bacteria. Other symptoms include abdominal pain, malaise, fever, nausea and vomiting; and begin three to five days after exposure. The illness is frequently over within two to five days and usually lasts no more than 10 days. **Campylobacteriosis** outbreaks have most often been associated with food, especially chicken and un-pasteurized milk, as well as un-chlorinated water. These organisms are also an important cause of "**travelers' diarrhea**." Medical treatment generally is not prescribed for campylobacteriosis because recovery is usually rapid.

Cholera, Legionellosis, salmonellosis, shigellosis, yersiniosis, are other bacterial diseases that can be transmitted through water. All bacteria in water are readily killed or inactivated with chlorine or other disinfectants.

Viral Diseases



Hepatitis A is an example of a common viral disease that may be transmitted through water. The onset is usually abrupt with fever, malaise, loss of appetite, nausea and abdominal discomfort, followed within a few days by jaundice. The disease varies in severity from a mild illness lasting one to two weeks, to a severely disabling disease lasting several months (rare). The incubation period is 15-50 days and averages 28-30 days. Hepatitis A outbreaks have been related to fecally contaminated water; food contaminated by infected food handlers, including sandwiches and salads that are not cooked or are handled after cooking, and raw or undercooked mollusks harvested from contaminated waters. Aseptic meningitis, polio and viral gastroenteritis (**Norwalk agent**) are other viral diseases that can be transmitted through water. Most viruses in drinking water can be inactivated by chlorine or other disinfectants.

Protozoan Diseases

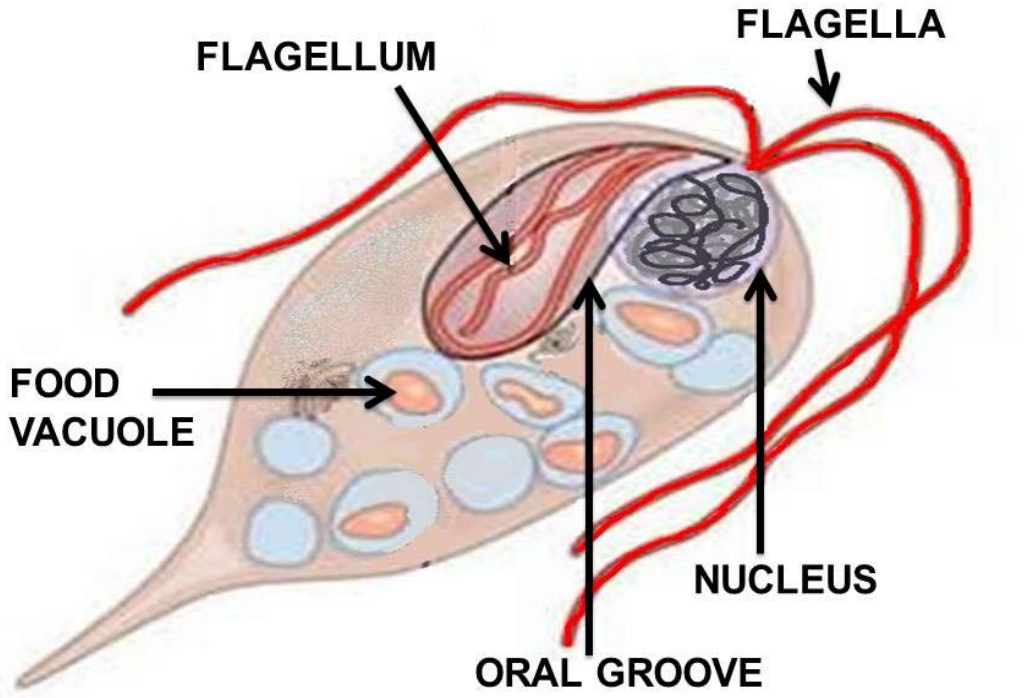
Protozoan pathogens are larger than bacteria and viruses, but still microscopic. They invade and inhabit the gastrointestinal tract. Some parasites enter the environment in a dormant form, with a protective cell wall called a "**cyst**." The cyst can survive in the environment for long periods of time and be extremely resistant to conventional disinfectants such as chlorine. Effective filtration treatment is therefore critical to removing these organisms from water sources.



Giardia lamblia

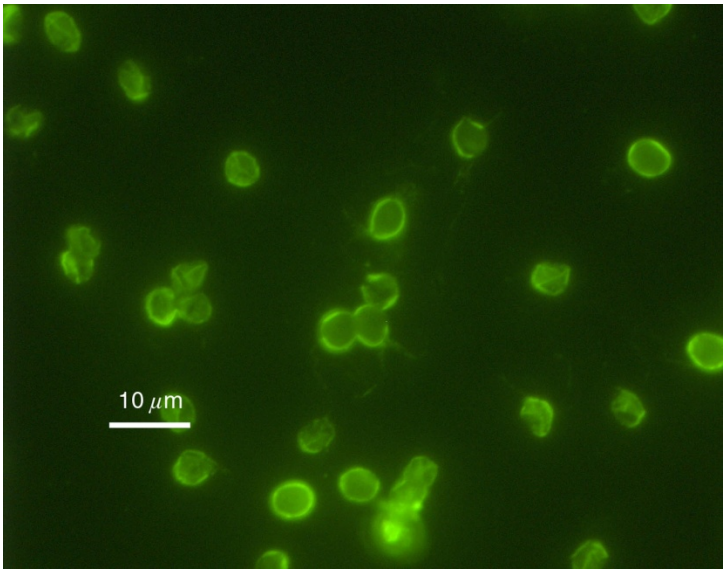
More on this subject in the Microorganism Appendix.

Giardiasis is a commonly reported protozoan-caused disease. It has also been referred to as "**backpacker's disease**" and "**beaver fever**" because of the many cases reported among hikers and others who consume untreated surface water. Symptoms include chronic diarrhea, abdominal cramps, bloating, frequent loose and pale greasy stools, fatigue and weight loss. The incubation period is 5-25 days or longer, with an average of 7-10 days. Many infections are asymptomatic (no symptoms). Giardiasis occurs worldwide. Waterborne outbreaks in the United States occur most often in communities receiving their drinking water from streams or rivers without adequate disinfection or a filtration system. The organism, ***Giardia lamblia,*** has been responsible for more community-wide outbreaks of disease in the U.S. than any other pathogen. Drugs are available for treatment, but these are not 100% effective.



Giardia lamblia

Cryptosporidiosis



Cryptosporidiosis is an example of a protozoan disease that is common worldwide, but was only recently recognized as causing human disease. The major symptom in humans is diarrhea, which may be profuse and watery.

The diarrhea is associated with cramping abdominal pain. General malaise, fever, anorexia, nausea, and vomiting occur less often. Symptoms usually come and go, and end in fewer than 30 days in most cases. The incubation period is 1-12 days, with an average of about seven days. *Cryptosporidium* organisms have been identified in human fecal specimens from more than 50 countries on six continents.

The mode of transmission is fecal-oral, either by person-to-person or animal-to-person. There is no specific treatment for *Cryptosporidium* infections. All these diseases, with the exception of hepatitis A, have one symptom in common: diarrhea. They also have the same mode of transmission, fecal-oral, whether through person-to-person or animal-to-person contact, and the same routes of transmission, being either foodborne or waterborne.

Although most pathogens cause mild, self-limiting disease, on occasion, they can cause serious, even life threatening illness. Particularly vulnerable are persons with weak immune systems, such as those with HIV infections or cancer.

By understanding the nature of waterborne diseases, the importance of properly constructed, operated and maintained public water systems becomes obvious. While water treatment cannot achieve sterile water (no microorganisms), the goal of treatment must clearly be to produce drinking water that is as pathogen-free as possible at all times.

For those who operate water systems with inadequate source protection or treatment facilities, the potential risk of a waterborne disease outbreak is real. For those operating systems that currently provide adequate source protection and treatment, operating and maintaining the system at a high level on a continuing basis is critical to prevent disease.

More on this subject in the Microorganism Appendix.

Waterborne Diseases

Name	Causative organism	Source of organism	Disease
Viral gastroenteritis	**Rotavirus** (mostly in young children)	Human feces	Diarrhea or vomiting
Norwalk Agent	**Noroviruses** (genus *Norovirus*, family *Caliciviridae*) [*1]	Human feces; also, shellfish; lives in polluted waters	Diarrhea and vomiting
Salmonellosis	***Salmonella*** (bacterium)	Animal or human feces	Diarrhea or vomiting
Gastroenteritis Escherichia *coli*	-- ***E. coli O1*** **57:H7** (bacterium): Other *E. coli* organisms:	Human feces	Symptoms vary with type caused
Typhoid	***Salmonella typhi*** (bacterium)	Human feces, urine	Inflamed intestine, enlarged spleen, high temperature-sometimes fatal
Shigellosis	***Shigella*** (bacterium)	Human feces	Diarrhea
Cholera	***Vibrio choleras*** (bacterium)	Human feces; also, shellfish; lives in many coastal waters	Vomiting, severe diarrhea, rapid dehydration, mineral loss-high mortality
Hepatitis A	**Hepatitis A** virus	Human feces; shellfish grown in polluted waters	Yellowed skin, enlarged liver, fever, vomiting, weight loss, abdominal pain-low mortality, lasts up to four months
Amebiasis	***Entamoeba histolytica*** (protozoan)	Human feces	Mild diarrhea, dysentery, extra intestinal infection
Giardiasis	***Giardia lamblia*** (protozoan)	Animal or human feces	Diarrhea, cramps, nausea, and general weakness — lasts one week to months
Cryptosporidiosis	***Cryptosporidium parvum***	Animal or human feces	Diarrhea, stomach pain — lasts (protozoan) days to weeks

Notes:

*1 http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus.htm
http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5009a1.htm

General Contaminant Information

The sources of drinking water include rivers, lakes, streams, ponds, reservoirs, springs, and wells. As water travels over the surface of the land or through the ground, it dissolves naturally occurring minerals and in some cases, radioactive material, and can pick up substances resulting from the presence of animals or human activity.

Contaminants that may be present in sources of drinking water include:
Microbial contaminants, such as viruses and bacteria, which may come from sewage treatment plants, septic systems, agricultural livestock operations and wildlife;
Inorganic contaminants, such as salts and metals, which can be naturally occurring or result from urban stormwater runoff, industrial or domestic wastewater discharges, oil and gas production, mining or farming;
Pesticides and herbicides, which may come from a variety of sources such as agriculture, urban stormwater run-off, and residential uses;
Organic chemical contaminants, including synthetic and volatile organic chemicals, which are by-products of industrial processes and petroleum production, and can also come from gas stations, urban stormwater run-off, and septic systems;
Radioactive contaminants, which can be naturally occurring or be the result of oil and gas production and mining activities.

Background
Coliform bacteria and chlorine residual are the only routine sampling and monitoring requirements for small ground water systems with chlorination. The coliform bacteriological sampling is governed by the Total Coliform Rule (**TCR**) of the SDWA. Although there is presently no requirement for chlorination of groundwater systems under the SDWA, State regulations require chlorine residual monitoring of those systems that do chlorinate the water.

TCR The TCR requires all Public Water Systems (**PWS**) to monitor their distribution system for coliform bacteria according to the written sample sitting plan for that system. The sample sitting plan identifies sampling frequency and locations throughout the distribution system that are selected to be representative of conditions in the entire system. Coliform contamination can occur anywhere in the system, possibly due to problems such as; low pressure conditions, line breaks, or well contamination, and therefore routine monitoring is required. A copy of the sample sitting plan for the system should be kept on file and accessible to all who are involved in the sampling for the water system.

Number of Monthly Samples
The number of samples to be collected monthly depends on the size of the system. The TCR specifies the minimum number of coliform samples collected, but it may be necessary to take more than the minimum number in order to provide adequate monitoring.

This is especially true if the system consists of multiple sources, pressure zones, booster pumps, long transmission lines, or extensive distribution system piping. Since timely detection of coliform contamination is the purpose of the sample sitting plan, sample sites should be selected to represent the varying conditions that exist in the distribution system. The sample sitting plan should be updated as changes are made in the water system, especially the distribution system.

Sampling Procedures
The sample sitting plan must be followed and all operating staff must be clear on how to follow the sampling plan. In order to properly implement the sample sitting plan, staff must be aware of how often sampling must be done, the proper procedures and sampling containers to be used for collecting the samples, and the proper procedures for identification, storage and transport of the samples to an approved laboratory.

In addition, proper procedures must be followed for repeat sampling whenever a routine sample result is positive for total coliform. The following diagram outlines the requirements for responding to a positive Total Coliform sample.

Troubleshooting Table for Sampling Monitoring

Problem
1. Positive Total Coliform.
2. Chlorine taste and odor.
3. Inability to maintain an adequate free chlorine residual at the furthest points of the distribution system or at dead end lines.

Possible Causes
1A. Improper sampling technique.
1B. Contamination entering distribution system.
1C. Inadequate chlorine residual at the sampling site.
1D. Growth of **biofilm** in the distribution system.
2A. High total chlorine residual and low free residual.
3A. Inadequate chlorine dose at treatment plant.
3B. Problems with chlorine feed equipment.
3C. Ineffective distribution system flushing program.
3D. Growth of biofilm in the distribution system.

Possible Solutions
1A/ Check distribution system for low pressure conditions, possibly due to line breaks or excessive flows that may result in a backflow problem.
1B. Insure that all staff are properly trained in sampling and transport procedures as described in the TCR.
1C. Check the operation of the chlorination feed system. Refer to issues described in the sections on pumps and hypochlorination systems. Insure that residual test is being performed properly.
1D. Thoroughly flush effected areas of the distribution system. **Superchlorination** may be necessary in severe cases.
2A. The free residual should be at least 85% of the total residual. Increase the chlorine dose rate to get past the breakpoint in order to destroy some of the combined residual that causes taste and odor problems. Additional system flushing may also be required.
3A. Increase chlorine feed rate at point of application.
3B. Check operation of chlorination equipment.
3C. Review distribution system flushing program and implement improvements to address areas of inadequate chlorine residual.
3D. Increase flushing in area of biofilm problem.

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There is nothing in the lab that is difficult to understand or eventually master. All of you should be able to learn and master the basic lab procedures. Don't be intimidated, learn to take samples and learn all you can about the lab, it is an excellent career. Bottom, normal sampling supplies.



Chain of Custody Procedures

Because a sample is physical evidence, chain of custody procedures are used to maintain and document sample possession from the time the sample is collected until it is introduced as evidence. Chain of custody requirements will vary from agency to agency.

However, these procedures are similar and the chain of custody outlined in this manual is only a guideline. Consult your project manager for specific requirements.

If you have physical possession of a sample, have it in view, or have physically secured it to prevent tampering then it is defined as being in ***"custody."*** A chain of custody record, therefore, begins when the sample containers are obtained from the laboratory. From this point on, a chain of custody record will accompany the sample containers.

Handle the samples as little as possible in the field. Each custody sample requires a chain of custody record and may require a seal. If you do not seal individual samples, then seal the containers in which the samples are shipped.

When the samples transfer possession, both parties involved in the transfer must sign, date and note the time on the chain of custody record. If a shipper refuses to sign the chain-of-custody you must seal the samples and chain of custody documents inside a box or cooler with bottle seals or evidence tape. The recipient will then attach the shipping invoices showing the transfer dates and times to the custody sheets. If the samples are split and sent to more than one laboratory, prepare a separate chain of custody record for each sample. If the samples are delivered to after-hours night drop-off boxes, the custody record should note such a transfer and be locked with the sealed samples inside sealed boxes.



Using alcohol to disinfect a special sample tap before obtaining a sample.

Laboratory
123 W. Main St
Sun City, Arizona 85541

LAB I.D. NUMBER

Sampler:

DATE:

PAGE 1 OF 1

Company:
Department:
Address:
Contact:
Telephone:

Sample Identification	Date	Time	Matrix	Lab ID	Metals* See Attached	TSS	Lead/Copper	BOD/COD	Nitrate	Nitrate + Nitrite	TKN / Ammonia	VOC / THM's	Semi Voltal Organics (625)	Chloride		Cyanide	Florida	Surfactants (MBAS)	Tot. Coliform MPN	Fecal Coliform MPN-HPC	Organo-Phosphorus Pest. (8141)	Sulfate	EC Conductivity	Number/Containers

Project Name

Project Number

Field Measurements:

pH:

Temp:

Sample Receipt

No. Containers:

Custody Seals: Yes No

Received Intact: Yes No

Received Cold: Yes No

Temperature:

PRIORITY:

RELINQUISHED BY:

Signature: Time:

Printed Name: Date:

Company

RELINQUISHED BY:

Signature: Time:

Printed Name: Date:

Company

SAMPLED RECEIVED BY:

Signature: Time:

Printed Name: Date:

SAMPLED RECEIVED BY:

Signature: Time:

Printed Name: Date:

Company

Chain of Custody Example.



Carefully follow these steps when collecting a coliform sample:

1. Select the sampling site, which must be a faucet from which water is commonly taken for consumer use or a dedicated site in the distribution system.
a. The sampling point should be a non-swivel faucet.
b. If it is a faucet with an aerator, remove the aerator, screen and gasket and flush thoroughly.
c. If an outside faucet is used, disconnect any hoses or other attachments and flush the line thoroughly.
d. It should be a faucet that does not leak around the packing or valve mechanism. Leaking faucets can promote bacterial growth.
e. Do not use fire hydrants or drinking fountains as sampling points.
f. Do not dip sample bottles in reservoirs, spring boxes or storage tanks in order to collect a sample.
If you have any questions about proper sampling sites, please contact your laboratory, environmental or health department or the state drinking water section.

2. **Use only sample bottles provided by the laboratory specifically for bacteriological sampling.** These bottles are sterile and should not be rinsed before sampling. A chemical, usually sodium thiosulfate, is placed in the bottle by the lab and is used for chlorine deactivation. Do not remove it.



3. Don't open the sample bottle until the moment you are going to fill it.
4. Flush the line thoroughly. Run water through the faucet for three to five minutes before opening the bottle and collecting the sample.
5. Uncap the sample bottle, being careful not to touch the inside of the bottle with your fingers or other objects. Do not set the lid down while taking the sample.
6. Reduce the water flow to a slow steady stream. Continue flushing for at least 1-2 minutes, then gently fill the sample bottle to the fill mark.

At least 100 ml. of water is necessary for analysis. Leave an air space in the top of the bottle. Do not overfill.
7. Replace the cap immediately, making sure it is tight and does not leak.
8. Label the laboratory form. Complete the following information:
a. Your Public Water System (**PWS**) ID number.
b. Your water system name, address, city and phone number.
c. Collection date and time.
d. Type of sample: Routine, Repeat, and Special. Refer to previous discussion of definitions.
e. Name of person collecting sample and sample location.
f. Free chlorine residual if your system is chlorinated. The residual should be measured at the time of sample collection.
g. Complete the section for the return address where the report is to be sent.
9. Package the sample for delivery to the laboratory. Be sure to include the lab form. The sample should be kept cool if at all possible.
10. Mail or deliver the sample to the lab immediately. Samples over 30 hours old will not be analyzed by the laboratory. If the sample is too old or leaks in transit, the lab will notify you and you must collect another.



Various IOC, VOs, SOCs sample bottles and chain-of-custody form.

Sampling Plan Example

A written sampling plan must be developed by the water system. These plans will be reviewed by the Health Department or State Drinking Water agency during routine field visits for sanitary surveys or technical assistance visits. This plan should include:

1. The location of routine sampling sites on a system distribution map. You will need to locate more routine sampling sites than the number of samples required per month or quarter. A minimum of three sites is advised and the sites should be rotated on a regular basis.
2. Map the location of repeat sampling sites for the routine sampling sites. Remember that repeat samples must be collected within five (5) connections upstream and downstream from the routine sample sites.
3. Establish a sampling frequency of the routine sites.
4. Sampling technique, establish a minimum flushing time and requirements for free chlorine residuals at the sites (if you chlorinate continuously).

The sampling sites should be representative of the distribution network and pressure zones. If someone else, e.g., the lab, collects samples for you, you should provide them with a copy of your sampling plan and make sure they have access to all sample sites.



This fellow is taking a sample from a stream to check the water quality.

Collection of Surface Water Samples

Representative samples may be collected from rivers, streams and lakes if certain rules are followed:

1. Watch out for flash floods! If a flooding event is likely and samples must be obtained, always go in two-person teams for safety. Look for an easy route of escape.

2. Select a sampling location at or near a gauging station, so that stream discharge can be related to water-quality loading. If no gauging station exists, then measure the flow rate at the time of sampling, using the streamflow method described below.

3. Locate a straight and uniform channel for sampling.

4. Unless specified in the sampling plan, avoid sampling locations next to confluences or point sources of contamination.

5. Use bridges or boats for deep rivers and lakes where wading is dangerous or impractical.

6. Do not collect samples along a bank, as they may not be representative of the surface water body as a whole.

7. Use appropriate gloves when collecting the sample.

Streamflow Measurement
Before collecting water quality samples, record the stream's flow rate at the selected station. The flow rate measurement is important for estimating contaminant loading and other impacts.

The first step in streamflow measurement is selecting a cross-section. Select a straight reach where the stream bed is uniform and relatively free of boulders and aquatic growth. Be certain that the flow is uniform and free of eddies, slack water and excessive turbulence.

After the cross-section has been selected, determine the width of the stream by stringing a measuring tape from bank-to-bank at right angles to the direction of flow. Next, determine the spacing of the verticals. Space the verticals so that no partial section has more than 5 per cent of the total discharge within it.

At the first vertical, face upstream and lower the velocity meter to the channel bottom, record its depth, then raise the meter to 0.8 and 0.2 of the distance from the stream surface, measure the water velocities at each level, and average them. Move to the next vertical and repeat the procedure until you reach the opposite bank. Once the velocity, depth and distance of the cross-section have been determined, the mid-section method can be used for determining discharge. Calculate the discharge in each increment by multiplying the averaged velocity in each increment by the increment width and averaged depth.

(Note that the first and last stations are located at the edge of the waterway and have a depth and velocity of zero.) Add up the discharges for each increment to calculate total stream discharge. Record the flow in liters (or cubic feet) per second in your field book.

Composite Sampling
Composite sampling is intended to produce a water quality sample representative of the total stream discharge at the sampling station. If your sampling plan calls for composite sampling, use an automatic type sampler.



This lab equipment is used for testing parameters in water such as Metals, Pesticides and Hydrocarbons. Often geotechnical water testing that is performed to support characterization regarding the fate and transport of contaminants in soils and sediments. Information such as the grain size distribution provides insight into the absorption, accumulation and movement of contaminants as it may relate to various particle sizes.

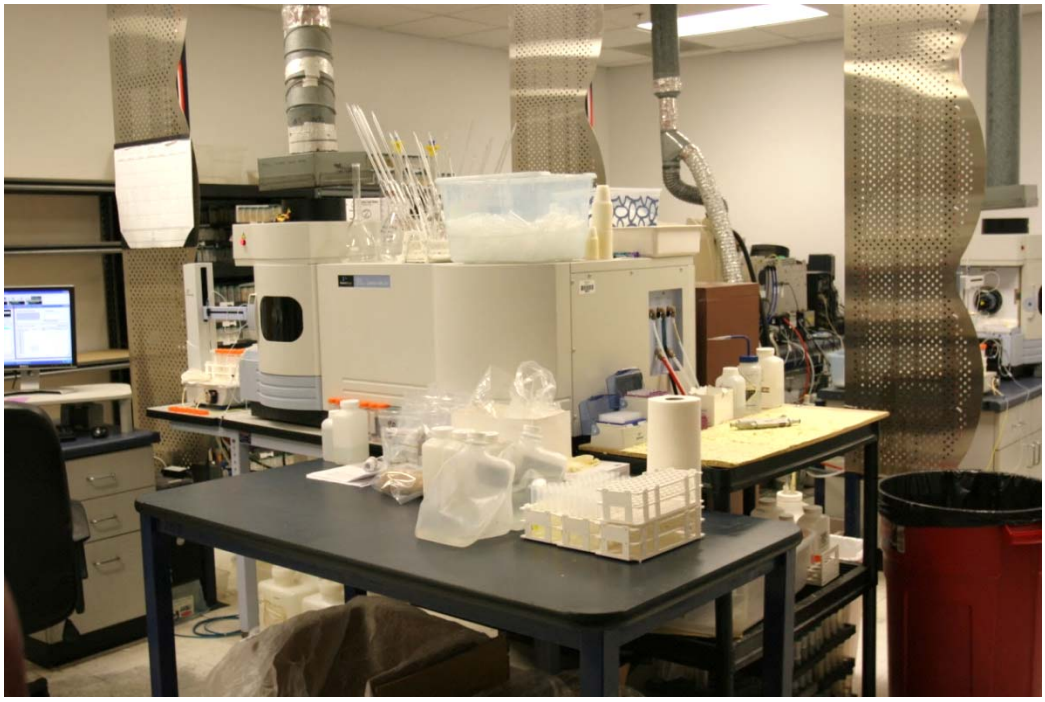




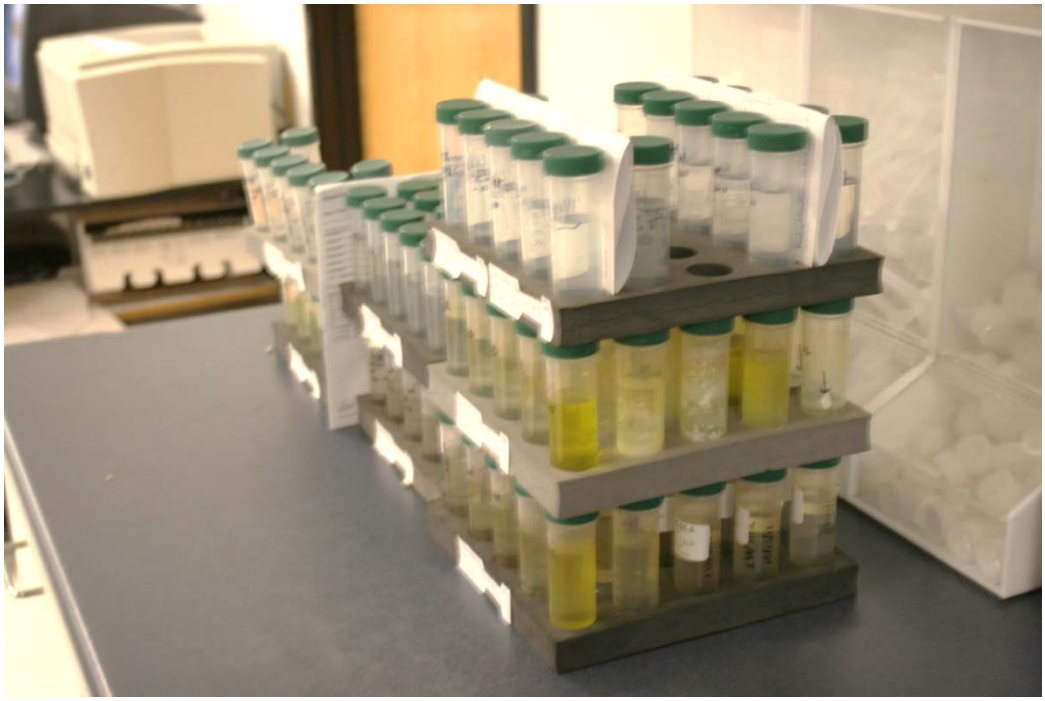
Top Photo: Extraction is a process used to concentrate trace levels of materials, in this case metals. Some metals are able to be complexed with an organic chelating agent. The organic chelating agent, Ammonium pyrrolidine dithiocarbamate (APDC), chemically binds the metals in the water. APDC is easily dissolved in the nonpolar organic solvent, methyl isobutyl ketone (MIBK). Because MIBK is nonpolar, it will not dissolve in water and will separate from the water like oil and water.

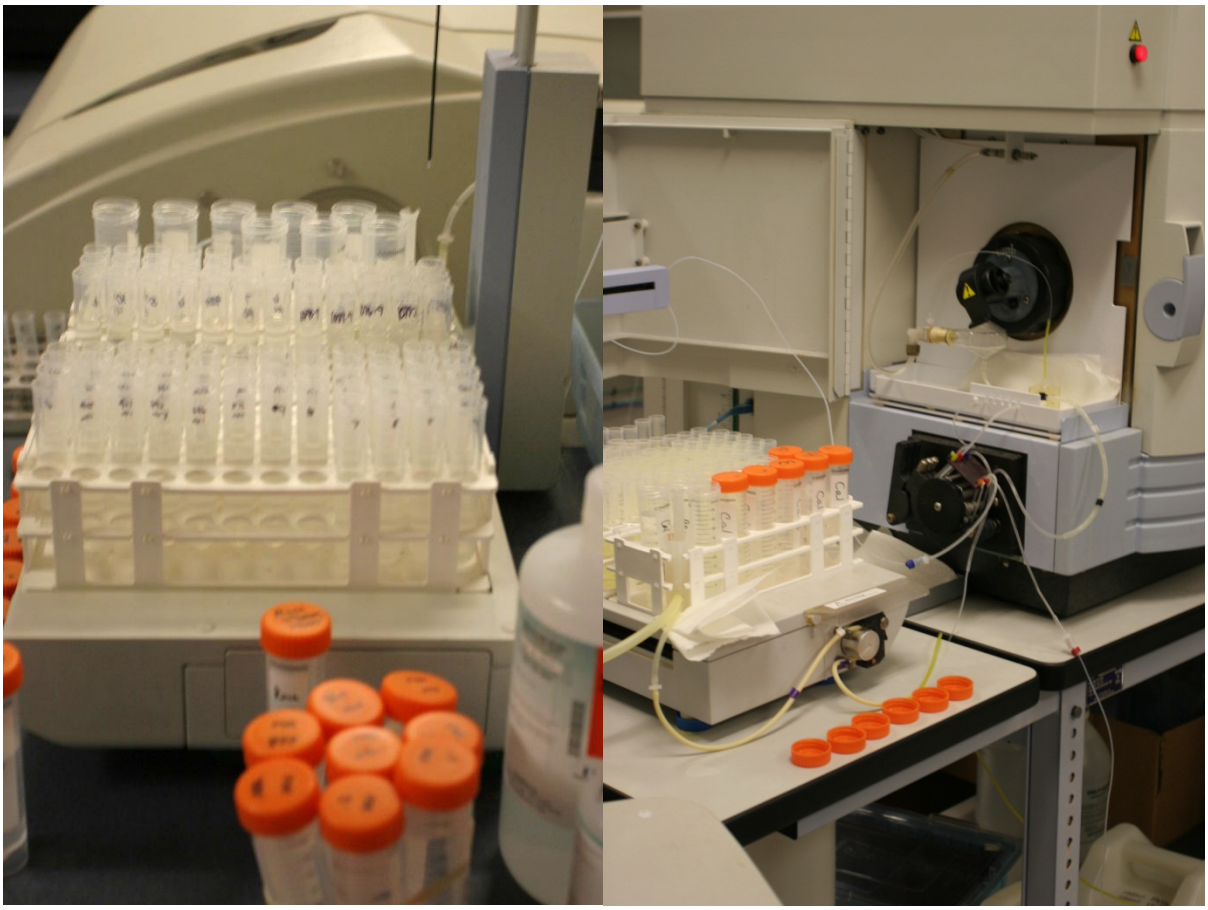
Bottom Photo: Atomic absorption requires the presence of ground state metal atoms (Me^{o}). The initial process which takes place in an atomic absorption spectrophotometer is to create a population of ground state atoms. This is accomplished in a variety of ways, usually classified as flame and non-flame. The simplest and most common method uses a flame to produce these atoms.





Vapor atomic fluorescence spectroscopy (CVAFS) analytical techniques were designed by the EPA for the analysis of Mercury at low and sub parts per trillion (ppt) concentrations. Low detection limits were developed to support risk assessment, Mercury bioaccumulation in fish is a heightened concern. Thirty-nine states have issued fish consumption advisories due to mercury contamination. Mercury is a toxic pollutant across most regulatory programs (air, water, hazardous waste & pollution prevention). It is persistent and harmful to human health and the environment at relatively low levels.





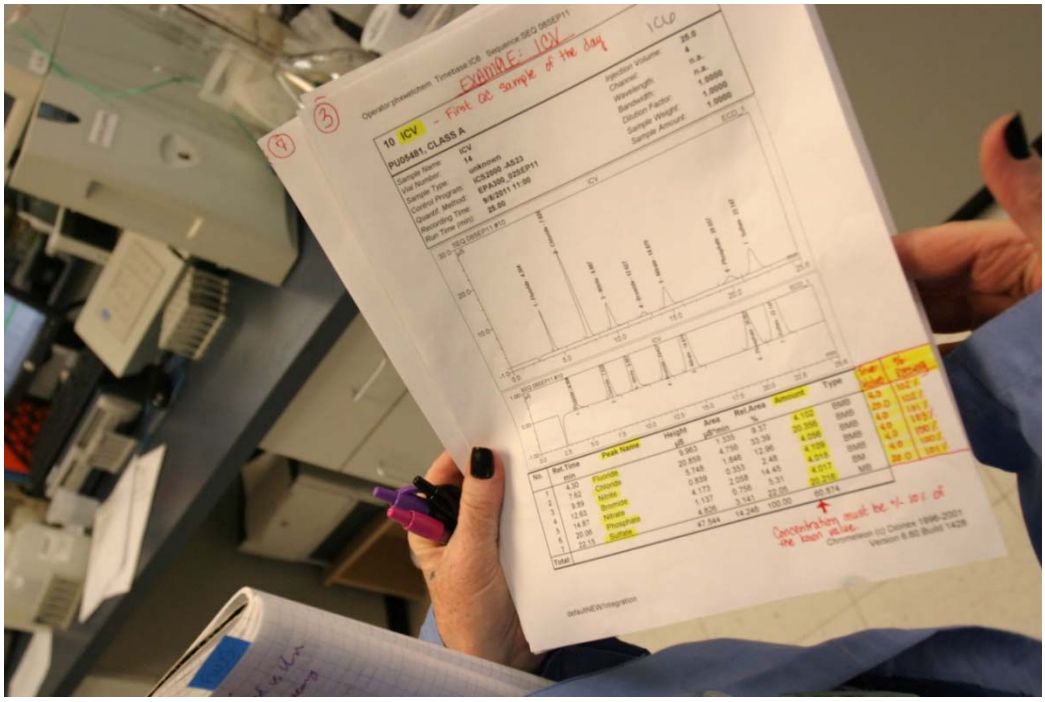
This lab's Quality Assurance Quality Control (QAQC) methods includes spikes, performance samples, replicates, detection limits and blanks.





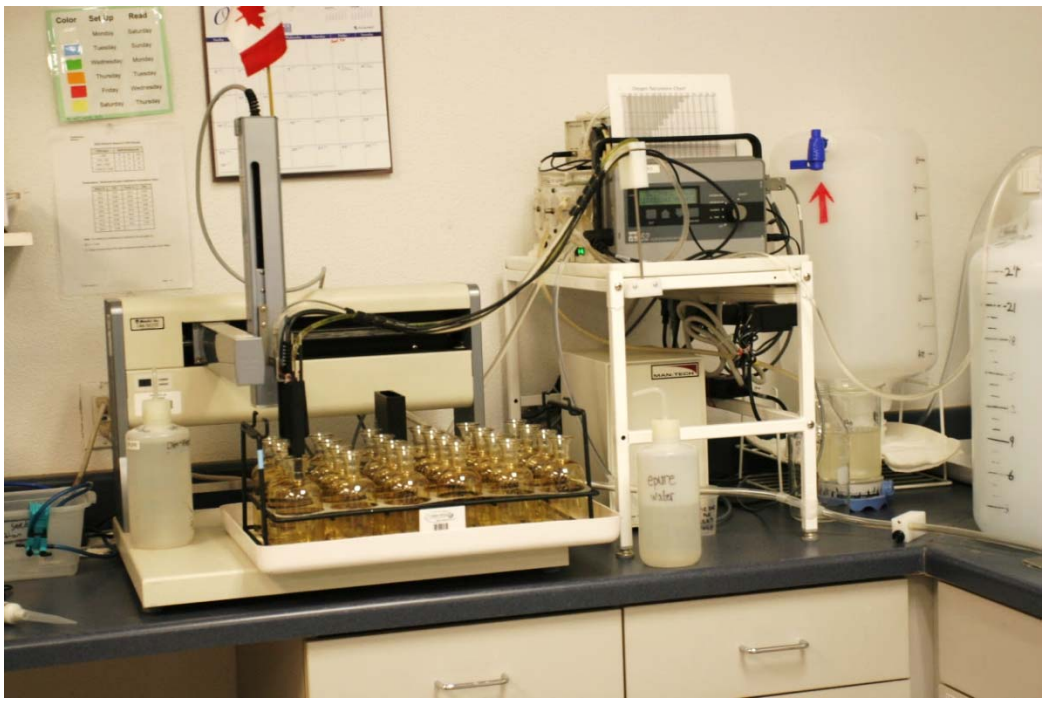
Prepared samples stored for metal analysis.

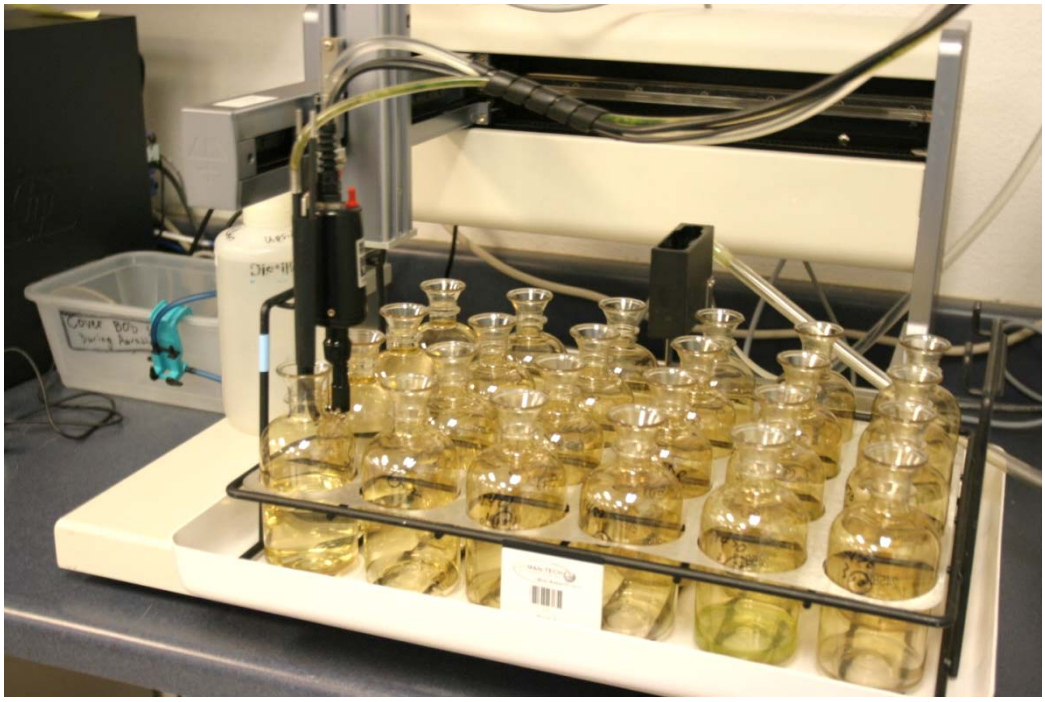




Top Photo: This form shows a typical ion chromatography run will have a standard curve consisting of 4 or 5 points for each ion of interest. A combined ion stock standard is used. The correlation coefficient of the standard curve for each ion should be >.998. The coefficient is calculated by plotting the peak area against the standard concentration using a linear fit.

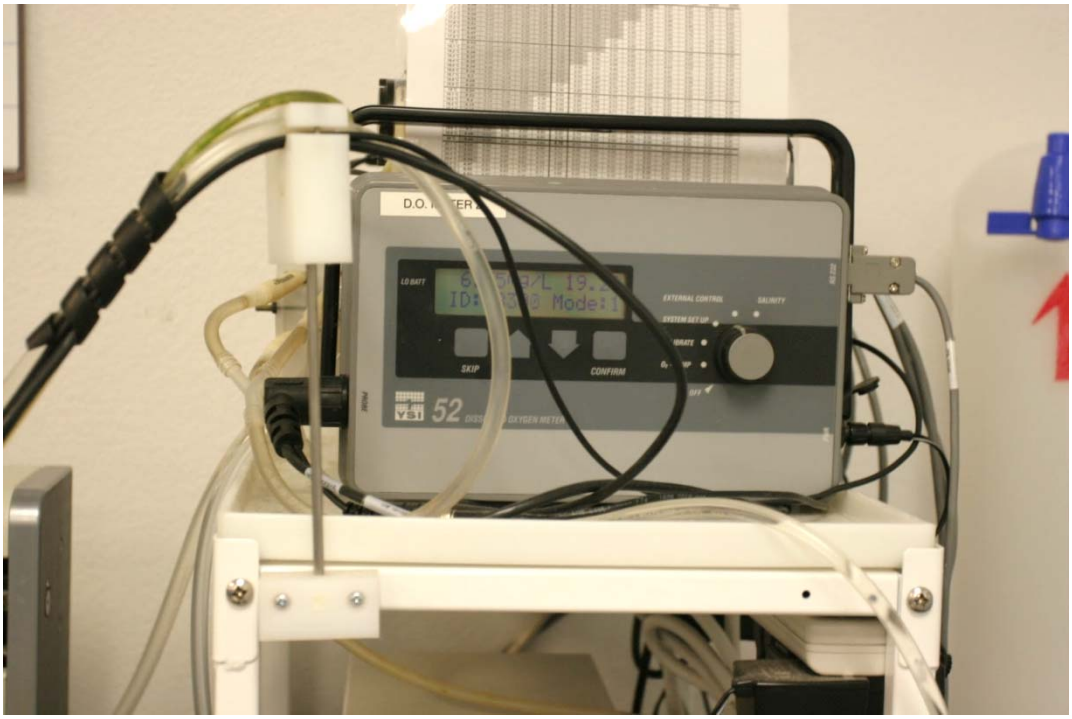
Bottom Photo: Some labs have the luxury of automatic filling dilution water for BOD bottles. If the BOD bottle is filled too rapidly, excessive agitation and bubbling may result in supersaturated water. This device also has the capability of measuring the oxygen level.

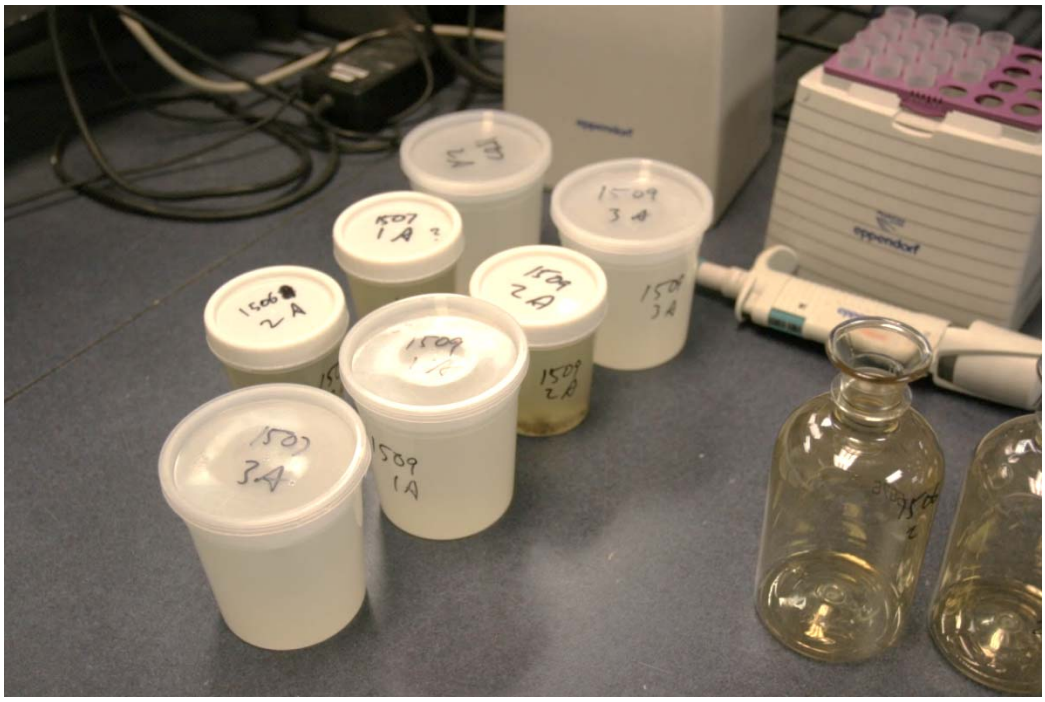




Top Photo: Running a BOD analysis on a sample consists of placing a portion of a sample (along with prepared dilution water) into an air-tight bottle (300 ml volume) and incubating the bottle at 20 +/- 1 deg C for (usually) 5 days.

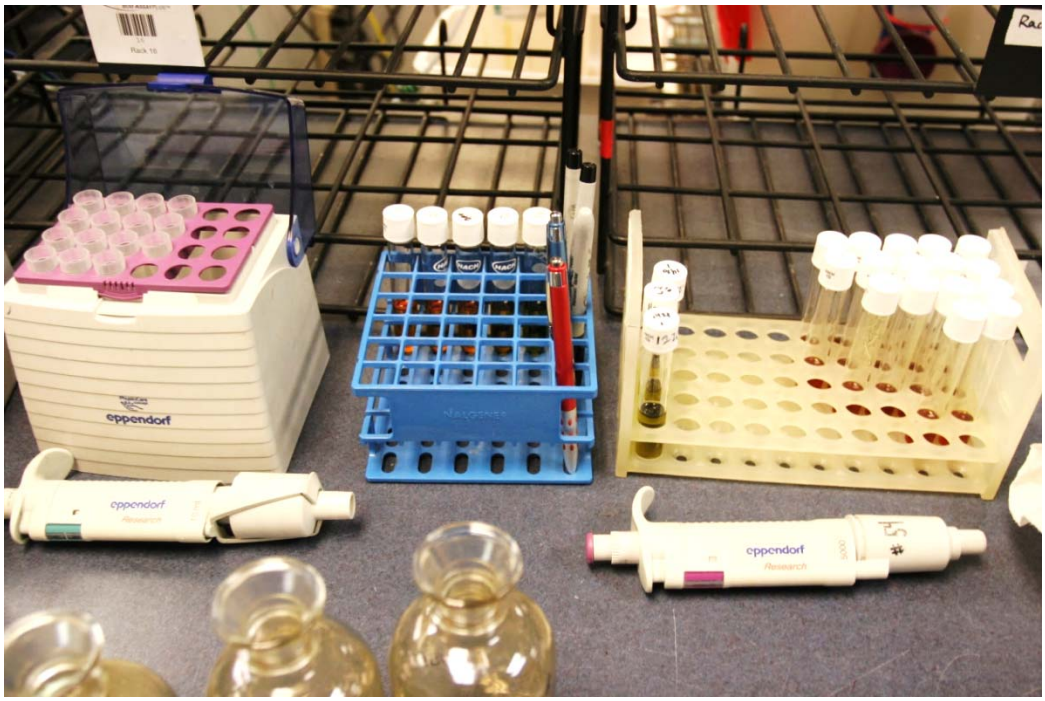
Bottom Photo: Dissolved oxygen is often measured to determine the oxygen level in receiving streams, in the aeration basin, and in the BOD test. The DO meter and electrode work in similar fashion to other electronic meters but unlike the others, this meter must be continually "on" to remain polarized.





Top Photo: Collecting the seed in a 500 ml bottle and let settle at least 1 hour and up to 36 hours. This will allow settleable solids to settle and help assure the seed is homogeneous.

Bottom Photo: In order to validate the BOD test conditions, reagents, and procedure, it is necessary to measure a solution with a known amount of organics. A solution that has a known value is called a standard.





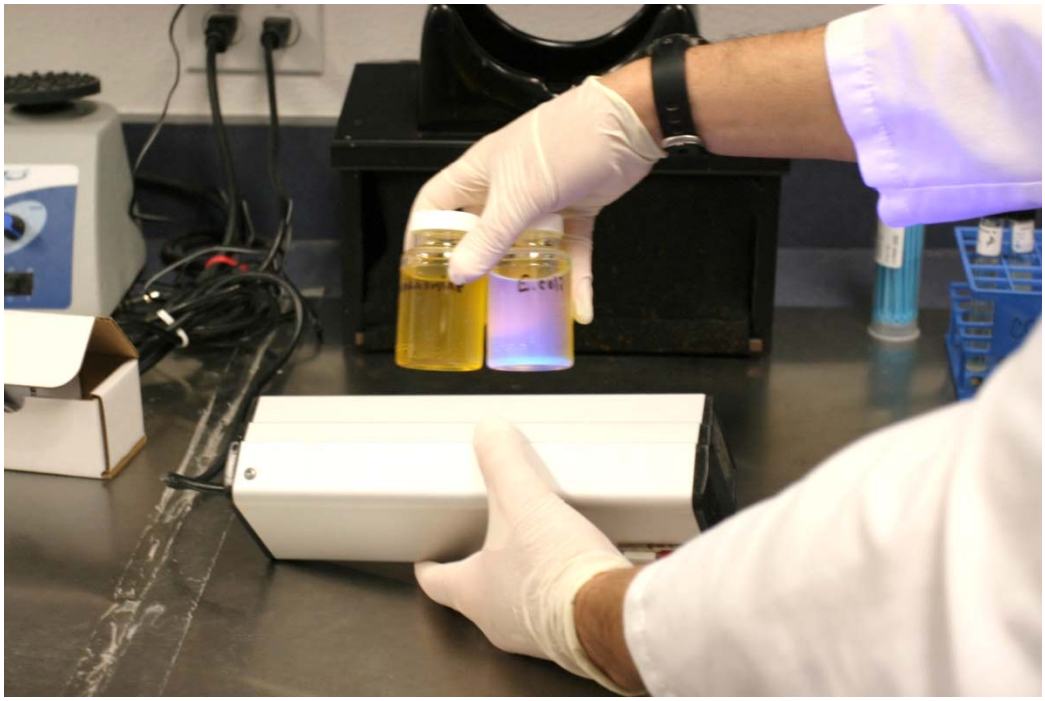
Top Photo: This area is used for Fecal coliform which the most common dilution is prepared by transferring 11 ml of sample to 99 ml of sterile phosphate dilution water using a sterile serological pipet.

Bottom Photo: Some labs perform a variation of coliform testing this technician is making sure his area follows QAQC standards.





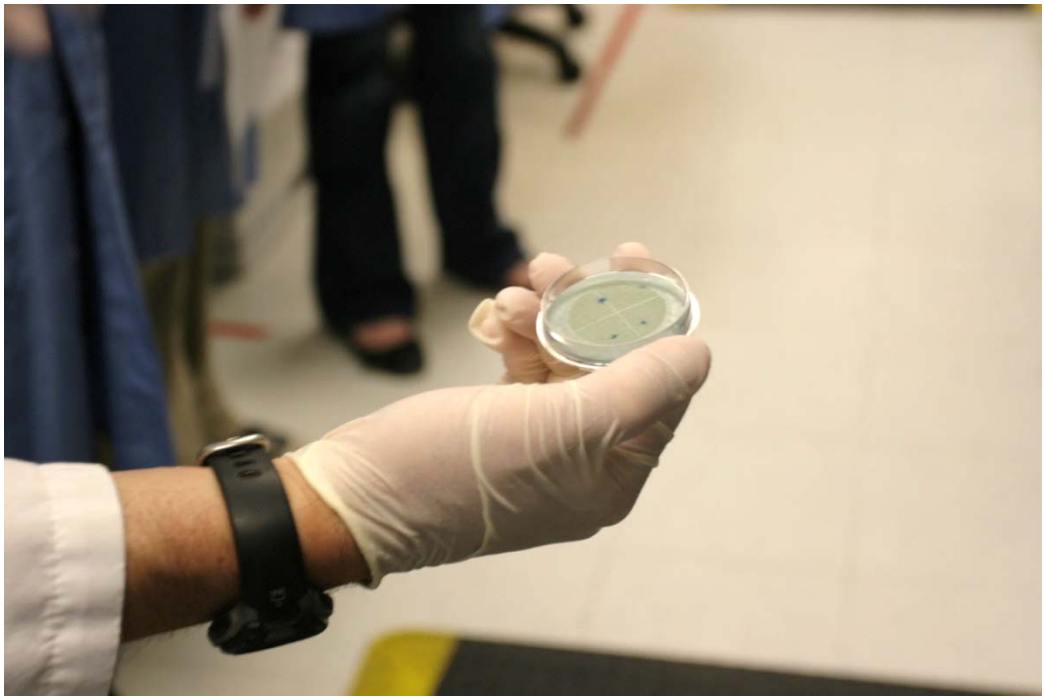
IDEXX bottles are clear plastic disposable containers that are supplied by the manufacturer with the colilert testing kits. Many labs that use the colilert method also issue the IDEXX bottles. Positive identification of total coliform is indicated by fluorescent under the UV light. E-coli are indicated by fluorescent blue colonies.





Top Photo: This technician is using Colilert which is a commercially available enzyme-substrate liquid-broth medium (IDEXX Laboratories, Inc.) that allows the simultaneous detection of total coliforms and *Escherichia coli* (*E. coli*). It is available in the most-probable number (MPN) or the presence/absence (PA) format. The MPN method is facilitated by use of a specially designed disposable incubation tray called the Quanti-Tray®.

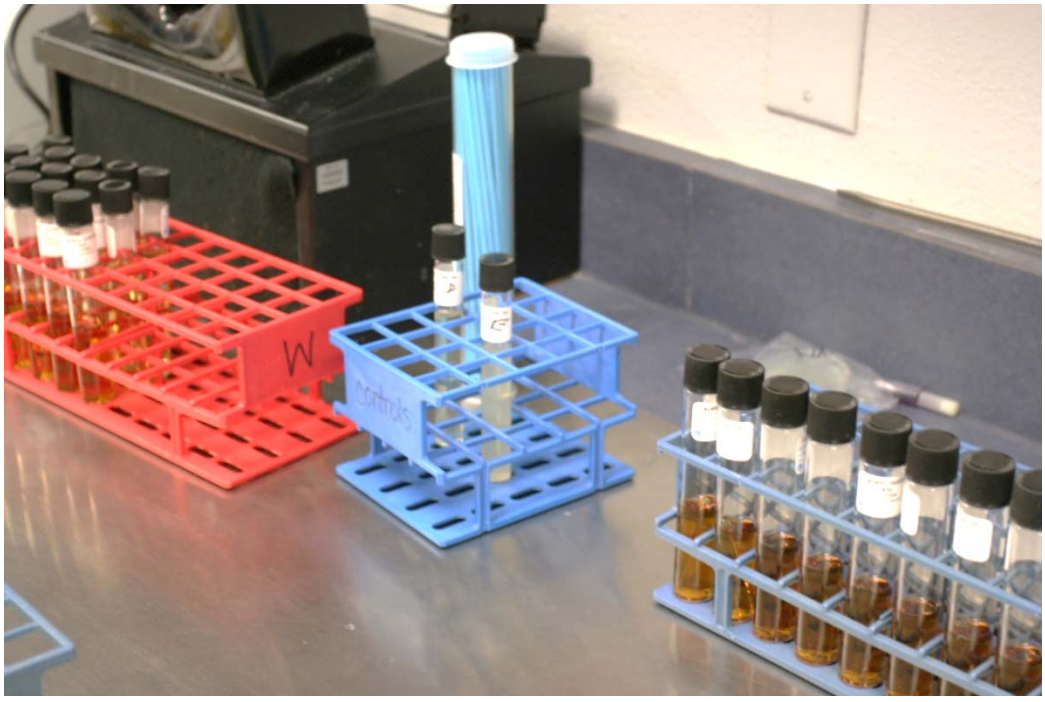
Bottom Photo: Another method is using a petri dish with a filter membrane. The broth and membrane used vary depending on the sample type for water or wastewater.

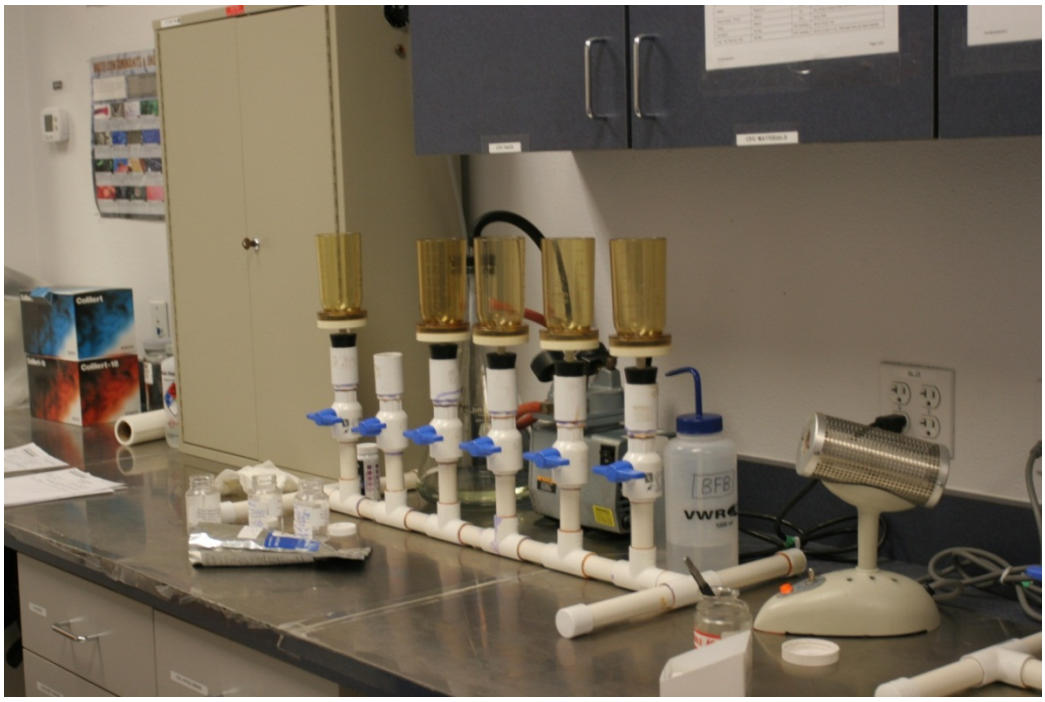




The MPN method (also called Multiple Tube Fermentation Technique) for fecal coliform detection is often used when the sample has excessive turbidity. Excessive turbidity in the sample will plug the membrane filter, causing poor bacteria recovery and slow filtration times.

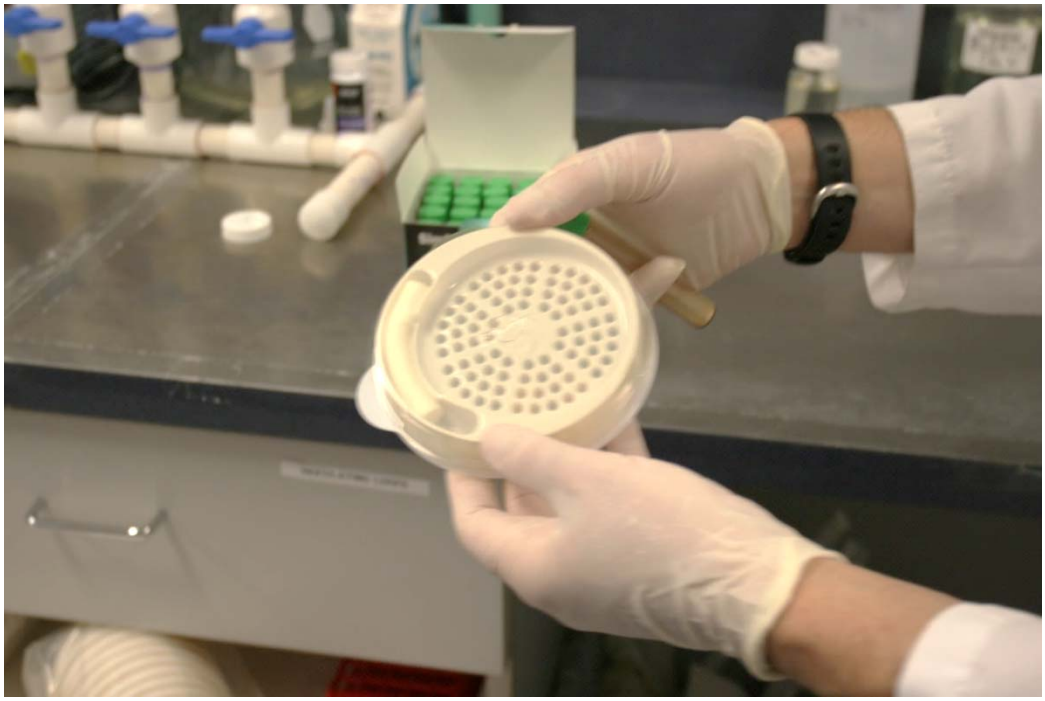
The MPN method involves adding the wastewater sample to a series of 5 sets of tubes, each of which contains either lactose broth or lauryl tryptose broth and an inverted tube. The tubes are then incubated at 35 + 0.5oC for 24 to 48 hours.





Top Photo: Analytical funnels are 100 ml filtration units that allow the membrane to be removed.

Bottom Photo: The heterotrophic plate count (HPC) is a procedure for estimating the number of live heterotrophic bacteria (requiring organic compounds of carbon and nitrogen for nourishment) in water. The technician will count the colored holes for the results.



Water Quality & River Sampling Photos



Top Photo: Technicians use several different devices to sample wells depending on the depth of the water table. Some use hand bailers or small gas powered submersible pumps.

Bottom Photo: Technicians are always concerned with Quality Assurance; here the containers have DI water for rinsing in the field. The containers that look like milk bottles are used for the equal width depth integrated sampler.





Top Photo: This multi probe device measures dissolved oxygen (DO), pH, conductivity and total dissolved solids (TDS), the device requires calibration for each parameter.

Bottom Photo: Collection of isokinetic, depth-integrated samples is done using either an equal-width-increment (EWI) or equal-discharge-increment (EDI) sampling method. The methods typically result in a composite sample that represents the streamflow-weighted concentrations of the stream cross section being sampled. That sample is poured into the bottles that resemble old fashion milk bottles.





The churn splitter was designed to facilitate the withdrawal of a representative subsample from a large composite sample of a water-sediment mixture. For example, samples from several verticals in a stream cross section, differing slightly from each other in chemical quality and sediment concentration, can be placed in the churn and be mixed into a relatively homogenous suspension, any subsample withdrawn from the churn should be equal in chemical quality and sediment concentration to any other subsample from the churn.





Ampullariidae, common name the apple snails, is a family of large freshwater snails, aquatic gastropod mollusks with a gill and an operculum. This family is in the superfamily Ampullarioidea and is the type family of that superfamily. The Ampullariidae are unusual because they have both a gill and a lung, the mantle cavity being divided in order to separate the two types of respiratory structures. This adaptation allows these snails to be amphibious. Bottom photo, snail eggs clusters on rocks.





Top Photo: When sampling in the river it is suggested that a minimum of two people participate. One person is holding the collection net while the other carefully disturbs the sediment for collection.

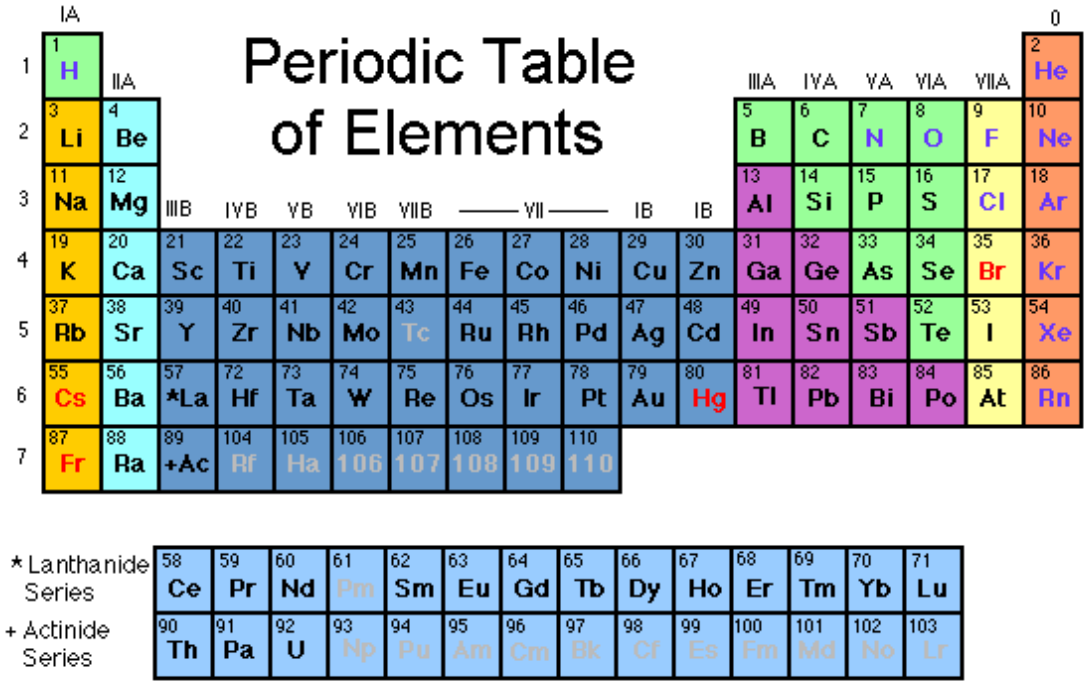
Bottom Photo: This river contained larvae of mayfly and stone flies along with leaches.





Sieving invertebrate samples reduces the volume of sediment that must be sorted through in the lab. A #60 sieve is recommended because the smaller invertebrates will be retained by the #60 sieve and should yield more complete invertebrate community data for a site. Any large debris should be cleaned (remove invertebrates and add them to the sample) and removed from the sample. The sample is then washed through the sieve over the side of the boat or in a tub with site water until no more fine sediment washes through the mesh.





History of the Periodic Table
Dimitri Mendeleev created the periodic table when he first listed the elements in order of atomic mass in 1869. He found that the elements with similar properties occur in a periodic manner. Mendeleev was able to arrange the elements in a table form where similar elements are found in the same column.

How is the Periodic Table Organized?
The periodic table is organized with eight principal vertical columns called groups and seven horizontal rows called periods (The groups are numbered I to VIII from left to right, and the periods are numbered 1 to 7 from top to bottom) .

All the metals are grouped together on the left side of the periodic table, and all the nonmetals are grouped together on the right side of the periodic table. Semimetals are found in between the metals and nonmetals.

What are the Eight Groups of the Periodic Table?

- ✓ **Group I: Alkali Metals - Li, Na, K, Rb, Cs, Fr**
  known as alkai metals
  most reactive of the metals
  react with all nonmetals except the noble gases
  contain typical physical properties of metals (ex. shiny solids and good conductors of heat and electricity) softer than most familiar metals; can be cut with a knife

- ✓ **Group II: Alkaline Earth Metals-Be, Mg, Ca, Sr, Ba, Ra**
  known as alkaline earth metals
  react with nonmetals, but more slowly than the Group I metals
  solids at room temperature

have typical metallic properties
harder than the Group I metals
higher melting points than the Group I metals

- ✓ **Group III: B, Al, Ga, In, Tl**
  boron is a semimetal; all the others are metals

- ✓ **Group IV: C, Si, Ge, Sn, Pb**
  carbon is a nonmetal; silicon and germanium are semimetals; tin and lead are metals

- ✓ **Group V: N, P, As, Sb, Bi**
  nitrogen and phosphorus are nonmetals; arsenic and antimony are semimetals; bismuth is a metal

- ✓ **Group VI: O, S, Se, Te, Po**
  oxygen, sulfur, and selenium are nonmetals; tellurium and polonium are semimetals

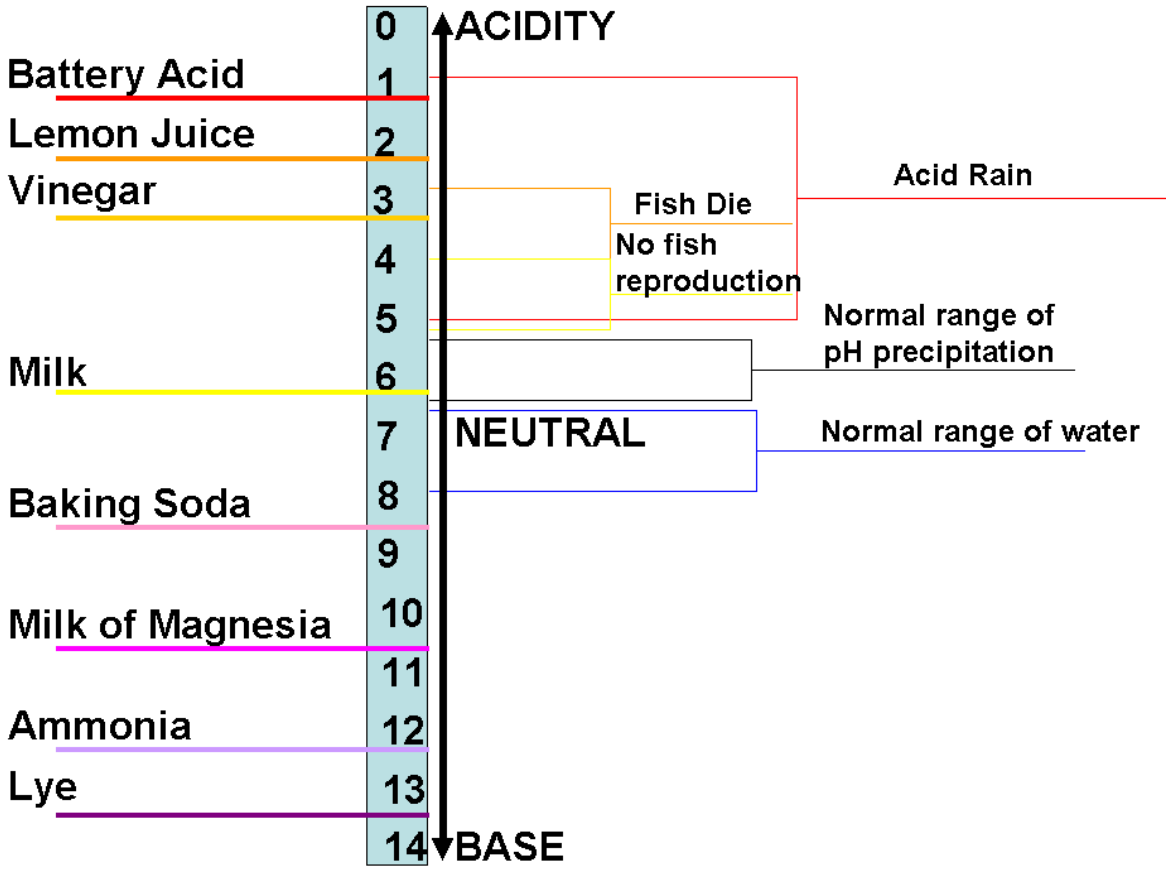
- ✓ **Group VII: Halogens-F, Cl, Br, I, At**
  very reactive nonmetals

- ✓ **Group VIII: Noble Gases-He, Ne, Ar, Kr, Xe, Rn**
  very unreactive

Assignment
How do the properties of metals and nonmetals differ?



The pH Scale



pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity.

pH = (**Power of Hydroxyl Ion Activity**).

The acidity of a water sample is measured on a pH scale. This scale ranges from **0** (maximum acidity) to **14** (maximum alkalinity). The middle of the scale, **7**, represents the neutral point. The acidity increases from neutral toward **0**.

Because the scale is logarithmic, a difference of one pH unit represents a tenfold change. For example, the acidity of a sample with a pH of **5** is ten times greater than that of a sample with a pH of **6**. A difference of 2 units, from **6** to **4**, would mean that the acidity is one hundred times greater, and so on.

Normal rain has a pH of **5.6** – slightly acidic because of the carbon dioxide picked up in the earth's atmosphere by the rain.

Water Disinfectant Terminology

Many water suppliers add a disinfectant to drinking water to kill germs such as giardia and e coli. Especially after heavy rainstorms, your water system may add more disinfectant to guarantee that these germs are killed.

Chlorine. Some people who use drinking water containing chlorine well in excess of the EPA standard could experience irritating effects to their eyes and nose. Some people who drink water containing chlorine well in excess of the EPA standard could experience stomach discomfort.

Chloramine. Some people who use drinking water containing chloramines well in excess of the EPA standard could experience irritating effects to their eyes and nose. Some people who drink water containing chloramines well in excess of the EPA standard could experience stomach discomfort or anemia.

Chlorine Dioxide. Some infants and young children who drink water containing chlorine dioxide in excess of the EPA standard could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorine dioxide in excess of the EPA standard. Some people may experience anemia.

Disinfection Byproducts
Disinfection byproducts form when disinfectants added to drinking water to kill germs react with naturally-occurring organic matter in water.

Total Trihalomethanes. Some people who drink water containing trihalomethanes in excess of the EPA standard over many years may experience problems with their liver, kidneys, or central nervous systems, and may have an increased risk of getting cancer.

Haloacetic Acids. Some people who drink water containing haloacetic acids in excess of the EPA standard over many years may have an increased risk of getting cancer.

Bromate. Some people who drink water containing bromate in excess of the EPA standard over many years may have an increased risk of getting cancer.

Chlorite. Some infants and young children who drink water containing chlorite in excess of EPA standard could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of the EPA's standard. Some people may experience anemia.

MTBE is a fuel additive, commonly used in the United States to reduce carbon monoxide and ozone levels caused by auto emissions. Due to its widespread use, reports of MTBE detections in the nation's ground and surface water supplies are increasing. The Office of Water and other EPA offices are working with a panel of leading experts to focus on issues posed by the continued use of MTBE and other oxygenates in gasoline. The EPA is currently studying the implications of setting a drinking water standard for MTBE.

Health advisories provide additional information on certain contaminants. Health advisories are guidance values based on health effects other than cancer. These values are set for different durations of exposure (e.g., one-day, ten-day, longer-term, and lifetime).

Chemical Monitoring *We will go more in to detail later.*

The final federal rules regarding Phase II and V contaminants were promulgated by the U.S. EPA in 1992 and initial monitoring began in January 1993. This group of contaminants consists of Inorganic Chemicals (**IOC**), Volatile Organic Chemicals (**VOC**) and Synthetic Organic Chemicals (**SOC**) and the rule applies to all community and non-transient non-community public water systems.

The monitoring schedule for these contaminants is phased in by water system population size according to a "**standardized monitoring framework**" established by the U.S. EPA. This standardized monitoring framework establishes nine-year compliance cycles consisting of three 3-year compliance periods. The first compliance cycle began in January 1993 and ended December 31, 2001, with subsequent compliance cycles following the nine-year timeframe. The three-year compliance period of each cycle is the standard monitoring period for the water system.

Turbidity Monitoring
Monitoring for turbidity is applicable to all public water systems using surface water sources or ground water sources under the direct influence of surface water in whole or part. Check with your state drinking water section or health department for further instructions.

The maximum contaminant level for turbidity for systems that provide filtration treatment:
1. Conventional or direct filtration: less than or equal to 0.5 NTU in at least 95% of the measurements taken each month. Conventional filtration treatment plants should be able to achieve a level of 0.1 NTU with proper chemical addition and operation.
2. Slow sand filtration, cartridge and alternative filtration: less than or equal to 1 NTU in at least 95% of the measurements taken each month. The turbidity levels must not exceed 5 NTU at any turbidity measurements must be performed on representative samples of the filtered water every four (4) hours that the system serves water to the public. A water system may substitute continuous turbidity monitoring for grab sample monitoring if it validates the continuous measurement for accuracy on a regular basis using a protocol approved by the Health or Drinking Water Agency, such as confirmation by a bench top turbidimeter. For systems using slow sand filtration, cartridge, or alternative filtration treatment the Health or Drinking Water Agency may reduce the sampling frequency to once per day if it determines that less frequent monitoring is sufficient to indicate effective filtration performance.

Inorganic Chemical Monitoring
All systems must monitor for inorganics. The monitoring for these contaminants is also complex with reductions, waivers and detections affecting the sampling frequency. Please refer to the monitoring schedules provided by your state health or drinking water sections for assistance in determining individual requirements. All transient non-community water systems are required to complete a one-time inorganic chemical analysis. The sample is to be collected at entry points (**POE**) to the distribution system representative of each source after any application of treatment.



Nitrates
Nitrate is an inorganic chemical that occurs naturally in some groundwater but most often is introduced into ground and surface waters by man. The most common sources are from fertilizers and treated sewage or septic systems.

At high levels (over 10 mg/l) it can cause the "**blue baby**" syndrome in young infants, which can lead to serious illness and even death. It is regarded as an "**acute health risk**" because it can quickly cause illness.

Every water system must test for ***Nitrate*** at least yearly. Systems that use ground water only must test yearly. Systems that use surface water and those that mix surface and ground water must test every quarter. A surface water system may go to yearly testing if community and nontransient noncommunity water must do quarterly monitoring whenever they exceed 5 mg/l in a test. After 4 quarters of testing and the results show that the nitrate level is not going up, they may go back to yearly testing.

Radiological Contaminants
All community water systems shall monitor for gross alpha activity every four years for each source. Depending on your state rules, compliance will be based on the annual composite of 4 consecutive quarters or the average of the analyses of 4 quarterly samples. If the average annual concentration is less than one half the MCL, an analysis of a single sample may be substituted for the quarterly sampling procedure.

Total Trihalomethanes (TTHM)
All community water systems serving a population of 10,000 or more and which add a disinfectant in any part of the drinking water treatment process shall monitor for total trihalomethanes (**TTHM**). The MCL is 0.1 mg/l and consists of a calculation of the running average of quarterly analyses of the sum of the concentrations of bromodichloromethane, di-bromochloromethane, bromoform and chloroform.

Lead and Copper Rule
The Lead and Copper Rule was promulgated by the U.S. EPA on June 7, 1991, with monitoring to begin in January 1992 for larger water systems. This rule applies to all community and nontransient, noncommunity water systems and establishes action levels for these two contaminants at the consumer's tap. Action levels of 0.015 mg/l for lead and 1.3 mg/l for copper have been established.

This rule establishes maximum contaminant level goals (**MCLGs**) for lead and copper, treatment technique requirements for optimal corrosion control, source water treatment, public education and lead service line replacement. Whenever an action level is exceeded, the corrosion control treatment requirement is triggered. This is determined by the concentration measured in the 90th percentile highest sample from the samples collected at consumers' taps. Sample results are assembled in ascending order (lowest to highest) with the result at the 90th percentile being the action level for the system. For example, if a water system collected 20 samples, the result of the 18th highest sample would be the action level for the system.

The rule also includes the best available technology (**BAT**) for complying with the treatment technique requirements, mandatory health effects language for public notification of violations and analytical methods and laboratory performance requirements.

Initial monitoring began in January 1992 for systems with a population of 50,000 or more, in July 1992 for medium-sized systems (3,300 to 50,000 population) and in July 1993 for small-sized systems (less than 3,300 population),

One-liter tap water samples are to be collected at high-risk locations by either water system personnel or residents. Generally, high-risk locations are homes with lead-based solder installed after 1982 or with lead pipes or service lines. If not enough of these locations exist in the water system, the rule provides specific guidelines for selecting other sample sites.

The water must be allowed to stand motionless in the plumbing pipes for at least six (6) hours and collected from a cold water tap in the kitchen or bathroom. It is a first draw sample, which means the line is not to be flushed prior to sample collection. The number of sampling sites is determined by the population of the system and sample collection consists of two, six-month monitoring periods; check with your state rule or drinking water section for more information.

Sampling Sites by Population

System size - No. of sites (no. of persons served)	*No. of sites (standard monitoring)*	*No. of sites (reduced monitoring)*
>100,000	100	50
10,001-100,000	60	30
3,301 to 10,000	40	20
501 to 3,300	20	10
101 to 500	10	5
< 100	5	5

If a system meets the lead and copper action levels or maintains optimal corrosion control treatment for two consecutive six-month monitoring periods, then reduced monitoring is allowed and sampling frequency drops to once per year. After three consecutive years of reduced monitoring, sample frequency drops to once every three years. In addition to lead and copper testing, all large water systems and those medium- and small-sized systems that exceed the lead or copper action levels will be required to monitor for the following water quality parameters: pH, alkalinity, calcium, conductivity, orthophosphate, silica and water temperature.

These parameters are used to identify optimal corrosion control treatment and determine compliance with the rule once treatment is installed. The sampling locations for monitoring water quality parameters are at entry points and representative taps throughout the distribution system.

Coliform sampling sites can be used for distribution system sampling. The number of sites required for monitoring water quality during each six-month period is shown below.

Number of Water Quality Parameters per Population

System size (no. of persons served)	*# of sites for water quality parameters*
>100,000	25
10,001-100,000	10
3,301 to 10,000	3
501 to 3,300	2
101 to 500	1
<100	1

Water systems which maintain water quality parameters reflecting optimal corrosion control for two consecutive six-month monitoring periods qualify for reduced monitoring. After three consecutive years, the monitoring frequency can drop to once per year.

All large water systems must demonstrate that their water is minimally corrosive or install corrosion control treatment regardless of lead and copper sampling results.

QA/QC Measures

In addition to standard samples, the field technicians collect equipment blanks (**EB**), field cleaned equipment blanks (**FB**), split samples (**SS**), and field duplicate samples (**FD**).

Overall care must be taken in regards to equipment handling, container handling/storage, decontamination, and record keeping. Sample collection equipment and non-preserved sample containers must be rinsed three times with sample water before the actual sample is taken. Exceptions to this are any pre-preserved container or bac-t type samples.

If protective gloves are used, they shall be clean, new and disposable. These should be changed upon arrival at a new sampling point. Highly contaminated samples shall never be placed in the same ice chest as environmental samples. It is good practice to enclose highly contaminated samples in a plastic bag before placing them in ice chests. The same is true for wastewater and drinking water samples.

Ice chests or shipping containers with samples suspected of being highly contaminated shall be lined with new, clean, plastic bags. If possible, one member of the field team should take all the notes, fill out labels, etc., while the other member does all of the sampling.

Preservation of Samples
Proper sample preservation is the responsibility of the sampling team, not the lab providing sample containers. The best reference for preservatives is Standard Methods or your local laboratory.



It is the responsibility of the field team to assure that all samples are appropriately preserved.

Follow the preservative solution preparation instructions.

Always use strong safety precautions diluting the acid.

Put a new label on the dispensing bottle with the current date.

Slowly add the acid or other preservative to the water sample; not water to the acid or preservative.

Wait 3-4 hours for the preservative to cool most samples down to 4 degrees Celsius.

Most preservatives have a shelf life of one year from the preparation date.

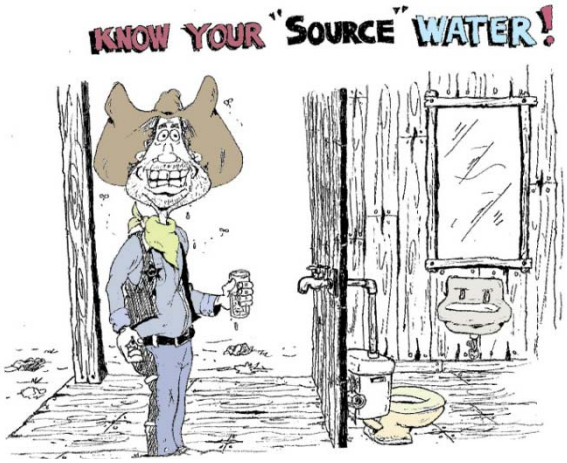
When samples are analyzed for TKN, TP, NH4 and NOx 1 mL of 50% Trace Metal grade sulfuric acid is added to the each discrete auto sampler bottles/bags in the field lab before sampling collection. The preservative maintains the sample at 1.5<pH<2 after collection. To meet maximum holding time for these preserved samples (28 days), pull and ship samples every 14 days.

Narrow range pH paper (test strips) can be used to test an aliquot of the preserved sample.

Place the pH paper into the container and compare the color with the manufacturer's color chart.

Troubleshooting Table for Sampling Monitoring

Problem
1. Positive Total Coliform.
2. Chlorine taste and odor.
3. Inability to maintain an adequately free chlorine residual at the furthest points of the distribution system or at dead end lines.



Possible Cause
1A. Improper sampling technique.
1B. Contamination entering distribution system.
1C. Inadequate chlorine residual at the sampling site.
1D. Growth of biofilm in the distribution system.
2A. High total chlorine residual and low free residual.
3A. Inadequate chlorine dose at treatment plant.
3B. Problems with chlorine feed equipment.
3C. Ineffective distribution system flushing program.
3D. Growth of biofilm in the distribution system.

Possible Solution
1A/ Check distribution system for low pressure conditions, possibly due to line breaks or excessive flows that may result in a backflow problem.

1B. Insure that all staff are properly trained in sampling and transport procedures as described in the TCR.

1C. Check the operation of the chlorination feed system. Refer to issues described in the sections on pumps and hypochlorination systems. Insure that residual test is being performed properly.

1D. Thoroughly flush effected areas of the distribution system. Superchlorination may be necessary in severe cases.

2A. The free residual should be at least 85% of the total residual. Increase the chlorine dose rate to get past the breakpoint in order to destroy some of the combined residual that causes taste and odor problems. Additional system flushing may also be required.

3A. Increase chlorine feed rate at point of application.

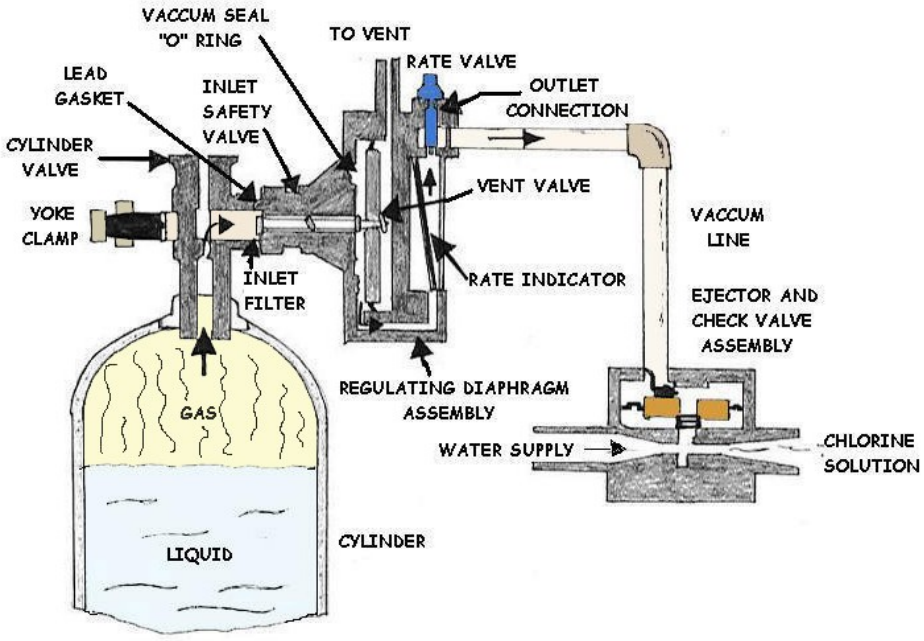
3B. Check operation of chlorination equipment.

3C. Review distribution system flushing program and implement improvements to address areas of inadequate chlorine residual.

3D. Increase flushing in area of biofilm problem.



150-pound chlorine gas cylinder.



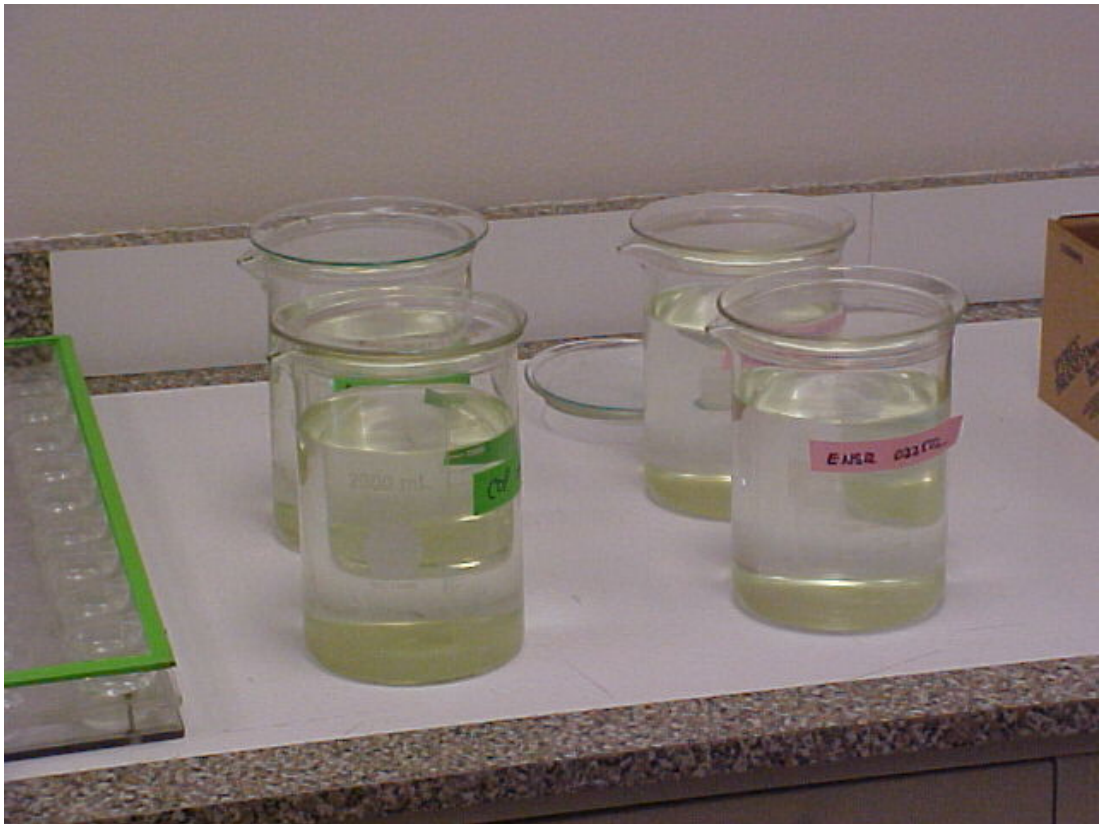
Microbes

Coliform bacteria are common in the environment and are generally not harmful. However, the presence of these bacteria in drinking water are usually a result of a problem with the treatment system or the pipes which distribute water, and indicates that the water may be contaminated with germs that can cause disease.

Fecal Coliform and E. coli are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Microbes in these wastes can cause short-term effects, such as diarrhea, cramps, nausea, headaches, or other symptoms.

Cryptosporidium is a parasite that enters lakes and rivers through sewage and animal waste. It causes cryptosporidiosis, a mild gastrointestinal disease. However, the disease can be severe or fatal for people with severely weakened immune systems. The EPA and CDC have prepared advice for those with severely compromised immune systems who are concerned about ***Cryptosporidium***.

Giardia lamblia is a parasite that enters lakes and rivers through sewage and animal waste. It causes gastrointestinal illness (e.g. diarrhea, vomiting, and cramps).



Counting water fleas is just one daily task for many water treatment operators. Water Fleas or Daphnia are small crustaceans and great bio-indicators. Changes in heart rate might suggest a chemical compound has a physiological effect, and more importantly-*Daphnia Magna* is used to measure the toxicity of a chemical compound in water (LD50 measurements).



Fluoride. Many communities add fluoride to their drinking water to promote dental health. Each community makes its own decision about whether or not to add fluoride. The EPA has set an enforceable drinking water standard for fluoride of 4 mg/L (some people who drink water containing fluoride in excess of this level over many years could develop bone disease, including pain and tenderness of the bones). The EPA has also set a secondary fluoride standard of 2 mg/L to protect against dental fluorosis.

Safe Drinking Water Act (SDWA)

On August 6, 1996, President Clinton signed the Reauthorization of the Safe Drinking Water Act, bringing to a successful conclusion to years of work on the part of water professionals and a broad range of public interest groups throughout the nation. This law strikes a balance among federal, state, local, urban, rural, large and small water systems in a manner that improves the protection of public health and brings reason and good science to the regulatory process.



The major elements of this law include:

- The law updates the standard-setting process by focusing regulations on contaminants known to pose greater public health risks.
- It replaces the current law's demand for 25 new standards every three years with a new process based on occurrence, relative risk and cost-benefit considerations.
- It also requires the EPA to select at least five new candidate contaminants to consider for regulation every five years.
- The EPA is directed to require public water systems to provide customers with annual "**Consumer Confidence Reports**" in newspapers and by direct mail.
- The reports must list levels of regulated contaminants along with Maximum Contaminant Levels (**MCLs**) and Maximum Contaminant Level Goals (**MCLGs**), along with plainly worded definitions of both.
- The reports must also include a plainly worded statement of the health concerns for any contaminants for which there has been a violation, describe the utility's sources of

drinking water and provide data on unregulated contaminants for which monitoring is required, including Cryptosporidium and radon.

- The EPA must establish a toll-free hot line customers can call to get additional information.
- The EPA is required to publish guidelines for states to develop water source assessment programs that delineate protection areas and assess contamination risks.
- The EPA is required to identify technologies that are affordable for small systems to comply with drinking water regulations.
- Technical assistance funds and Small System Technical Assistance Centers are authorized to meet the training and technical needs of small systems.
- States are authorized to grant variances for compliance with drinking water regulations for systems serving 3,300 or fewer persons.
- The EPA is required to publish certification guidelines for operators of community and nontransient noncommunity public water systems.
- States that do not have operator certification programs that meet the requirements of the guidelines will lose 20 percent of their SRLF grant.
- A source water petition program for voluntary, incentive-based partnerships among public water systems and others to reduce contamination in source water is authorized.
- The law establishes a new State Revolving Loan Fund (**SRLF**) of $1 billion per year to provide loans to public water systems to comply with the new SDWA.
- It also requires states to allocate 15 percent of the SRLF to systems serving 10,000 or fewer people unless no eligible projects are available for loans.
- It also allows states to jointly administer SDWA and Clean Water Act loan programs and transfer up to 33 percent between the two accounts.
- States must ensure that all new systems have compliance capacity and that all current systems maintain capacity, or lose 20 percent of their SRLF grant.

Although the EPA will continue to provide policy, regulations and guidance, state governments will now have more regulatory flexibility allowing for improved communication between water providers and their local regulators. Increased collaboration will result in solutions that work better and are more fully supported by the regulated community. States that have a source water assessment program may adopt alternative monitoring requirements to provide permanent monitoring relief for public water systems in accordance with EPA guidance.

Safe Drinking Water Act of 1974

(PL 93-523) as amended by:

- The Safe Drinking Water Act Amendments of 1986
- National Primary Drinking Water Regulations, 40 CFR 141
- National Interim Primary Drinking Water Regulations Implementation, 40 CFR142
- National Secondary Drinking Water Regulations, 40 CFR 143

This is the primary Federal legislation protecting drinking water supplied by public water systems (those serving more than 25 people). The Environmental Protection Agency (**EPA**) is the lead agency and is mandated to set standards for drinking water. The EPA establishes national standards of which the states are responsible for enforcing.

The act provides for the establishment of primary regulations for the protection of the public health and secondary regulations relating to the taste, odor, and appearance of drinking water. Primary drinking water regulations, by definition, include either a maximum contaminant level (**MCL**) or, when a MCL is not economically or technologically feasible, a prescribed treatment technique which would prevent adverse health effects to humans.

An MCL is the permissible level of a contaminant in water that is delivered to any user of a public water system. Primary and secondary drinking water regulations are stated in 40 CFR 141 and 143, respectively. As amended in 1986, the EPA is required to set maximum contaminant levels for 83 contaminants deemed harmful to humans (with specific deadlines). It also has authority over groundwater. Water agencies are required to monitor water to ensure it meets standards.

National Drinking Water Regulations

The Act instructs the EPA on how to select contaminants for regulation and specifies how the EPA must establish national primary drinking water regulations once a contaminant has been selected (Section 1412). As of late 1996, the EPA had promulgated 84 drinking water regulations.

Contaminant Selection

P.L. 104-182 establishes a new process for the EPA to select contaminants for regulatory consideration based on occurrence, health effects, and meaningful opportunity for health risk reduction. By February 1998 and every 5 years thereafter, the EPA must publish a list of contaminants that may warrant regulation. Every 5 years thereafter, the EPA must determine whether or not to regulate at least 5 of the listed contaminants. The Act directs the EPA to evaluate contaminants that present the greatest health concern and to regulate contaminants that occur at concentration levels and frequencies of public health concern. The law also includes a schedule for the EPA to complete regulations for disinfectants and disinfection byproducts (**D/DBPs**) and ***Cryptosporidium*** (a waterborne pathogen).

Standard Setting

Developing national drinking water regulations is a two-part process. For each contaminant that the EPA has determined merits regulation, the EPA must set a non-enforceable maximum contaminant level goal (**MCLG**) at a level at which no known or anticipated adverse health effects occur, and which allows an adequate margin of safety. The EPA must then set an enforceable standard, a maximum contaminant level (**MCL**), as close to the MCLG as is "***feasible***" using the best technology, treatment techniques, or other means available (taking costs into consideration).

Standards are generally based on technologies that are affordable for large communities; however, under P.L. 104-182, each regulation establishing an MCL must list any technologies, treatment techniques, or other means that comply with the MCL and that are affordable for three categories of small public water systems.

The 1996 Amendments authorize the EPA to set a standard at other than the feasible level if the feasible level would lead to an increase in health risks by increasing the concentration of other contaminants or by interfering with the treatment processes used to comply with other SDWA regulations. In such cases, the standard or treatment techniques must minimize the overall health risk.

Also, when proposing a regulation, the EPA must now publish a determination as to whether or not the benefits of the standard justify the costs. If the EPA determines that the benefits do not justify the costs, the EPA may, with certain exceptions, promulgate a standard that maximizes health risk reduction benefits at a cost that is justified by the benefits.

Risk Assessment
P.L. 104-182 adds risk assessment and communication provisions to SDWA. When developing regulations, the EPA is now required to: (1) use the best available, peer-reviewed science and supporting studies and data; and (2) make publicly available a risk assessment document that discusses estimated risks, uncertainties, and studies used in the assessment. When proposing drinking water regulations, the EPA must publish a health risk reduction and cost analysis. The law permits the EPA to promulgate an interim standard without first preparing a benefit-cost analysis or making a determination as to whether the benefits of a regulation would justify the costs if the EPA determines that a contaminant presents an urgent threat to public health.

New regulations generally become effective 3 years after promulgation. Up to 2 additional years may be allowed if the EPA (or a state in the case of an individual system) determines the time is needed for capital improvements. Section 1412 includes specific provisions for arsenic, sulfate, and radon. The law authorizes states to grant Systems variances from a regulation if raw water quality prevents meeting the standards despite application of the best technology (Section 1415). A new provision authorizes small system variances based on best affordable technology. States may grant these variances to systems serving 3,300 or fewer persons if the system cannot afford to comply (through treatment, an alternative water source, or restructuring) and the variance ensures adequate protection of public health; states may grant variances to systems serving between 3,300 and 10,000 persons with EPA approval. To receive a small system variance, the system must install a variance technology identified by the EPA. The variance technology need not meet the MCL, but must protect public health. The EPA must identify variance technologies for existing regulations. Variances are not available for microbial contaminants. The Act also provides for exemptions if a regulation cannot be met for other compelling reasons (including costs) and if the system was in operation before the effective date of a standard or treatment requirement (Section 1416). An exemption is intended to give a public water system more time to comply with a regulation and can be issued only if it will not result in an unreasonable health risk. Small systems may receive exemptions for up to 9 years.

State Primacy
The primary enforcement responsibility for public water systems lies with the states, provided they adopt regulations as stringent as the national requirements, adopt authority for administrative penalties, develop adequate procedures for enforcement, maintain records, and create a plan for providing emergency water supplies (Section 1413). Currently, 55 of 57 states and territories have primacy authority. P.L. 104-182 authorizes $100 million annually for EPA to make grants to states to carry out the public water system supervision program. States may also use a portion of their SRF grant for this purpose (Section 1443).

Whenever the EPA finds that a public water system in a state with primary enforcement authority does not comply with regulations, the Agency must notify the state and the system and provide assistance to bring the system into compliance. If the state fails to commence enforcement action within 30 days after the notification, the EPA is authorized to issue an administrative order or commence a civil action.

Nonprimacy State
In a non-primacy state, the EPA must notify an elected local official (if any has jurisdiction over the water system) before commencing an enforcement action against the system (Section 1414). Primacy states may establish alternative monitoring requirements to provide interim monitoring relief for systems serving 10,000 or fewer persons for most contaminants, if a contaminant is not detected in the first quarterly sample. States with approved source water protection programs may adopt alternative monitoring requirements to provide permanent monitoring relief to qualified systems for chemical contaminants (Section 1418).

P.L. 104-182 requires states to adopt programs for training and certifying operators of community and nontransient noncommunity systems. The EPA must publish guidelines specifying minimum standards for operator certification by February 1999. Two years thereafter, the EPA must withhold 20% of a state's SRF grant unless the state has an operator certification program (Section 1419). States are also required to establish capacity development programs based on EPA guidance.

State programs must include: 1) legal authority to ensure that new systems have the technical, financial, and managerial capacity to meet SDWA requirements; and 2) a strategy to assist existing systems that are experiencing difficulties to come into compliance. Beginning in 2001, the EPA is required to withhold a portion of SRF grants from states that do not have compliance development strategies (Section 1420).

Underground Injection Control
Another provision of the Act requires the EPA to promulgate regulations for state underground injection control (**UIC**) programs to protect underground sources of drinking water. These regulations contain minimum requirements for the underground injection of wastes in five well classes to protect underground sources of drinking water and to require that a state prohibit, by December 1977, any underground injection that was not authorized by state permit (Section 1421).

Ground Water Protection Grant Programs
The Act contains three additional ground water protection programs. Added in 1986, Section 1427 established procedures for demonstration programs to develop, implement, and assess critical aquifer protection areas already designated by the Administrator as sole source aquifers. Section 1428, also added in 1986, and established an elective state program for protecting wellhead areas around public water system wells.

If a state established a wellhead protection program by 1989, and the EPA approved the state's program, then the EPA may award grants covering between 50% and 90% of the costs of implementing the program. Section 1429, added by P.L. 104-182, authorizes the EPA to make 50% grants to states to develop programs to ensure coordinated and comprehensive protection of ground water within the states. Appropriations for these three programs and for LYIC state program grants are authorized starting back in FY2003.

Source Water Protection Programs
P.L. 104-182 broadens the pollution prevention focus of the Act to embrace surface water as well as ground water protection. New Section 1453 directs the EPA to publish guidance for states to implement source water assessment programs that delineate boundaries of assessment areas from which systems receive their water, and identify the origins of contaminants in delineated areas to determine systems' susceptibility to contamination.

States with approved assessment programs may adopt alternative monitoring requirements to provide systems with monitoring relief under Section 1418.

New Section 1454 authorizes a source water petition program based on voluntary partnerships between state and local governments. States may establish a program under which a community water system or local government may submit a source water quality partnership petition to the state requesting assistance in developing a voluntary partnership to: (1) reduce the presence of contaminants in drinking water; (2) receive financial or technical assistance; and (3) develop a long-term source water protection strategy. This section authorizes $5 million each year for grants to states to support petition programs. Also, states may use up to 10% of their annual SRF capitalization grant for the source water assessment activities or for the petition program.

State Revolving Funds
Section 1452, added by P.L. 104-182 authorizes a State Revolving Loan Fund (**SRF**) program to help systems finance improvements needed to comply with drinking water regulations. The law authorizes the EPA to make grants to states to capitalize SDWA SRFs, which states then use to make loans to public water systems. States must match 20% of the federal grant.

Grants will be allotted to states using the formula for distributing state PWSS grants through FY1997; then, grants will be allotted based on a needs survey. Each state will receive at least 1% of funds. The District of Columbia will receive 1% of funds as well. A state may transfer up to 33% of the grant to the Clean Water Act (**CWA**) SRF, or an equivalent amount from the CWA SRF to the SDWA SRF.

Drinking water SRFs may be used to provide loan and grant assistance for expenditures that the EPA has determined will facilitate compliance or significantly further the Act's health protection objectives. States must make available 15% of their annual allotment for loan assistance to systems that serve 10,000 or fewer persons. States may use up to 30% of their SRF grant to provide grants or forgive loan principle to help economically disadvantaged communities. Also, states may use a portion of funds for technical assistance, source water protection and capacity development programs, and for operator certification.



Other Provisions
Public water systems must notify customers of violations with potential for serious health effects within 24 hours. Systems must also issue to customers annual reports on contaminants detected in their drinking water (Section 1414). Section 1417 requires any pipe, solder, or flux used in the installation or repair of public water systems or of plumbing in residential or nonresidential facilities providing drinking water to be "**lead free**" (as defined in the Act). As of August 1998, it will be unlawful to sell pipes, plumbing fittings or fixtures that are not "**lead free**" or to sell solder or flux that is not lead free(unless it is properly labeled); with the exception of pipes used in manufacturing or industrial processing. P.L. 104-182 sets limits on the amount of lead that may leach from new plumbing fixtures, and allows one year for a voluntary standard to be established before requiring EPA to take regulatory action.

The Administrator has emergency powers to issue orders and commence civil action if a contaminant likely to enter a public drinking water supply system poses a substantial threat to public health and state or local officials have not taken adequate action(Section 1431).

If a chemical necessary for water treatment is not reasonably available, the Administrator can issue a "***certification of need***," in which case the President can order an allocation of the chemical to those needing it (Section 1441).

EPA is provided authority to conduct research, studies, and demonstrations related to the causes, treatment, control, and prevention of diseases resulting from contaminants in water. The Agency is directed to provide technical assistance to the states and municipalities in administering their public water system regulatory responsibilities. The law authorizes annually, $15 million for technical assistance to small systems and Indian Tribes, and $25 million for health effects research (Section 1442). P.L. 104-182 authorizes additional appropriations for drinking water research, not to exceed $26.6 million annually.

The Administrator may make grants to develop and demonstrate new technologies for providing safe drinking water and to investigate health implications involved in the reclamation/reuse of waste waters (Section 1444).

Also, suppliers of water who may be subject to regulation under the Act are required to establish and maintain records, monitor, and provide any information that the Administrator requires to carry out the requirements of the Act (Section 1445).

The Administrator may also enter and inspect the property of water suppliers to enable him/her to carry out the purposes of the Act. Failure to comply with these provisions may result in criminal penalties.

The Act established a National Drinking Water Advisory Council, composed of 15 members (with at least 2 representing rural systems), to advise, consult, and make recommendations to the Administrator on activities and policies derived from the Act (Section 1446).

National Security

Any federal agency having jurisdiction over federally owned and maintained public water systems must comply with all federal, state, and local drinking water requirements, as well as any underground injection control programs (Section 1447). The Act provides for waivers in the interest of national security. Procedures for judicial review are outlined (Section 1448), and provision for citizens' civil actions is made (Section 1449).

Water Quality Key Words

Activated alumina: It is manufactured from aluminum hydroxide by dehydroxylating it in a way that produces a highly porous material; this material can have a surface area significantly over 200 square meters/g. The compound is used as a desiccant (to keep things dry by absorbing water from the air) and as a filter of fluoride, arsenic and selenium in drinking water. It is made of aluminum oxide (alumina; Al2O3), the same chemical substance as sapphire and rubies (but without the impurities that give those gems their color). It has a very high surface-area-to-weight ratio. That means it has a lot of very small pores, almost like tunnels, that run throughout it.

Activated carbon: It is also called activated charcoal or activated coal, is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions. The word activated in the name is sometimes substituted by active. Due to its high degree of microporosity, just one gram of activated carbon has a surface area of approximately 500 m², as determined typically by nitrogen gas adsorption. Sufficient activation for useful applications may come solely from the high surface area, though further chemical treatment often enhances the adsorbing properties of the material. Activated carbon is usually derived from charcoal.

De-ionized: Water with the irons removed.

Dissolved organic carbon: Dissolved organic carbon (DOC) is a broad classification for organic molecules of varied origin and composition within aquatic systems. The "dissolved" fraction of organic carbon is an operational classification. Many researchers place the dissolved/colloidal cutoff at 0.45 micrometers, but 0.22 micrometers is also typical.

Ethylenediaminetetraacetic acid (EDTA): EDTA is a widely used abbreviation for the chemical compound ethylenediaminetetraacetic acid (and many other names, see table). EDTA refers to the chelating agent with the formula $(HO_2CCH_2)_2NCH_2CH_2N(CH_2CO_2H)_2$. This amino acid is widely used to sequester di- and trivalent metal ions (Ca^{2+} and Mg^{2+} for example). EDTA binds to metals via four carboxylate and two amine groups. EDTA forms especially strong complexes with Mn(II), Cu(II), Fe(III), Pb (II) and Co(III).

High temperature metals recovery: An improved method and apparatus for recovering metal values from Electric Arc Furnace dust, particularly zinc and iron values, by mixing EAF dust and carbonaceous fines to form a particulate mixture; heating the mixture at a sufficient temperature and for a sufficient time to reduce and release volatile metals and alkali metals in a flue gas; collecting the released metals, and removing the metal values from the process as product.

Microfiltration: A low pressure membrane filtration process that removes suspended solids and colloids generally larger than 0.1 micron diameter.

Nanofiltration: It is a relatively recent membrane process used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening (polyvalent cation removal) and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter.

SDWA Water Quality Information and MCLs

Radionuclides

Alpha Emitters Certain minerals are radioactive and may emit a form of radiation known as alpha radiation. Some people who drink water containing alpha emitters in excess of EPA standards over many years may have an increased risk of getting cancer.

Beta/photon Emitters Certain minerals are radioactive and may emit forms of radiation known as photons and beta radiation. Some people who drink water containing beta and photon emitters in excess of EPA standards over many years may have an increased risk of getting cancer.

Combined Radium 226/228 Some people who drink water containing radium 226 or 228 in excess of EPA standards over many years may have an increased risk of getting cancer.

Radon gas can dissolve and accumulate in underground water sources, such as wells, and in the air in your home. Breathing radon can cause lung cancer. Drinking water containing radon presents a risk of developing cancer. Radon in air is more dangerous than radon in water.



These are commonly found examples of various water sampling bottles. VOC and THM bottles are in the front. You have to make sure there is absolutely no air inside these tiny bottles. Any air bubble can ruin the sample. There are several ways to get the air out. The best one is slowly overfill the bottle to get a reverse meniscus. Second, is to fill the cap with water before screwing it onto the bottle. The third one is to use a thin copper tube and slowly fill the bottle.

Inorganic Contaminants

Antimony	Cadmium	Cyanide	Nitrite
Asbestos	Chromium	Mercury	Selenium
Barium	Copper	Nitrate	Thallium
Beryllium			

Inorganic Contaminants

Arsenic. Some people who drink water containing arsenic in excess of EPA standards over many years could experience skin damage or problems with their circulatory system, and may have an increased risk of getting cancer.

Fluoride. Many communities add fluoride to their drinking water to promote dental health. Each community makes its own decision about whether or not to add fluoride. The EPA has set an enforceable drinking water standard for fluoride of 4 mg/L (some people who drink water containing fluoride in excess of this level over many years could get bone disease, including pain and tenderness of the bones). The EPA has also set a secondary fluoride standard of 2 mg/L to protect against dental fluorosis.

Dental fluorosis, in its moderate or severe forms, may result in a brown staining and/or pitting of the permanent teeth. This problem occurs only in developing teeth, before they erupt from the gums. Children under nine should not drink water that has more than 2 mg/L of fluoride.

Lead. Typically leaches into water from plumbing in older buildings. Lead pipes and plumbing fittings have been banned since August 1998. Children and pregnant women are most susceptible to lead health risks. For advice on avoiding lead, see the EPA's "***Lead in Your Drinking Water"*** fact sheet.

Synthetic Organic Contaminants, including Pesticides & Herbicides

2,4-D	Dibromochloropropane	Hexachlorobenzene
2,4,5-TP (Silvex)	Dinoseb	Hexachlorocyclopentadiene
Acrylamide	Dioxin (2,3,7,8-TCDD)	Lindane
Alachlor	Diquat	Methoxychlor
Atrazine	Endothall	Oxamyl [Vydate]
Benzoapyrene	Endrin	PCBs [Polychlorinated biphenyls]
Carbofuran	Epichlorohydrin	Pentachlorophenol
Chlordane	Ethylene dibromide	Picloram
Dalapon	Glyphosate	Simazine
Di 2-ethylhexyl adipate	Heptachlor	Toxaphene
Di 2-ethylhexyl phthalate	Heptachlor epoxide	

Volatile Organic Contaminants

Benzene	trans-1,2-Dicholoroethylene	1,2,4-Trichlorobenzene
Carbon Tetrachloride	Dichloromethane	1,1,1,-Trichloroethane
Chlorobenzene	1,2-Dichloroethane	1,1,2-Trichloroethane
o-Dichlorobenzene	1,2-Dichloropropane	Trichloroethylene
p-Dichlorobenzene	Ethylbenzene	Toluene
1,1-Dichloroethylene	Styrene	Vinyl Chloride
cis-1,2-Dichloroethylene	Tetrachloroethylene	Xylenes

New EPA Water Rules

Arsenic
Arsenic is a chemical that occurs naturally in the earth's crust. When rocks, minerals, and soil erode, they release arsenic into water supplies. When people either drink this water or eat animals and plants that drink it, they are exposed to arsenic. In the U.S., eating and drinking are the most common ways that people are exposed to arsenic, although it can also come from industrial sources. Studies have linked long-term exposure of arsenic in drinking water to a variety of cancers in humans.

To protect human health, an EPA standard limits the amount of arsenic in drinking water. Back in January 2001, the EPA revised the standard from 50 parts per billion (**ppb**), ordering that it fall to 10 ppb back in 2006. After adopting 10ppb as the new standard for arsenic in drinking water, the EPA decided to review the decision to ensure that the final standard was based on sound science and accurate estimates of costs and benefits. In October 2001, the EPA decided to move forward with implementing the 10ppb standard for arsenic in drinking water.

More information on the rulemaking process and the costs and benefits of setting the arsenic limit in drinking water at 10ppb can be found at www.epa.gov/safewater/arsenic.html or in the Water Quality Chapter in the Arsenic information section.

ICR Information Collection Rule
The EPA has collected data required by the Information Collection Rule (**ICR**) to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts. The rule is intended to provide the EPA with information on chemical byproducts that form when disinfectants used for microbial control react with chemicals already present in source water (disinfection byproducts (**DBPs**)); disease-causing microorganisms (pathogens), including Cryptosporidium; and engineering data to control these contaminants.

Drinking water microbial and disinfection byproduct information collected for the ICR is now available in the EPA's ***Envirofacts Warehouse***.



Gas Chromatograph

Disinfection Byproduct Regulations
In December 1998, the EPA established the Stage 1 Disinfectants/Disinfection Byproducts Rule that requires public water systems to use treatment measures to reduce the formation of disinfection byproducts and to meet the following specific standards:

Total trihalomethanes (TTHM)	80 parts per billion (ppb)
Haloacetic acids (HAA5)	60 ppb
Bromate	10 ppb
Chlorite	1.0 parts per million (ppm)

Currently trihalomethanes are regulated at a maximum allowable annual average level of 100 parts per billion for water systems serving over 10,000 people under the Total Trihalomethane Rule finalized by the EPA in 1979. The Stage 1 Disinfectant/Disinfection Byproduct Rule standards became effective for trihalomethanes and other disinfection byproducts listed above in December 2001 for large surface water public water systems. These new standards became effective in December 2003 for small surface water and all ground water public water systems.

Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite.

Trihalomethanes (**THM**) are a group of four chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate total trihalomethanes (**TTHM**) at a maximum allowable annual average level of **80 parts per billion**.

Haloacetic Acids (**HAA5**) are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids, known as HAA5, are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate HAA5 at **60 parts per billion** annual average.

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water. The EPA has established the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate bromate at annual average of **10 parts per billion** in drinking water.

Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. The EPA has published the **Stage 1 Disinfectants/Disinfection Byproducts Rule** to regulate chlorite at a monthly average level of **1 part per million** in drinking water.

Microbial Regulations

One of the key regulations developed and implemented by the United States Environmental Protection Agency (**USEPA**) to counter pathogens in drinking water is the **Surface Water Treatment Rule**. Among its provisions, the rule requires that a public water system, using surface water (or ground water under the direct influence of surface water) as its source, have sufficient treatment to reduce the source water concentration of ***Giardia*** and viruses by at least 99.9% and 99.99%, respectively.

The Surface Water Treatment Rule specifies treatment criteria to assure that these performance requirements are met; they include turbidity limits, disinfectant residual, and disinfectant contact time conditions.

The **Interim Enhanced Surface Water Treatment Rule** was established in December 1998 to control ***Cryptosporidium***, and to maintain control of pathogens while systems lower disinfection byproduct levels to comply with the **Stage 1 Disinfectants/Disinfection Byproducts Rule**. The EPA established a Maximum Contaminant Level Goal (**MCLG**) of zero for all public water systems and a 99% removal requirement for Cryptosporidium in filtered public water systems that serve at least 10,000 people.

The new rule tightened turbidity standards back in December 2001. Turbidity is an indicator of the physical removal of particulates, including pathogens.

The EPA is also planning to develop other rules to further control pathogens. The EPA has promulgated a Long Term 1 Enhanced Surface Water Treatment Rule, for systems serving fewer than 10,000 people, to improve physical removal of *Cryptosporidium*, and to maintain control of pathogens while systems comply with **Stage 1 Disinfectants/Disinfection Byproducts Rule**.





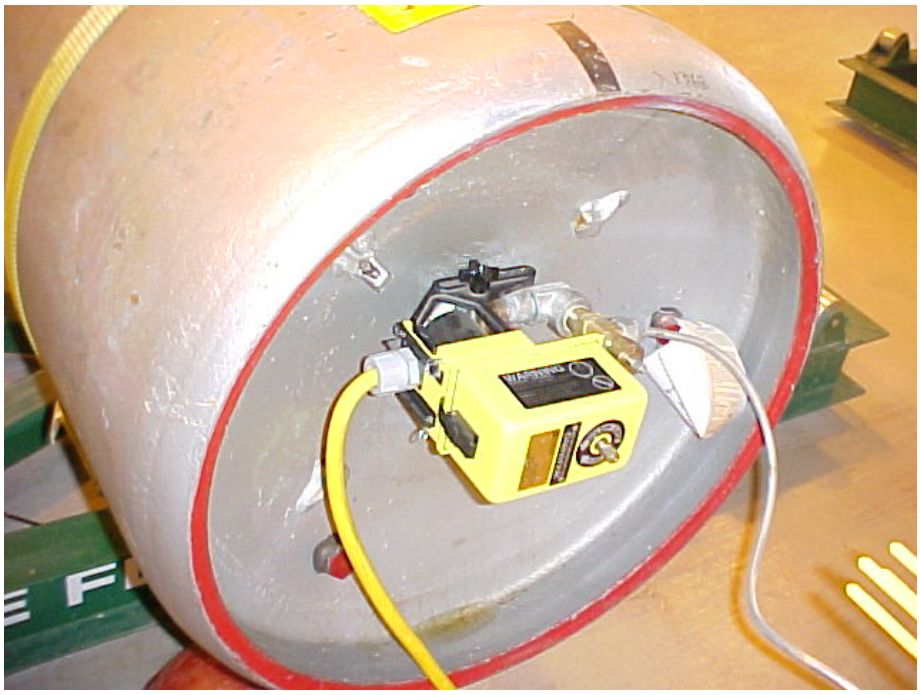
Here is one of TLC's professors Marcos Aparecido Silva Bueno showing microscopic views of commonly found MO's in a classroom setting. Professor Marcos Aparecido Silva Bueno is a world renowned microbiological expert.



National Primary Drinking Water Regulations

Inorganic Chemicals	MCLG [1] (mg/L) [4]	MCL [2] or TT [3] (mg/L) [4]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood glucose	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	none[5]	0.010	Skin damage; circulatory system problems; increased risk of cancer	Discharge from semiconductor manufacturing; petroleum refining; wood preservatives; animal feed additives; herbicides; erosion of natural deposits
Asbestos (fiber >10 micrometers)	7 million fibers per Liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Some people who use water containing chromium well in excess of the MCL over many years could experience allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	Action Level=1.3; TT[6]	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. Those with Wilson's Disease should consult their personal doctor if their water systems exceed the copper action level.	Corrosion of household plumbing systems; erosion of natural deposits; leaching from wood preservatives
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth.	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	Action Level=0.015; TT[6]	Infants and children: Delays in physical or mental development. Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits

Inorganic Mercury	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and cropland
Nitrate (measured as Nitrogen)	10	10	"Blue baby syndrome" in infants under six months - life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	"Blue baby syndrome" in infants under six months - life threatening without immediate medical attention. Symptoms: Infant looks blue and has shortness of breath.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and pharmaceutical companies



1-ton chlorine gas container with an automatic leak detection and shut-off device.

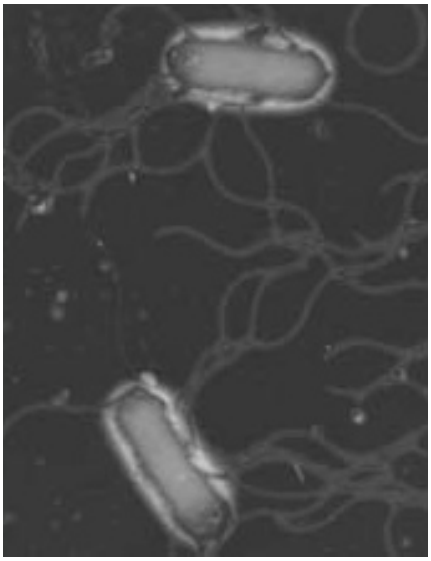
Organic Chemicals	MCLG [1] (mg/L) [4]	MCL [2] or TT [3] (mg/L) [4]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Acrylamide	zero	TT [7]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system problems; reproductive difficulties	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood or nervous system; reproductive difficulties.	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharger from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1-1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1, 2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; increased risk of cancer	Discharge from pharmaceutical and chemical factories
1-2-Dichloropropane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl)adipate	0.4	0.4	General toxic effects or reproductive difficulties	Leaching from PVC plumbing systems; discharge from chemical factories
Di(2-ethylhexyl)phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables

Dioxin (2,3,7,8-TCDD)	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Nervous system effects	Residue of banned insecticide
Epichlorohydrin	zero	TT[7]	Stomach problems; reproductive difficulties; increased risk of cancer	Discharge from industrial chemical factories; added to water during treatment process
Ethylbenzene	0.7	0.7	Liver or kidney problems	Discharge from petroleum refineries
Ethelyne dibromide	zero	0.00005	Stomach problems; reproductive difficulties; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of hepatachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased risk of cancer	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, and circulatory problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Total Trihalomethanes (TTHMs)	none[5]	0.10	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection
Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories

1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from petroleum refineries
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

Radionuclides	MCLG[1] (mg/L)[4]	MCL[2] or TT[3] (mg/L)[4]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Beta particles and photon emitters	none[5]	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits
Gross alpha particle activity	none[5]	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits
Radium 226 and Radium 228 (combined)	none[5]	5 pCi/L	Increased risk of cancer	Erosion of natural deposits

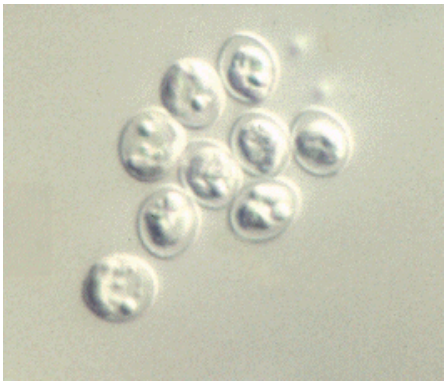
Microorganisms	MCLG[1] (mg/L)[4]	MCL[2] or TT[3] (mg/L)[4]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Giardia lamblia	zero	TT[8]	Giardiasis, a gastroenteric disease	Human and animal fecal waste
Heterotrophic plate count	N/A	TT[8]	HPC has no health effects, but can indicate how effective treatment is at controlling microorganisms.	n/a
Legionella	zero	TT[8]	Legionnaire's Disease, commonly known as pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and *E. Coli*)	zero	5.0%[9]	Used as an indicator that other potentially harmful bacteria may be present[10]	Human and animal fecal waste
Turbidity	N/A	TT[8]	Turbidity has no health effects but can interfere with disinfection and provide a medium for microbial growth. It may indicate the presence of microbes.	Soil runoff
Viruses (enteric)	zero	TT[8]	Gastroenteric disease	Human and animal fecal waste



E. coli HO-157



Legionella



Cryptosporidium

I've met lab personnel who couldn't tell these 3 bugs apart.

National Secondary Drinking Water Regulations

National Secondary Drinking Water Regulations (NSDWRs or secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.

The EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Notes

[1] Maximum Contaminant Level Goal (**MCLG**) - The maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health effect of persons would occur, and which allows for an proper margin of safety. MCLGs are non-enforceable public health goals.

[2] Maximum Contaminant Level (**MCL**) - The maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are enforceable standards. The margins of safety in MCLGs ensure that exceeding the MCL slightly does not pose significant risk to public health.

[3] Treatment Technique - An enforceable procedure or level of technical performance which public water systems must follow to ensure control of a contaminant.

[4] Units are in milligrams per Liter (mg/L) unless otherwise noted.

[5] MCLGs were not established before the 1986 Amendments to the Safe Drinking Water Act. Therefore, there is no MCLG for this contaminant.

[6] Lead and copper are regulated in a Treatment Technique which requires systems to take tap water samples at sites with lead pipes or copper pipes that have lead solder and/or are served by lead service lines. The action level, which triggers water systems into taking treatment steps, if exceeded in more than 10% of tap water samples, for copper is 1.3 mg/L, and for lead is 0.015mg/L.

[7] Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used in drinking water systems, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows:

- **Acrylamide** = 0.05% dosed at 1 mg/L (or equivalent)
- **Epichlorohydrin** = 0.01% dosed at 20 mg/L (or equivalent)

[8] The Surface Water Treatment Rule requires systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- ***Giardia lamblia**:* 99.9% killed/inactivated
  Viruses: 99.99% killed/inactivated
- ***Legionella**:* No limit, but EPA believes that if ***Giardia*** and viruses are inactivated, ***Legionella*** will also be controlled.
- **Turbidity**: At no time can turbidity (**cloudiness of water**) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month.
- **HPC**: NO more than 500 bacterial colonies per milliliter.

[9] No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive). Every sample that has total coliforms must be analyzed for fecal coliforms. There cannot be any fecal coliforms.

[10] Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human animal wastes. Microbes in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms.

Regulated Chemical Contaminants

EPA established Maximum Contaminant Levels (MCL), Maximum Contaminant Level Goals (MCLG), monitoring requirements and best available technologies for removal for 65 chemical contaminants over a five year period as EPA gathered and analyzed occurrence and health effects data. This series of rules are known as the Chemical Phase Rules and they define regulations for three contaminant groups:

- Inorganic Chemicals (IOC),
- Synthetic Organic Chemicals (SOC), and
- Volatile Organic Chemicals (VOC).

The Chemical Phase rules provide public health protection through the reduction of chronic risks from:

- cancer;
- organ damage; and
- circulatory,
- nervous, and
- reproductive system disorders.

They also help to reduce the occurrence of Methemoglobinemia or "blue baby syndrome" from ingestion of elevated levels of nitrate or nitrite. All public water systems must monitor for Nitrate and Nitrite. Community water systems and Non-transient non-community water systems must also monitor for IOCs, SOCs, and VOCs.

For more information on each of these contaminants, see specialized sections.

Phased Rules	VOC	SOC	IOC
Phase I, July 7, 1987 (52 FR 25690) Effective: 1989	benzene carbon tetrachloride p-dichlorobenzene trichloroethylene vinyl chloride 1,1,1-trichloroethane 1,1-dichloroethylene 1,2-dichloroethane		
Phase II, January 1991[1] (56 FR 3526) Effective: 1992	cis-1,2-dichloroethylene ethylbenzene monochlorobenzene (chlorobenzene) o-dichlorobenzene styrene tetrachloroethylene toluene trans-1,2-dichloroethylene xylenes	alachlor atrazine carbofuran chlordane EDB (ethylene dibromide) DBCP (1,2-dibromo-3-chloropropane) heptachlor heptachlor epoxide lindane	asbestos cadmium chromium fluoride mercury nitrate nitrite selenium

Phased Rules	VOC 1,2-dichloropropane	SOC methoxychlor toxaphene PCBs 2,4-D 2,4,5-TP	IOC
Phase IIB, July 1991 (56 FR 30266) Effective: 1993		pentachlorophenol	barium
Phase V, July 1992 (57 FR 31776) Effective: 1994	dichloromethane 1,1,2-trichloroethane 1,2,4-trichlorobenzene	benzo(a)pyrene dalapon di(ethylhexyl)-adipate di(ethylhexyl)-phthalate dinoseb diquat endothall endrin glyphosate hexachlorobenzene hexachlorocyclo-pentadiene oxymal picloram simazine 2,3,7,8-TCDD (dioxin)	antimony beryllium cyanide nickel (remanded 1995) thallium

[1]Aldicarb, aldicarb sulfone, and aldicarb sulfoxide are considered regulated chemicals although their MCLs are stayed. Therefore PWS are not required to meet an MCL.

For each contaminant, EPA set a health goal, or Maximum Contaminant Level Goal (MCLG). This is the level at which a person could drink two liters of water containing the contaminant every day for 70 years without suffering any ill effects. This goal is not a legal limit with which water systems must comply; it is based solely on human health. For known cancer-causing agents (carcinogens), EPA set the health goal at zero, under the assumption that any exposure to the chemical could present a cancer risk.

The rules also set a legal limit, or Maximum Contaminant Level (MCL), for each contaminant. EPA sets legal limits as close to the health goal as possible, keeping in mind the technical and financial barriers that exist. Except for contaminants regulated as carcinogens, most legal limits and health goals are the same. Even when they are less strict than the health goals, the legal limits provide substantial public health protection.

The Standardized Monitoring Framework

The Standardized Monitoring Framework (SMF), promulgated in the Phase II rule on January 30, 1991 and revised under Phases IIB and V, includes contaminants regulated under Phases I, II, IIB, V, the revised Arsenic Rule and the Radionuclides Rule Monitoring under the SMF began in 1993. The goal of the Standardized Monitoring Framework is to standardize, simplify, and consolidate drinking water monitoring requirements across contaminant groups. In order to do this, EPA has established nine-year compliance cycles. Each nine-year compliance cycle is divided into 3 three-year compliance periods, which may be further subdivided into annual and quarterly periods. Compliance periods run on a calendar year basis, from January 1 through December 31. Compliance cycle 1 began January 1, 1993 and ended December 31, 2001; the

second compliance cycle began January 1, 2002 and ends December 31, 2010; the third compliance cycle begins January 1, 2011 and ends December 31, 2019. Monitoring schedules and sample requirements are standardized for each compliance cycle for each contaminant group.

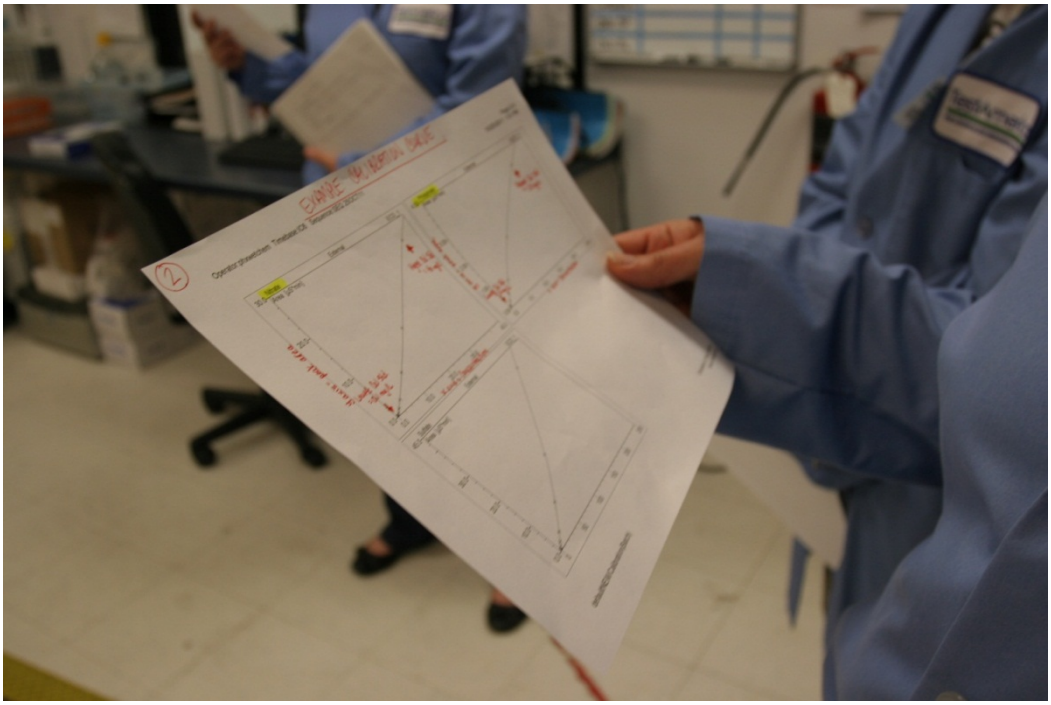
Standardized Monitoring Framework – Compliance Cycles and Period

2nd Compliance Cycle			3rd Compliance Cycle		
1st Period	2nd Period	3rd Period	1st Period	2nd Period	3rd Period
2002	2005	2008	2011	2014	2017
2003	2006	2009	2012	2015	2018
2004	2007	2010	2013	2016	2019



Monitoring Waivers

The SMF allows States to grant waivers to water systems to reduce the sampling frequencies to once every 3, 6 or 9 years for inorganic compounds, synthetic organic compounds, and volatile organic compound. Waivers of sampling requirements are granted for specified contaminants based on both a vulnerability assessment and the analytical results of previous sampling. The vulnerability assessment may be based on a determination that either the contaminant has not been used in the area or that the system is not susceptible to contamination.



Analytical Method

An analytical method is a procedure that determines the concentration of a contaminant in a water sample.

Analytical methods generally describe:

- How to collect, preserve, and store the sample.
- Procedures to concentrate, separate, identify, and quantify contaminants present in the sample.
- Quality control criteria the analytical data must meet.
- How to report the results of the analysis.

In general, an analytical method:

- Is applicable to routine analyses of samples.
- Is suitable for measuring the drinking water contaminant in the concentration range of interest.
- Provides data with the necessary accuracy and precision to demonstrate compliance or meet monitoring objectives in a wide variety of drinking water matrices.
- Includes instructions for all aspects of the analysis from sample collection to data reporting.
- Incorporates appropriate quality control criteria so that acceptable method performance is demonstrated during the analysis of samples.

Drinking Water Analysis Chart

ANALYSIS	METHOD	HOLDING TIME
Inorganic Compounds (IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Selenium, Silver, Sodium, Thallium, Zinc, Hardness, Conductivity, Turbidity, Color, Chloride, Cyanide, Fluoride, Nitrate, Nitrite, Sulfate, and Total Dissolved Solids.	**(various)**	**48 hours**
Primary Pollutants (Short IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver, Sodium, Thallium, Turbidity, Fluoride, Cyanide, Nitrate, and Nitrite.	**(various)**	**48 hours**
Municipal Testing		
Lead and Copper	**EPA 200.9 for Pb** **EPA 200.7 for Cu**	**14 days**
Public or Individual Water Source Testing		
Nitrate	**SM-4500 NO3 D**	**48 hours**
Total Coliform & E. Coli	**SM-9223 B**	**30 Hours**
Metals Analysis on Drinking Water (per element)		
GFAA **(As, Pb, Sb, Se, Tl)**	**EPA 200.9**	**6 months**
ICP (Ag, Al, B, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Na, Ni, Zn)	**EPA 200.7**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**
Primary Pollutant Metals	**GFAA/ICP/CVAA**	**6 months**
Drinking Water Analysis		
PH	**EPA 150.1**	
Acidity	**SM-2310 B (4b)**	**14 days**
Alkalinity (Bicarbonate & Carbonate)	**SM-2320 B (4a)**	**14 days**
BOD	**SM-5210 B**	**48 hours**
Calcium	**EPA 200.7**	**6 months**
Chloride	**SM-4500 Cl**	**8 days**
Chlorine, total	**SM-4500 Cl**	**5 hours**
Color	**SM-2120 B**	**8 hours**
COD	**EPA 410.4 (7.3)**	**28 days**
Cyanide	**EPA 335.2 (8.7)**	**28 days**
Dissolved Oxygen	**SM-4500 O C**	**8 hours**
Fluoride	**SM-4500 F C**	**28 days**
Hardness	**SM-2340 B**	**6 months**
Magnesium	**EPA 200.7**	**6 months**
Nitrogen, ammonia	**SM-4500 NH3 E**	**28 days**

	SM-4500 NH3 H	
Nitrogen, nitrate	SM-4500 NO3 D	48 hours
Nitrogen, nitrite	SM-4500 NO2	48 hours
Nitrate + Nitrite	SM-4500 NO3 E	48 hours
Nitrogen, TKN	EPA 351.4	28 days
Odor	SM-2150	6 days
Phosphorous, ortho	EPA 200.7	48 hours
Phosphorous, total	SM-4500 P	28 days
Solids, settle able	SM-2540	7 days
Solids, suspended	SM-2540 D	7 days
Drinking Water Analysis		
Solids, total	SM-2540 B	7 days
Solids, volatile	SM-2540 E	7 days
Specific Conductance	SM-2510 B	28 days
Sulfate	SM-4500 SO-4 E	28 days
Sulfide	SM-4500 S-2 D	28 days
Sulfite	EPA 377.1	28 days
Silica	SM-4500 Sl E	28 days
Total Organic Carbon	EPA 415.1	28 days
Turbidity	SM- 2130 B	48 hours

ORGANICS		
Semi-volatile Organics in Water (SOC)*	(various)	7 days
Volatile Organics in Water*	(various)	7 days
Trihalomethanes*	EPA 501.1	7 days
Gross Alpha & Bata (Radionuclides)*	(various)	7 days
BOD	SM-5210 B	48 hours
COD	EPA 410.4(7.3)	28 days
Oil and Grease	EPA 413.1(1.2)	28 days
Hardness W/digestion	SM-2340 B	6 months
Nitrogen, TKN	EPA 351.4	28 days
Nitrogen, ammonia	SM-4500 NH3 F	28 days
Nitrogen, Total Organic	SM-4500 NorgNH3	28 days
Nitrogen, nitrate	SM-4500 NO3 D	48 hours
Nitrogen, nitrite	SM-4500 NO2 B	48 hours
Phosphorous, ortho	SM-4500 P E	48 hours
Sulfate	SM-4500 SO4 E	28 days
Solids, dissolved	SM-2540	7 days
Solids, settle able	SM-2540 F	7 days
Solids, suspended	SM-2540 D	7 days
Solids, total	SM-2540 B	7 days
Solids, volatile	SM-2540 E	7 days
Total Organic Carbon	EPA 415.1	28 days
PH	EPA 150.1	
Metals (per element)		
ICP (Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Sb, V, Zn)	EPA 200.7	6 months

GFAA **(As, Pb, Ba, Se, Tl)**	**EPA 200.9**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**

Definitions:

Action level - the concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

Maximum Contaminant Level - the "Maximum Allowed" (MCL) is the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

Maximum Contaminant Level Goal - the "Goal" (MCLG) is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

Non-Detects (ND) - laboratory analysis indicates that the constituent is not present.

Parts per million (ppm) or Milligrams per liter (mg/L) - one part per million corresponds to one minute in two years or a single penny in $10,000.

Parts per billion (ppb) or Micrograms per liter (ug/L) - one part per billion corresponds to one minute in 2,000 years, or a single penny in $10,000,000.

Picocuries per liter (pCi/L) - picocuries per liter is a measure of the radioactivity in water.

SAMPLE CONTAINERS and PRESERVATION

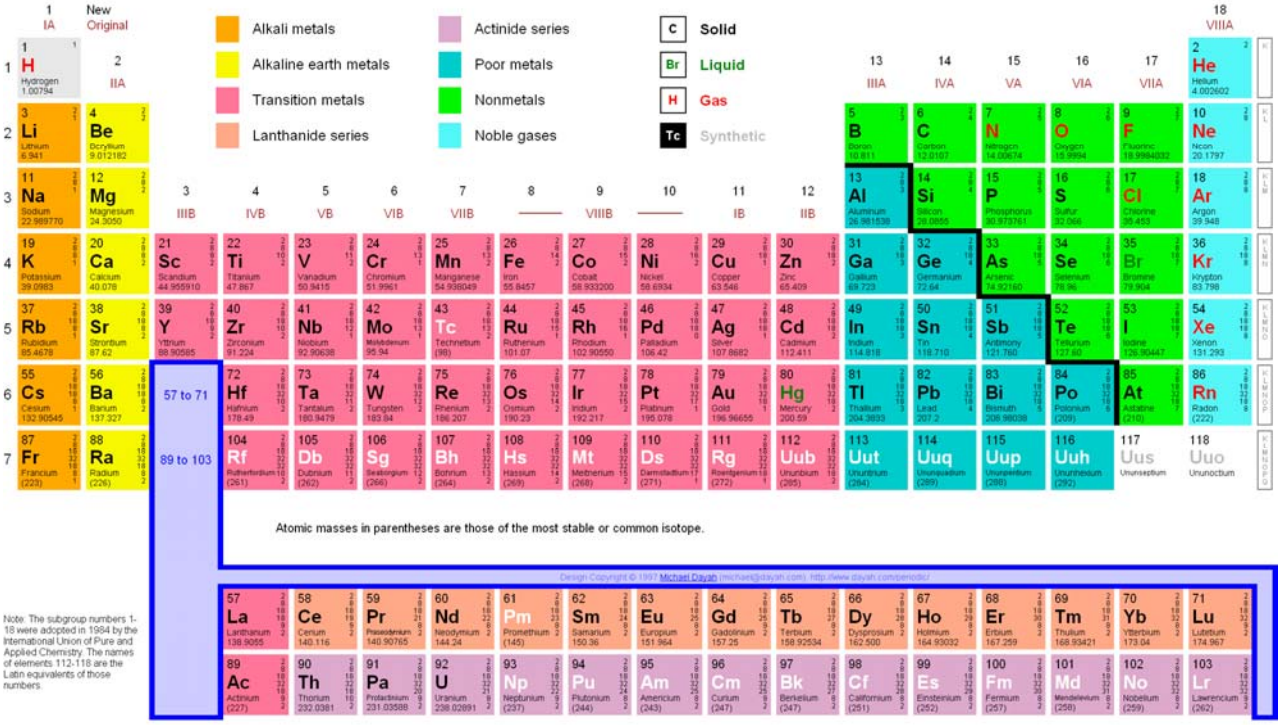
Methods used by the laboratory usually specify what type of container and how much sample is required to run an analysis. The following table provides a summary of the sample handling and preservation requirements for some of the most common tests.

Parameter	Bottle Type	Minimum Sample Size	Maximum Holding Time	Storage & Preservation
Acidity	P or G[B]	100ml	24 hrs/14 days	refrigerate
Alkalinity	P or G	200ml	24 hrs/14 days	refrigerate
BOD (5 day)	P or G	1L	6 hrs/48 hrs	refrigerate
Boron	P	100ml	28 days/6 months	
Chloride	P or G	250ml	28 days	
Chlorine, residual	P or G	500ml	0.5 hr/stat	analyze on site ASAP
COD	P or G	500ml	28 days/28 days	analyze on site ASAP
Color	P or G	500ml	48 hrs/48 hrs	refrigerate
Coliform, Total	P or G	125ml	30 hrs	refrigerate
Conductivity	P or G	500ml	48 hrs/48 hrs	refrigerate
Cyanide, Total	P or G	500ml	28 days/28 days	add NaOH to pH>12
				refrigerate in dark
Fluoride	P	300ml	28days/ 28 days	
Hardness	P or G	100ml	6 months/6 months	add HNO_3 to pH<2
Metals, general	P[A] or G[A]	250ml	6 months/6 months	add HNO_3 to pH<2
Furnace	P[A] or G[A]	250ml	6 months/6 months	
Flame	P[A] or G[A]	250ml	6 months/6 months	
Mercury	P[A] or G[A]	500ml	28 days/28 days	add HNO_3 to pH<2
Nitrogen *Ammonia*	P or G	500ml	7 days/ 28 days	ASAP or add H_2SO_4 to pH<2 & refrigerate
Nitrate	P or G	100ml	48 hrs/48 hrs	ASAP & refrigerate
Nitrate + Nitrite	P or G	200ml	48 hrs/28 days	ASAP & refrigerate
Nitrite	P or G	100ml	none/48 hrs	ASAP & refrigerate
TKN	P or G	500ml	7 days/28	add H_2SO_4 to

			days	pH<2
Oxygen, dissolved	G (BOD)	300ml		
Electrode			0.5 hrs/stat	ASAP on site
Winkler			8hrs/8 hrs	ASAP on site
pH	P or G	50ml	2 hrs/stat	ASAP on site
Phosphate,	G^A			
Ortho		100ml	48hrs	filter ASAP refrigerate
Total		100ml	28 days/28 days	refrigerate
Solids,	P or G			
Dissolved		250ml	7 days	refrigerate
Settleable		1L	48 hrs	refrigerate
Suspended		250ml	7 days	refrigerate
Total		250ml	7 days	refrigerate
Volatile		250ml	7 days	refrigerate
Silica	P	200ml	28 days/28 days	refrigerate
Sulfate	P or G	100ml	28 days/28 days	refrigerate
Turbidity	P or G	100ml	24 hrs/48 hrs	ASAP/refrigerate, store in dark up to 24 hrs

Refrigerate = storage at 4 degrees C, in the dark. P = plastic (polyethylene or equivalent); G = glass, G^A or P^A = rinsed with 1:1 HNO_3; G^B = glass, borosilicate, G^S = glass rinsed with organic solvents; NS = not stated in cited reference; stat = no storage allowed; analyze immediately.

Periodic Table of the Elements





Left, Tellurium, right Astatine with Fluorine



Common water sample bottles for distribution systems.

Radiochems, VOCs, (Volatile Organic Compounds), TTHMs, Total Trihalomethanes), Nitrate, Nitrite.

Most of these sample bottles will come with the preservative already inside the bottle.

Some bottles will come with a separate preservative (acid) for the field preservation.

Slowly add the acid or other preservative to the water sample; not water to the acid or preservative.



Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as	0.2	0.2	Nerve damage or thyroid problems	Discharge from

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
free cyanide)				steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[7]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Chemical Treatment before the Filter

The coagulation and flocculation stages of the water treatment must be monitored continuously. Adjustments in the amount of coagulant added must be made frequently to prevent the filter from becoming overloaded with suspended material. This overload may cause the filter to prematurely reach its maximum headloss.

If there is early turbidity breakthrough in the filter effluent, more coagulant may have to be added to the coagulation process. There may be a need for better mixing during the coagulation or the addition of more filter aid.

If there is a rapid increase in filter head loss, too much coagulant may be clogging the filter. Less coagulant or less filter aid should be used. The operator needs to learn to recognize these problems and choose the proper corrections.



Filter aid being fed at the weirs of sedimentation.



In the photograph above, overfeeding flocculants to meet federal regulations caused Iron to precipitate on the filter walls.

IOC Sample Collection – Things to Remember

Sample instructions should be supplied with the sample containers from the laboratory. If the laboratory fails to include sample instructions, contact the laboratory and request sample instructions.

Some general practices to remember:

• Samples should be collected at the entry point to the distribution system after all treatment (finished water)
• Select a sampling faucet that does NOT have an aerator (sampling must be done with minimum aeration
• Run the water until the temperature is as cold as it gets
• Just before sample collection, adjust to a very low flow. Do not change the flow while collecting the sample
• Routine nitrate and nitrite samples should be collected on a Monday or a Tuesday
• When filling sample bottle, tip bottle slightly so that water flows down the side wall of the container. Bring bottle to an upright position as it fills
• Call the laboratory if bottles are received broken (or break while collecting samples)
• The owner or operator of a water supply must maintain chemical analysis reports (results) or a summary of those reports for at least 10 years



Antimony - Inorganic Contaminant 0.006 mg/L MCL
Metalloid

Antimony is a toxic chemical element with symbol **Sb** and atomic number 51. A lustrous gray metalloid, it is found in nature mainly as the sulfide mineral stibnite (Sb_2S_3). Antimony compounds have been known since ancient times and were used for cosmetics; metallic antimony was also known, but it was erroneously identified as lead. It was established to be an element around the 17th century.



For some time, China has been the largest producer of antimony and its compounds, with most production coming from the Xikuangshan Mine in Hunan. The industrial methods to produce antimony are roasting and subsequent carbothermal reduction or direct reduction of stibnite with iron.

What are EPA's drinking water regulations for antimony?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for antimony is 0.006 mg/L or 6 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for antimony, called a maximum contaminant level (MCL), at 0.006 mg/L or 6 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for antimony, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed antimony as part of the Six Year Review and determined that the 0.006 mg/L or 6 ppb MCLG and 0.006 mg/L or 6 ppb MCL for antimony are still protective of human health.

Applications
The largest applications for metallic antimony are as alloying material for lead and tin and for lead antimony plates in lead-acid batteries. Alloying lead and tin with antimony improves the properties of the alloys which are used in solders, bullets and plain bearings. Antimony compounds are prominent additives for chlorine- and bromine-containing fire retardants found in many commercial and domestic products. An emerging application is the use of antimony in microelectronics.

Antimony is in the nitrogen group (group 15) and has an electronegativity of 2.05. As expected by periodic trends, it is more electronegative than tin or bismuth, and less electronegative than tellurium or arsenic. Antimony is stable in air at room temperature, but reacts with oxygen if heated to form antimony trioxide, Sb_2O_3. Antimony is a silvery, lustrous gray metal that has a Mohs scale hardness of 3. Therefore, pure antimony is not used to make hard objects: coins made of antimony were issued in China's Guizhou province in 1931, but because of their rapid wear, their minting was discontinued. Antimony is resistant to attack by acids.

Four allotropes of antimony are known, a stable metallic form and three metastable forms, explosive, black and yellow. Metallic antimony is a brittle, silver-white shiny metal. When molten antimony is slowly cooled, metallic antimony crystallizes in a trigonal cell, isomorphic with that of the gray allotrope of arsenic. A rare explosive form of antimony can be formed from the electrolysis of antimony (III) trichloride. When scratched with a sharp implement, an exothermic reaction occurs and white fumes are given off as metallic antimony is formed; when rubbed with a pestle in a mortar, a strong detonation occurs.

Black antimony is formed upon rapid cooling of vapor derived from metallic antimony. It has the same crystal structure as red phosphorus and black arsenic; it oxidizes in air and may ignite spontaneously. At 100 °C, it gradually transforms into the stable form. The yellow allotrope of antimony is the most unstable. It has only been generated by oxidation of stibine (SbH_3) at −90 °C. Above this temperature and in ambient light, this metastable allotrope transforms into the more stable black allotrope.

Metallic antimony adopts a layered structure (space group R3m No. 166) in which layers consist of fused ruffled six-membered rings. The nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 6.697 g/cm^3, but the weak bonding between the layers leads to the low hardness and brittleness of antimony.

Isotopes

Antimony exists as two stable isotopes, ^{121}Sb with a natural abundance of 57.36% and ^{123}Sb with a natural abundance of 42.64%. It also has 35 radioisotopes, of which the longest-lived is ^{125}Sb with a half-life of 2.75 years. In addition, 29 metastable states have been characterized. The most stable of these is ^{124}Sb with a half-life of 60.20 days, which has an application in some neutron sources. Isotopes that are lighter than the stable ^{123}Sb tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

Occurrence

The abundance of antimony in the Earth's crust is estimated at 0.2 to 0.5 parts per million, comparable to thallium at 0.5 parts per million and silver at 0.07 ppm. Even though this element is not abundant, it is found in over 100 mineral species. Antimony is sometimes found natively, but more frequently it is found in the sulfide stibnite (Sb_2S_3) which is the predominant ore mineral.

Antimony compounds are often classified into those of Sb(III) and Sb(V). Relative to its congener arsenic, the +5 oxidation state is more stable.

Arsenic- Inorganic Contaminant 0.010 mg/L MCL
Metalloid

Arsenic is a chemical element with symbol **As** and the atomic number is 33. Arsenic occurs in many minerals, usually in conjunction with sulfur and metals, and also as a pure elemental crystal. It was first documented by Albertus Magnus in 1250. Arsenic is a metalloid. It can exist in various allotropes, although only the gray form has important use in industry.



In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for arsenic is zero. EPA has set this level of protection based on the best available science to prevent potential health problems. Based on the MCLG, EPA has set an enforceable regulation for arsenic, called a maximum contaminant level (MCL), at 0.010 mg/L or 10 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring Final Rule, the regulation for arsenic, became effective in 2002. The Safe Drinking Water Act requires EPA to periodically review and revise contaminants, if appropriate, based on new scientific data. The regulation for arsenic will be included in a future review cycle.

The main uses of metallic arsenic is for strengthening alloys of copper and especially lead (for example, in car batteries). Arsenic is a common n-type dopant in semiconductor electronic devices, and the optoelectronic compound gallium arsenide is the most common semiconductor in use after doped silicon. Arsenic and its compounds, especially the trioxide, are used in the production of pesticides (treated wood products), herbicides, and insecticides. These applications are declining, however.

Arsenic is notoriously poisonous to multicellular life, although a few species of bacteria are able to use arsenic compounds as respiratory metabolites. Arsenic contamination of groundwater is a problem that affects millions of people across the world.

Arsenic, a naturally occurring element, is found throughout the environment; for most people, food is the major source of exposure. Acute (short-term) high-level inhalation exposure to arsenic dust or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain); central and peripheral nervous system disorders have occurred in workers acutely exposed to inorganic arsenic. Chronic (long-term) inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes. Chronic oral exposure has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage in humans. Inorganic arsenic exposure in humans, by the inhalation route, has been shown to be strongly associated with lung cancer, while ingestion of inorganic arsenic in humans has been linked to a form of skin cancer and also to bladder, liver, and lung cancer. EPA has classified inorganic arsenic as a Group A, human carcinogen.

Contamination of Groundwater
Arsenic contamination of groundwater is often due to naturally occurring high concentrations of arsenic in deeper levels of groundwater. It is a high-profile problem due to the use of deep tubewells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people. In addition, mining techniques such as hydraulic fracturing mobilize arsenic in groundwater and aquifers due to enhanced methane 28 transport and resulting changes in redox conditions, and inject fluid containing additional arsenic.

A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic contamination of ground water is found in many countries throughout the world, including the USA.

Approximately 20 incidents of groundwater arsenic contamination have been reported from all over the world. Of these, four major incidents were in Asia, including locations in Thailand, Taiwan, and Mainland China. In South America, Argentina and Chile are affected. There are also many locations in the United States where the groundwater contains arsenic concentrations in excess of the Environmental Protection Agency standard of 10 parts per billion adopted in 2001. Millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that are not safe.

Arsine
Arsine is a gas consisting of arsenic and hydrogen. It is extremely toxic to humans, with headaches, vomiting, and abdominal pains occurring within a few hours of exposure. EPA has not classified arsine for carcinogenicity.

Drinking water regulations require public water systems to monitor for arsenic at the entry point to the distribution system. There is no federal requirement for systems to monitor for arsenic within the distribution system. You may, however, want to test your distribution system water for arsenic to be sure that the water being delivered has arsenic levels below the MCL. If you decide to monitor your distribution system, consider testing for arsenic at locations where the settling and accumulation of iron solids or pipe scales are likely (i.e., areas with cast iron pipe, ductile iron pipe, or galvanized iron pipe).

If your water system has installed some form of arsenic treatment, keep in mind that the treatment you installed may change the water quality in other ways. It might cause the water to react differently in the distribution system. Depending on the kind of treatment you've installed, consider what distribution system problems might result.

A change in the taste, odor or appearance of the water at customers' taps may be the first indication of a problem. Some water quality parameters to consider monitoring, depending on your arsenic treatment technology, include iron, pH, manganese, alkalinity, and aluminum.

The current drinking water standard or Maximum Contaminant Level (MCL) set by the U.S. Environmental Protection Agency (EPA) is 0.010 mg/L or parts per million (ppm). This is equivalent to 10 ug/L (micrograms per liter) or 10 ppb. In 2001, the U.S. Environmental Protection Agency (EPA) reduced the regulatory MCL from 50 ppb to 10 ppb on the basis on bladder and lung cancer risks. The MCL is based on the average individual consuming 2 liters of water a day for a lifetime. Long term exposure to drinking water containing arsenic at levels higher than 10 ppb increases the chances of getting cancer, while for lower arsenic water levels the chances are less.

If your water has arsenic levels above 10 ppb, you should obtain drinking water from another source or install a home treatment device. Concentrations above 10 ppb will increase the risk of long-term or chronic health problems, the higher the level and length of exposure, the greater the risk. It is especially important to reduce arsenic water concentrations if you have children or are pregnant. Children are at greater risk (to any agent in water) because of their greater water consumption on a per unit body weight basis.

Pregnant women may wish to reduce their arsenic exposures because arsenic has been found at low levels in mother's milk and will cross the placenta, increasing exposures and risks for the fetus. If your water has arsenic levels above 200 ppb, you should immediately stop drinking the water until you can either obtain water from another source or install and maintain treatment.

Physical Characteristics

The three most common arsenic allotropes are *metallic gray*, *yellow* and *black arsenic*, with gray being the most common. *Gray arsenic* (α-As, space group R3m No. 166) adopts a double-layered structure consisting of many interlocked ruffled six-membered rings. Because of weak bonding between the layers, gray arsenic is brittle and has a relatively low Mohs hardness of 3.5. Nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 5.73 g/cm^3. Gray arsenic is a semimetal, but becomes a semiconductor with a bandgap of 1.2–1.4 eV if amorphized. *Yellow arsenic* is soft and waxy, and somewhat similar to tetraphosphorus (P_4). Both have four atoms arranged in a tetrahedral structure in which each atom is bound to each of the other three atoms by a single bond. This unstable allotrope, being molecular, is the most volatile, least dense and most toxic. Solid yellow arsenic is produced by rapid cooling of arsenic vapor, As_4. It is rapidly transformed into the gray arsenic by light. The yellow form has a density of 1.97 g/cm^3. *Black arsenic* is similar in structure to red phosphorus.

Isotopes

Naturally occurring arsenic is composed of one stable isotope, ^{75}As. As of 2003, at least 33 radioisotopes have also been synthesized, ranging in atomic mass from 60 to 92. The most stable of these is ^{73}As with a half-life of 80.3 days. Isotopes that are lighter than the stable ^{75}As tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

At least 10 nuclear isomers have been described, ranging in atomic mass from 66 to 84. The most stable of arsenic's isomers is ^{68m}As with a half-life of 111 seconds.

Chemistry

When heated in air, arsenic oxidizes to arsenic trioxide; the fumes from this reaction have an odor resembling garlic. This odor can be detected on striking arsenide minerals such as arsenopyrite with a hammer. Arsenic (and some arsenic compounds) sublimes upon heating at atmospheric pressure, converting directly to a gaseous form without an intervening liquid state at 887 K (614 °C). The triple point is 3.63 MPa and 1,090 K (820 °C). Arsenic makes arsenic acid with concentrated nitric acid, arsenious acid with dilute nitric acid, and arsenic trioxide with concentrated sulfuric acid.

Compounds
Arsenic compounds resemble in some respects those of phosphorus, which occupies the same group (column) of the periodic table. Arsenic is less commonly observed in the pentavalent state, however. The most common oxidation states for arsenic are: −3 in the arsenides, such as alloy-like intermetallic compounds; and +3 in the arsenites, arsenates (III), and most organoarsenic compounds. Arsenic also bonds readily to itself as seen in the square As3− 4 ions in the mineral skutterudite. In the +3 oxidation state, arsenic is typically pyramidal, owing to the influence of the lone pair of electrons.

Inorganic
Arsenic forms colorless, odorless, crystalline oxides As_2O_3 ("white arsenic") and As_2O_5, which are hygroscopic and readily soluble in water to form acidic solutions. Arsenic (V) acid is a weak acid. Its salts are called arsenates, which is the basis of arsenic contamination of groundwater, a problem that affects many people. Synthetic arsenates include Paris Green (copper(II) acetoarsenite), calcium arsenate, and lead hydrogen arsenate. The latter three have been used as agricultural insecticides and poisons.

The protonation steps between the arsenate and arsenic acid are similar to those between phosphate and phosphoric acid. Unlike phosphorus acid, arsenous acid is genuinely tribasic, with the formula $As(OH)_3$.

A broad variety of sulfur compounds of arsenic are known. Orpiment (As_2S_3) and realgar (As_4S_4) are somewhat abundant and were formerly used as painting pigments. In As_4S_{10}, arsenic has a formal oxidation state of +2 in As_4S_4, which features As-As bonds so that the total covalency of As is still three.

The trifluoride, trichloride, tribromide, and triiodide of arsenic (III) are well known, whereas only Arsenic pentafluoride (AsF_5) is the only important pentahalide. Again reflecting the lower stability of the 5+ oxidation state, the pentachloride is stable only below −50 °C.

Organoarsenic Compounds
A large variety of organoarsenic compounds are known. Several were developed as chemical warfare agents during World War I, including vesicants such as lewisite and vomiting agents such as adamsite. Cacodylic acid, which is of historic and practical interest, arises from the methylation of arsenic trioxide, a reaction that has no analogy in phosphorus chemistry.

Alloys
Arsenic is used as the group 5 element in the III-V semiconductors gallium arsenide, indium arsenide, and aluminum arsenide. The valence electron count of GaAs is the same as a pair of Si atoms, but the band structure is completely different, which results distinct bulk properties. Other arsenic alloys include the II-IV semiconductor cadmium arsenide.

Occurrence and Production
Minerals with the formula MAsS and MAs_2 (M = Fe, Ni, Co) are the dominant commercial sources of arsenic, together with realgar (an arsenic sulfide mineral) and native arsenic. An illustrative mineral is arsenopyrite (FeAsS), which is structurally related to iron pyrite. Many minor As-containing minerals are known. Arsenic also occurs in various organic forms in the environment. Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolized to a less toxic form of arsenic through a process of methylation.

Other naturally occurring pathways of exposure include volcanic ash, weathering of arsenic-containing minerals and ores, and dissolved in groundwater. It is also found in food, water, soil, and air. Arsenic is absorbed by all plants, but is more concentrated in leafy vegetables, rice, apple and grape juice, and seafood. An additional route of exposure is through inhalation.

In 2005, China was the top producer of white arsenic with almost 50% world share, followed by Chile, Peru, and Morocco, according to the British Geological Survey and the United States Geological Survey. Most operations in the US and Europe have closed for environmental reasons. The arsenic is recovered mainly as a side product from the purification of copper. Arsenic is part of the smelter dust from copper, gold, and lead smelters.

On roasting in air of arsenopyrite, arsenic sublimes as arsenic (III) oxide leaving iron oxides, while roasting without air results in the production of metallic arsenic. Further purification from sulfur and other chalcogens is achieved by sublimation in vacuum or in a hydrogen atmosphere or by distillation from molten lead-arsenic mixture.

Health Hazard Information
Arsenic
Arsenic is known to cause cancer, as well as many other serious health problems. Here we review the hazards of arsenic exposure and ways people can protect themselves from these hazards.

Arsenic is an element in the environment that can be found naturally in rocks and soil, water, air, and in plants and animals. It can also be released into the environment from some agricultural and industrial sources.

Arsenic has no taste or smell. Although sometimes found in its pure form as a steel grey metal, arsenic is usually part of chemical compounds. These compounds are divided into 2 groups:

- Inorganic compounds (combined with oxygen, iron, chlorine, and sulfur)
- Organic compounds (combined with carbon and other atoms)

Inorganic arsenic compounds are found in industry, in building products (in some "pressure-treated" woods), and in arsenic-contaminated water. This is the form of arsenic that tends to be more toxic and has been linked to cancer.

Organic arsenic compounds are much less toxic than the inorganic arsenic compounds and are not thought to be linked to cancer. These compounds are found in some foods, such as fish and shellfish.

While arsenic levels may fluctuate over time, what is most significant from the standpoint of cancer risk is long-term exposure.

For water systems in the 25 states that reported arsenic data to the EPA, we have calculated two estimates of average long-term levels: one is a very conservative estimate, the other our best estimate, based on what we believe to be the most reasonable analytical techniques (details on how we arrived at the estimates are included with the charts).

The table below shows the lifetime risks of dying of cancer from arsenic in tap water, based on the National Academy of Sciences' 1999 risk estimates.

Arsenic Level in Tap Water (in parts per billion, or ppb)	Approximate Total Cancer Risk (assuming 2 liters consumed/day)
0.5 ppb	1 in 10,000
1 ppb	1 in 5,000
3 ppb	1 in 1,667
4 ppb	1 in 1,250
5 ppb	1 in 1,000
10 ppb	1 in 500
20 ppb	1 in 250
25 ppb	1 in 200
50 ppb	1 in 100

Arsenic Diabetes
New research findings from the National Health and Nutrition Examination Survey suggest that exposure to levels of arsenic commonly found in drinking water may be a risk factor for type 2 diabetes. The findings suggest that millions of Americans may be at increased risk for type 2 diabetes based on the level of arsenic in their drinking water.

Data on the nearly 800 participants in the study for which urinary arsenic concentrations were available, indicated that urine levels of arsenic were significantly associated with the prevalence of type 2 diabetes. After splitting the subjects into 5 groups based on the level of arsenic in their urine, the researchers determined that those in the highest category were more than three and one-half times more likely to have diabetes. The strength of arsenic as a risk factor for diabetes is similar to other factors such as obesity.

Inorganic arsenic in drinking water at concentrations higher than 100 parts per million has been linked to type 2 diabetes in studies that took place in Taiwan, Mexico, and Bangladesh where drinking water is commonly contaminated with high levels of arsenic. The US drinking water standard is currently 10 parts per million, but most people on private wells have not had their water tested and aren't required to. The researchers estimate that about 13 million Americans live in areas where public water systems exceed the EPA standard for arsenic and this number does not included private wells and water systems.

Animal studies have shown that arsenic affects the production of glucose, insulin secretion and can cause insulin resistance. The current findings reinforce the need to evaluate the role of arsenic in diabetes development in prospective epidemiologic studies conducted in populations exposed to a wide range of arsenic levels.

Acute Effects:

Inorganic Arsenic

- Acute inhalation exposure of workers to high levels of arsenic dusts or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain), while acute exposure of workers to inorganic arsenic has also resulted in central and peripheral nervous system disorders.

- Acute oral exposure to inorganic arsenic, at doses of approximately 600 micrograms per kilogram body weight per day (µg/kg/d) or higher in humans, has resulted in death. Oral exposure to lower levels of inorganic arsenic has resulted in effects on the gastrointestinal tract (nausea, vomiting), central nervous system (CNS) (headaches, weakness, delirium), cardiovascular system (hypotension, shock), liver, kidney, and blood (anemia, leukopenia).

- Acute animal tests in rats and mice have shown inorganic arsenic to have moderate to high acute toxicity.

Arsine

- Acute inhalation exposure to arsine by humans has resulted in death; it has been reported that a half-hour exposure to 25 to 50 parts per million (ppm) can be lethal.

- The major effects from acute arsine exposure in humans include headaches, vomiting, abdominal pains, hemolytic anemia, hemoglobinuria, and jaundice; these effects can lead to kidney failure.

- Arsine has been shown to have extreme acute toxicity from acute animal tests.



Chronic Effects (Non-cancer):

Inorganic arsenic

- Chronic inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes (dermatitis, conjunctivitis, pharyngitis, and rhinitis).

- Chronic oral exposure to inorganic arsenic in humans has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, gangrene of the extremities, vascular lesions, and liver or kidney damage.

- No chronic inhalation exposure studies have been performed in animals for any inorganic arsenic compound.

- Some studies have suggested that inorganic arsenic is an essential dietary nutrient in goats, chicks, and rats. However, no comparable data are available for humans. EPA has concluded that essentiality, although not rigorously established, is plausible.

- EPA has not established a Reference Concentration (RfC) for inorganic arsenic.

- The California Environmental Protection Agency (CalEPA) has established a chronic inhalation reference level of 0.00003 milligrams per cubic meter (mg/m^3) based on developmental effects in mice. The CalEPA reference exposure level is a concentration at or below which adverse health effects are not likely to occur. It is not a direct estimator of risk, but rather a reference point to gauge the potential effects. At lifetime exposures increasingly greater than the reference exposure level, the potential for adverse health effects increases.

- The Reference Dose (RfD) for inorganic arsenic is 0.0003 milligrams per kilogram body weight per day (mg/kg/d) based on hyperpigmentation, keratosis, and possible vascular complications in humans. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime.

- EPA has medium confidence in the study on which the RfD for inorganic arsenic was based because, although an extremely large number of people were included in the assessment (>40,000), the doses were not well characterized and other contaminants were present. The supporting human toxicity database, while extensive, is somewhat flawed and, consequently, EPA has assigned medium confidence to the RfD.

Arsine

- No information is available on the chronic effects of arsine in humans.

- The RfC for arsine is 0.00005 mg/m^3 based on increased hemolysis, abnormal red blood cell morphology, and increased spleen weight in rats, mice, and hamsters.

- EPA has medium confidence in the RfC based on: (1) high confidence in the studies on which the RfC for arsine was based because the sample sizes were adequate, statistical significance was reported, concentration dose-response relationships were documented, three species were investigated, and both a no-observed-adverse-effect level (NOAEL) and a lowest-observed-adverse-effect level (LOAEL) were identified, and (2) medium confidence in the database because while there were three inhalation animal studies and a developmental/reproductive study, there were no data available on human exposure.

Reproductive/Developmental Effects:

Inorganic arsenic

- Several studies have suggested that women who work in, or live near, metal smelters may have higher than normal spontaneous abortion rates, and their children may exhibit lower than normal birth weights. However, these studies are limited because they were designed to evaluate the effects of smelter pollutants in general, and are not specific for inorganic arsenic.

- Ingested inorganic arsenic can cross the placenta in humans, exposing the fetus to the chemical.

- Oral animal studies have reported inorganic arsenic at very high doses to be fetotoxic and to cause birth defects.

Arsine

- Human studies have indicated higher than expected spontaneous abortion rates in women in the microelectronics industry who were exposed to arsine. However, these studies have several limitations, including small sample size and exposure to other chemicals in addition to arsine.

Cancer Risk:

Inorganic arsenic

- Human, inhalation studies have reported inorganic arsenic exposure to be strongly associated with lung cancer.

- Ingestion of inorganic arsenic in humans has been associated with an increased risk of nonmelanoma skin cancer and also to an increased risk of bladder, liver, and lung cancer.

- Animal studies have not associated inorganic arsenic exposure via the oral route with cancer, and no cancer inhalation studies have been performed in animals for inorganic arsenic.

- EPA has classified inorganic arsenic as a Group A, human carcinogen.

- EPA used a mathematical model, using data from an occupational study of arsenic-exposed copper smelter workers, to estimate the probability of a person developing cancer from continuously breathing air containing a specified concentration of inorganic arsenic. EPA calculated an inhalation unit risk estimate of $4.3 \times 10^{-3}(\mu g/m^3)^{-1}$. EPA estimates that, if an individual were to continuously breathe air containing inorganic arsenic at an average of 0.0002 $\mu g/m^3$ (2×10^{-7} mg/m^3) over his or her entire lifetime, that person would theoretically have no more than a one-in-a-million increased chance of developing cancer as a direct result of breathing air containing this chemical. Similarly, EPA estimates that continuously breathing air containing 0.002 $\mu g/m^3$ (2×10^{-6} mg/m^3) would result in not greater than a one-in-a-hundred thousand increased chance of developing cancer, and air containing 0.02 $\mu g/m^3$ (2×10^{-5} mg/m^3) would result in not greater than a one-in-ten thousand increased chance of developing cancer. For a detailed discussion of confidence in the potency estimates, please see IRIS.

- EPA has calculated an oral cancer slope factor of 1.5 $(mg/kg/d)^{-1}$ for inorganic arsenic.

Arsine

- No cancer inhalation studies in humans or animals are available for arsine.

- EPA has not classified arsine for carcinogenicity.

Physical Properties

- Inorganic arsenic is a naturally occurring element in the earth's crust.

- Pure inorganic arsenic is a gray-colored metal, but inorganic arsenic is usually found combined with other elements such as oxygen, chlorine, and sulfur.

- The chemical symbol for inorganic arsenic is As, and it has an atomic weight of 74.92 g/mol.

- The chemical formula for arsine is AsH_3, and it has a molecular weight of 77.95 g/mol.

- Arsine is a colorless gas with a disagreeable garlic odor.

- Arsenic combined with elements such as oxygen, chlorine, and sulfur forms inorganic arsenic; inorganic arsenic compounds include arsenic pentoxide, arsenic trioxide, and arsenic acid. Arsenic combined with carbon and hydrogen forms organic arsenic; organic arsenic compounds include arsanilic acid, arsenobetaine, and dimethylarsinic acid.

Arsenic Control Measures Can Affect Finished Water Quality

Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion. Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps. This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Is Arsenic in your Storage Tank?

Is Your Ground Water System Installing Disinfection for Pathogen Control?
Water systems that disinfect their water should be aware of the possibility of an increase in arsenic concentrations in their distribution system, particularly if the water contains high concentrations of dissolved iron. When chlorinated, the dissolved iron forms particles on which arsenic can accumulate. As a result, high arsenic concentrations may occur in distribution system water even if arsenic concentrations in the raw water are below the MCL.

This happened to a small community water system in the Midwest that began chlorinating water from a series of wells that had raw water arsenic levels between 0.003 and 0.008 mg/L and iron concentrations up to 0.4 mg/L. At the same time, the system installed a polyphosphate feed system for corrosion control. Soon after chlorination began, the system received intermittent colored-water complaints from its customers with increasing frequency across the distribution system.

Samples collected from several representative locations throughout the service area had a reddish-brown color and contained particles. A metals analysis showed high levels of copper and iron oxides in the finished water, along with arsenic concentrations approaching 5 mg/L. Because of the water's colored appearance, it was considered unlikely that customers would consume the water. Doctors and health care professionals were notified of the situation and instructed to watch for signs of arsenic poisoning.

Researchers found that chlorinating the water caused the formation of ferri-hydroxide solids. The minimal arsenic present in the groundwater was being concentrated as it absorbed onto the solids. Copper oxide particulates also formed and were released. To some extent, the polyphosphates served a useful role by keeping iron in solution and counteracting the tendency for the iron oxides to form, but additional steps were needed. For six months the system alternated their chlorination schedule: on for one day then off two days. The system then returned to full-time chlorination, starting with a low distribution system residual of0.2 mg/L and gradually increasing it to 0.5 mg/L. The system continued to flush water mains on a semi-annual schedule using a unidirectional approach. In the last year, the system received only one colored water complaint.

Arsenic Environmental Issues
Arsenic Control Measures Can Affect Finished Water Quality
Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion. Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Occurrence in drinking water
Widespread arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Bangladesh and neighboring countries. It is estimated that approximately 57 million people in the Bengal basin are drinking groundwater with arsenic concentrations elevated above the World Health Organization's standard of 10 parts per billion (ppb). However, a study of cancer rates in Taiwan suggested that significant increases in cancer mortality appear only at levels above 150 ppb.

The arsenic in the groundwater is of natural origin, and is released from the sediment into the groundwater, owing to the anoxic conditions of the subsurface. This groundwater began to be used after local and western NGOs and the Bangladeshi government undertook a massive shallow tube well drinking-water program in the late twentieth century. This program was designed to prevent drinking of bacteria-contaminated surface waters, but failed to test for arsenic in the groundwater. Many other countries and districts in Southeast Asia, such as Vietnam and Cambodia have geological environments conducive to generation of high-arsenic groundwaters. Arsenicosis was reported in Nakhon Si Thammarat, Thailand in 1987, and the dissolved arsenic in the Chao Phraya River is suspected of containing high levels of naturally occurring arsenic, but has not been a public health problem owing to the use of bottled water.

In the United States, arsenic is most commonly found in the ground waters of the southwest. Parts of New England, Michigan, Wisconsin, Minnesota and the Dakotas are also known to have significant concentrations of arsenic in ground water. Increased levels of skin cancer have been associated with arsenic exposure in Wisconsin, even at levels below the 10 part per billion drinking water standard, although this link has not been proven. According to a recent film funded by the US Superfund, millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that exceed established limits.

Low-level exposure to arsenic at concentrations found commonly in US drinking water compromises the initial immune response to H1N1 or swine flu infection according to NIEHS-supported scientists. The study, conducted in laboratory mice, suggests that people exposed to arsenic in their drinking water may be at increased risk for more serious illness or death in response to infection from the virus.

Some Canadians are drinking water that contains inorganic arsenic. Private dug well waters are most at risk for containing inorganic arsenic. Preliminary well water analyses typically does not test for arsenic. Researchers at the Geological Survey of Canada have modeled relative variation in natural arsenic hazard potential for the province of New Brunswick. This study has important implications for potable water and health concerns relating to inorganic arsenic.

Epidemiological evidence from Chile shows a dose-dependent connection between chronic arsenic exposure and various forms of cancer, in particular when other risk factors, such as cigarette smoking, are present. These effects have been demonstrated to persist below 50 ppb. Analyzing multiple epidemiological studies on inorganic arsenic exposure suggests a small but measurable risk increase for bladder cancer at 10 ppb. According to Peter Ravenscroft of the Department of Geography at the University of Cambridge, roughly 80 million people worldwide consume between 10 and 50 ppb arsenic in their drinking water. If they all consumed exactly 10 ppb arsenic in their drinking water, the previously cited multiple epidemiological study analysis would predict an additional 2,000 cases of bladder cancer alone. This represents a clear underestimate of the overall impact, since it does not include lung or skin cancer, and explicitly underestimates the exposure. Those exposed to levels of arsenic above the current WHO standard should weigh the costs and benefits of arsenic remediation.

Early (1973) evaluations of the removal of dissolved arsenic by drinking water treatment processes demonstrated that arsenic is very effectively removed by co-precipitation with either iron or aluminum oxides. The use of iron as a coagulant, in particular, was found to remove arsenic with efficiencies exceeding 90%. Several adsorptive media systems have been approved for point-of-service use in a study funded by the United States Environmental Protection Agency (US EPA) and the National Science Foundation (NSF).

A team of European and Indian scientists and engineers have set up six arsenic treatment plants in West Bengal based on in-situ remediation method (SAR Technology). This technology does not use any chemicals and arsenic is left as an insoluble form (+5 state) in the subterranean zone by recharging aerated water into the aquifer and thus developing an oxidation zone to support arsenic oxidizing micro-organisms. This process does not produce any waste stream or sludge and is relatively cheap.

Another effective and inexpensive method to remove arsenic from contaminated well water is to sink wells 500 feet or deeper to reach purer waters. A recent 2011 study funded by the US National Institute of Environmental Health Sciences' Superfund Research Program shows that deep sediments can remove arsenic and take it out of circulation.

Through this process called adsorption in which arsenic sticks to the surfaces of deep sediment articles, arsenic can be naturally removed from well water.

Magnetic separations of arsenic at very low magnetic field gradients have been demonstrated in point-of-use water purification with high-surface-area and monodisperse magnetite (Fe_3O_4) nanocrystals. Using the high specific surface area of Fe_3O_4 nanocrystals the mass of waste associated with arsenic removal from water has been dramatically reduced.

Epidemiological studies have suggested a correlation between chronic consumption of drinking water contaminated with arsenic and the incidence of all leading causes of mortality. The literature provides reason to believe arsenic exposure is causative in the pathogenesis of diabetes.

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 µg/L. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

Water Purification Solutions

Small-scale water treatment

A review of methods to remove arsenic from groundwater in Pakistan summarizes the most technically viable inexpensive methods. A simpler and less expensive form of arsenic removal is known as the Sono arsenic filter, using three pitchers containing cast iron turnings and sand in the first pitcher and wood activated carbon and sand in the second. Plastic buckets can also be used as filter containers. It is claimed that thousands of these systems are in use and can last for years while avoiding the toxic waste disposal problem inherent to conventional arsenic removal plants. Although novel, this filter has not been certified by any sanitary standards such as NSF, ANSI, WQA and does not avoid toxic waste disposal similar to any other iron removal process.

In the United States small "under the sink" units have been used to remove arsenic from drinking water. This option is called "point of use" treatment. The most common types of domestic treatment use the technologies of adsorption (using media such as Bayoxide E33, GFH, or titanium dioxide) or reverse osmosis. Ion exchange and activated alumina have been considered but not commonly used.

Arsenic Large-scale water treatment

In some places, such as the United States, all the water supplied to residences by utilities must meet primary (health-based) drinking water standards. Regulations may necessitate large-scale treatment systems to remove arsenic from the water supply.

The effectiveness of any method depends on the chemical makeup of a particular water supply. The aqueous chemistry of arsenic is complex, and may affect the removal rate that can be achieved by a particular process.

Some large utilities with multiple water supply wells could shut down those wells with high arsenic concentrations, and produce only from wells or surface water sources that meet the arsenic standard. Other utilities, however, especially small utilities with only a few wells, may have no available water supply that meets the arsenic standard.

Coagulation/filtration (also known as flocculation) removes arsenic by coprecipitation and adsorption using iron coagulants. Coagulation/filtration using alum is already used by some utilities to remove suspended solids and may be adjusted to remove arsenic. But the problem of this type of filtration system is that it gets clogged very easily, mostly within two to three months. The toxic arsenic sludge are disposed of by concrete stabilization, but there is no guarantee that they won't leach out in future.

Iron oxide adsorption filters the water through a granular medium containing ferric oxide. Ferric oxide has a high affinity for adsorbing dissolved metals such as arsenic. The iron oxide medium eventually becomes saturated, and must be replaced. The sludge disposal is a problem here too.

Activated alumina is an adsorbent that effectively removes arsenic. Activated alumina columns connected to shallow tube wells in India and Bangladesh have successfully removed both As(III) and As(V) from groundwater for decades. Long-term column performance has been possible through the efforts of community-elected water committees that collect a local water tax for funding operations and maintenance. It has also been used to remove undesirably high concentrations of fluoride.

Ion Exchange has long been used as a water-softening process, although usually on a single-home basis. Traditional anion exchange is effective in removing As(V), but not As (III), or arsenic trioxide, which doesn't have a net charge. Effective long-term ion exchange removal of arsenic requires a trained operator to maintain the column.

Both **Reverse osmosis** and **electrodialysis** (also called *electrodialysis reversal*) can remove arsenic with a net ionic charge. (Note that arsenic oxide, As_2O_3, is a common form of arsenic in groundwater that is soluble, but has no net charge.) Some utilities presently use one of these methods to reduce total dissolved solids and therefore improve taste. A problem with both methods is the production of high-salinity waste water, called brine, or concentrate, which then must be disposed of.

Subterranean Arsenic Removal (SAR) Technology
In subterranean arsenic removal (SAR), aerated groundwater is recharged back into the aquifer to create an oxidation zone which can trap iron and arsenic on the soil particles through adsorption process. The oxidation zone created by aerated water boosts the activity of the arsenic-oxidizing microorganisms which can oxidize arsenic from +3 to +5 state SAR Technology.

No chemicals are used and almost no sludge is produced during operational stage since iron and arsenic compounds are rendered inactive in the aquifer itself. Thus toxic waste disposal and the risk of its future mobilization is prevented. Also, it has very long operational life, similar to the long lasting tube wells drawing water from the shallow aquifers.

Six such SAR plants, funded by the World Bank and constructed by Ramakrishna Vivekananda Mission, Barrackpore & Queen's University Belfast, UK are operating in West Bengal. Each plant has been delivering more than 3,000 liters of arsenic and iron-free water daily to the rural community. The first community water treatment plant based on SAR technology was set up at Kashimpore near Kolkata in 2004 by a team of European and Indian engineers led by Dr. Bhaskar Sen Gupta of Queen's University Belfast for TiPOT.

SAR technology had been awarded Dhirubhai Ambani Award, 2010 from IChemE UK for Chemical Innovation. Again, SAR was the winner of the St. Andrews Award for Environment, 2010. The SAR Project was selected by the Blacksmith Institute - New York & Green Cross-Switzerland as one of the "12 Cases of Cleanup & Success" in the World's Worst Polluted Places Report 2009.

The Hungarian Solution

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 microgram/liter. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

Arsenic Can Build Up on and Release in Pipes and Storage Tanks

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps. This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Public water systems with arsenic in their raw water may find that scales on pipes and other components in their distribution systems contain relatively high arsenic concentrations. These arsenic-rich scales can become dislodged and suspended in the water, and may be ultimately delivered to consumers.

Arsenic has been shown to attach to iron in distribution system pipes. Because iron is so effective at binding with arsenic, corrosion deposits can have high concentrations of arsenic solids. In a recent study, arsenic levels found in solids that were collected after pipe sections and hydrants were flushed were as high as 13.65 milligrams of arsenic per gram of solid.



Asbestos minerals which have been used commercially from the top: chrysotile, amosite and crocidolite.

Asbestos - Inorganic Contaminant 7 MFL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for asbestos is 7 MFL. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for asbestos, called a maximum contaminant level (MCL), at 7 MFL. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for asbestos, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed asbestos as part of the Six Year Review and determined that the 7 MFL MCLG and 7 MFL MCL for asbestos are still protective of human health.

How does Asbestos get into my Drinking Water?
The major sources of asbestos in drinking water are decay of asbestos cement water mains; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Asbestos is in my Drinking Water?
When routine monitoring indicates that asbestos levels are above the MCL, your water supplier must take steps to reduce the amount of asbestos so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will Asbestos be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing asbestos to below 7 MFL: coagulation/filtration, direct and diatomite filtration, and corrosion control.



Asbestos Cement Pipe (ACP)

Common water distribution pipe, notice that both pipes have been cut with a power saw. You are not allowed to cut this type of pipe with a power saw, because it will spread the Asbestos.

Wetting agents may be applied with garden sprayers or hoses. Garden sprayers are hand-held, portable, and have a one- to five-gallon capacity. Water hoses are usually attached to a faucet tap, fire hydrant or water tank. Generally, the hose has a nozzle attached which spreads the water stream so that a fine mist is created.

Asbestos-Cement Products

Asbestos-cement products (such as transite) are commonly used for duct insulation, pipes, and siding. Being a Category II nonfriable ACM, asbestos-cement products need to be removed prior to demolition if they have a high probability of becoming crumbled, pulverized, or reduced to powder during demolition activities. EPA believes that most demolition activities will subject such Category II nonfriable ACM to the regulation.

Asbestos is an Excellent …

Heat Stability

Asbestos will maintain its structural integrity at temperatures well above 800 F. The melting point is at about 2800 F

Thermal Insulation

The fibers have a relatively large surface area, along with numerous pores, and cracks. This allows for a low heat transfer. This makes it useful as an insulator in homes and machinery. The large surface area also absorbs water making it practical as pipe insulator to prevent sweating.

Chemical Resistance

The amphiboles are resistant to aqueous media and chemical attack. They also show high resistance to acids. This makes this class of asbestos useful for battery packing. Chrysotile is significantly less resistant to chemical destruction.

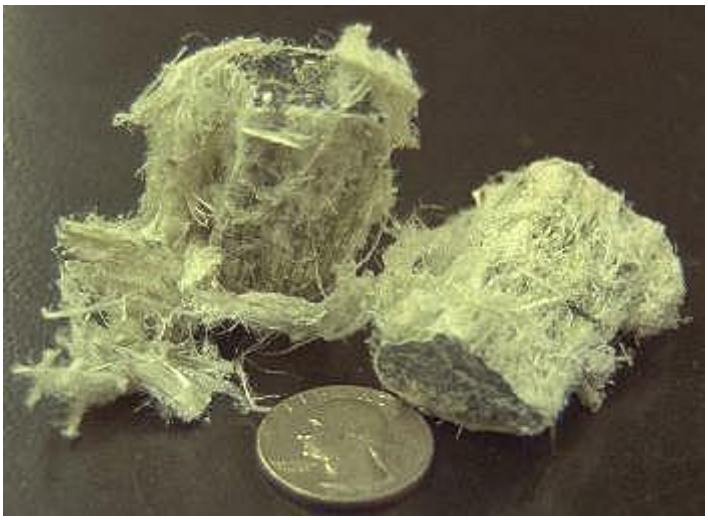
Sound Absorption
Asbestos have a large internal volume, large surface area, and the fibers are flexible. This makes it ideal for the absorption of sound energy. It is often uses to help acoustics.



Serpent

Asbestos

OSHA requires that employees who may be exposed to dangerous levels of asbestos must be made aware of the hazards and how to protect themselves. Employees must be told where in their workplace they can find copies of all applicable asbestos standards. Employers must provide any employee with the opportunity to review the regulations if they so desire. It is an employee's right to have access to the regulations.



What Is Asbestos?
Asbestos is the name given to a number of naturally occurring fibrous silicate minerals that have been mined for their useful properties such as thermal insulation, chemical and thermal stability, and high tensile strength. The three most common types of asbestos are: a) chrysotile, b) amosite and c) crocidolite. Chrysotile, also known as white asbestos and a member of the Serpentine mineral group is the commonest. Asbestos can only be identified under a microscope.
Asbestos differs from other minerals in its crystal development. The crystal formation of asbestos is in the form of long thin fibers. Asbestos is divided into two mineral groups

Serpentine and **Amphibole**. The division between the two types of asbestos is based upon the crystalline structure.

Serpentines have a sheet or layered structure where amphiboles have a chain-like structure. As the only member of the serpentine group, Chrysotile (A, B) is the most common type of asbestos found in buildings. Chrysotile makes up approximately 90%-95% of all asbestos contained in buildings in the United States.

Unlike most minerals, which turn into dust particles when crushed, asbestos breaks up into fine fibers that are too small to be seen by the human eye. Often, individual fibers are mixed with a material that binds them together, producing asbestos-containing material (**ACM**).

Health Effects of Asbestos Exposure
Asbestos is the largest single cause of fatal disease and ill-health caused by work in Great Britain. Although almost all the deaths and ill health related to asbestos today are due to exposures that happened several decades ago, if you work with asbestos, or come into contact with it as a result of repair and maintenance work, you need to be particularly careful. Asbestos can be found in most buildings built between 1950 and 1980, as insulation and lagging. It is still used in some brake pads and clutch linings and can be met in vehicle servicing and repair.

Asbestos-Related Health Problems

Some people exposed to asbestos develop asbestos-related health problems; some do not. Once inhaled, asbestos fibers can easily penetrate body tissues. They may be deposited and retained in the airways and lung tissue. Because asbestos fibers remain in the body, each exposure increases the likelihood of developing an asbestos-related disease. Asbestos-related diseases may not appear until years after exposure. A medical examination that includes a medical history, breathing capacity test, and chest X ray may detect problems early.

Many substances have a "**safe dose**" or an exposure that is unlikely to cause any harm. Above the safe dose, a health effect is expected. This concept is known as a dose response. As the dose increases, so does the expected severity of the health effect. However, in the case of asbestos, scientists have not determined a "**safe dose**" or threshold level for exposure to airborne asbestos. Still, the less exposure a person receives over a lifetime, the less likely it is that that person will develop an asbestos-related health problem.

In addition to breathing it, ingesting asbestos may also be harmful to you, but the consequences of this type of exposure have not been clearly documented. People who touch asbestos may get a rash similar to the rash caused by fiberglass. While the effects of skin exposure to asbestos have not been scientifically documented, it is best to minimize all contact with asbestos.

Asbestos was used in approximately 3,000 products. Two-thirds of this total (2,000) was used in construction products. Appendix A includes a short list of products where asbestos may be found.

Barium - Inorganic Contaminant 2 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.



The MCLG for barium is 2 mg/L or 2 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for barium, called a maximum contaminant level (MCL), at 2 mg/L or 2 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase IIB Rule, the regulation for barium, became effective in 1993. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed barium as part of the Six Year Review and determined that the 2 mg/L or 2 ppm MCLG and 2 mg/L or 2 ppm MCL for barium are still protective of human health.

The major sources of barium in drinking water are discharge of drilling wastes; discharge from metal refineries; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

When routine monitoring indicates that barium levels are above the MCL, your water supplier must take steps to reduce the amount of barium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will barium be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing barium to below 2 mg/L or 2 ppm: ion exchange, reverse osmosis, lime softening, and electrodialysis.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Barium Explained

Barium is a chemical element with symbol **Ba** and atomic number 56. It is the fifth element in Group 2, a soft silvery metallic alkaline earth metal. Because of its high chemical reactivity barium is never found in nature as a free element. Its hydroxide was known in pre-modern history as baryta; this substance does not occur as a mineral, but can be prepared by heating barium carbonate.

The most common naturally occurring minerals of barium are barite (barium sulfate, $BaSO_4$) and witherite (barium carbonate, $BaCO_3$), both being insoluble in water. Barium's name originates from the alchemical derivative "baryta", which itself comes from Greek βαρύς (*barys*), meaning "heavy." Barium was identified as a new element in 1774, but not reduced to a metal until 1808, shortly after electrolytic isolation techniques became available.

Barium has only a few industrial applications. The metal has been historically used to scavenge air in vacuum tubes. It is a component of YBCO (high-temperature superconductors) and electroceramics, and is added to steel and cast iron to reduce the size of carbon grains within the microstructure of the metal. Barium compounds are added to fireworks to impart a green color. For instance, barium sulfate is used as an insoluble heavy additive to oil well drilling fluid, and in purer form, as X-ray radiocontrast agents for imaging the human gastrointestinal tract. Soluble barium compounds are poisonous due to release of the soluble barium ion, and therefore have been used as rodenticides.

Physical Properties
Barium is a soft, silvery-white metal, with a slight golden shade when ultrapure. The silvery-white color of barium metal rapidly vanishes upon oxidation in air yielding a dark gray oxide layer. Barium has a medium specific weight and good electrical conductivity. Ultrapure barium is very hard to prepare, and therefore many properties of barium have not been accurately measured yet.

At room temperature and pressure, barium has a body-centered cubic structure, with a barium–barium distance of 503 picometers, expanding with heating at a rate of approximately 1.8×10^{-5}/°C. It is a very soft metal with a Mohs hardness of 1.25. Its melting temperature of 1000 K (727 °C, 1341 °F) is intermediate between those of the lighter strontium (1050 K) and heavier radium (973 K); however, its boiling point of 2170 K (1897 °C, 3447 °F) exceeds that of strontium (1655 K). The density (3.62 $g\cdot cm^{-3}$) is again intermediate between those of strontium (2.36 $g\cdot cm^{-3}$) and radium (~5 $g\cdot cm^{-3}$).

Chemical Reactivity
Barium is chemically similar to magnesium, calcium, and strontium, being even more reactive. It always exhibits the oxidation state of +2. Reactions with chalcogens are highly exothermic (release energy); the reaction with oxygen or air occurs at room temperature, and therefore barium is stored under oil or inert gas atmosphere. Reactions with other nonmetals, such as carbon, nitrogen, phosphorus, silicon, and hydrogen, are generally exothermic and proceed upon heating. Reactions with water and alcohols are also very exothermic and release hydrogen gas:

$$Ba + 2\ ROH \rightarrow Ba(OR)_2 + H_2\uparrow \text{ (R is an alkyl or a hydrogen atom)}$$

Additionally, barium reacts with ammonia to form complexes such as $Ba(NH_3)_6$.

Beryllium - Inorganic Contaminant 0.004 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.



The MCLG for beryllium is 0.004 mg/L or 4 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for beryllium, called a maximum contaminant level (MCL), at 0.004 mg/L or 4 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for beryllium, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed beryllium as part of the Six Year Review and determined that the 0.004 mg/L or 4 ppb MCLG and 0.004 mg/L or 4 ppb MCL for beryllium are still protective of human health.

How does Beryllium get into my Drinking Water?
Beryllium naturally enters surface water and ground water through the weathering of rocks and soils or from industrial wastewater discharges. The major source of environmental releases from human activities are coal and fuel oil combustion.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Beryllium is in my Drinking Water?
When routine monitoring indicates that beryllium levels are above the MCL, your water supplier must take steps to reduce the amount of beryllium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

Beryllium Explained

Beryllium is the chemical element with the symbol **Be** and atomic number 4. Because any beryllium synthesized in stars is short-lived, it is a relatively rare element in both the universe and in the crust of the Earth. It is a divalent element which occurs naturally only in combination with other elements in minerals. Notable gemstones which contain beryllium include beryl (aquamarine, emerald) and chrysoberyl. As a free element it is a steel-gray, strong, lightweight and brittle alkaline earth metal.

Beryllium increases hardness and resistance to corrosion when alloyed to aluminum, cobalt, copper (notably beryllium copper), iron and nickel. In structural applications, high flexural rigidity, thermal stability, thermal conductivity and low density (1.85 times that of water) make beryllium a quality aerospace material for high-speed aircraft, missiles, space vehicles and communication satellites. Because of its low density and atomic mass, beryllium is relatively transparent to X-rays and other forms of ionizing radiation; therefore, it is the most common window material for X-ray equipment and in particle physics experiments. The high thermal conductivities of beryllium and beryllium oxide have led to their use in heat transport and heat sinking applications.

The commercial use of beryllium metal presents technical challenges due to the toxicity (especially by inhalation) of beryllium-containing dusts. Beryllium is corrosive to tissue, and can cause a chronic life-threatening allergic disease called berylliosis in some people. The element is not known to be necessary or useful for either plant or animal life

Characteristics
Physical Properties
Beryllium is a steel gray and hard metal that is brittle at room temperature and has a close-packed hexagonal crystal structure. It has exceptional flexural rigidity (Young's modulus 287 GPa) and a reasonably high melting point. The modulus of elasticity of beryllium is approximately 50% greater than that of steel. The combination of this modulus and a relatively low density results in an unusually fast sound conduction speed in beryllium – about 12.9 km/s at ambient conditions. Other significant properties are high specific heat (1925 $J \cdot kg^{-1} \cdot K^{-1}$) and thermal conductivity (216 $W \cdot m^{-1} \cdot K^{-1}$), which make beryllium the metal with the best heat dissipation characteristics per unit weight. In combination with the relatively low coefficient of linear thermal expansion (11.4×10^{-6} K^{-1}), these characteristics result in a unique stability under conditions of thermal loading.

Nuclear Properties
Natural beryllium, save for slight contamination by cosmogenic radioisotopes, is essentially beryllium-9, which has a nuclear spin of 3/2-. Beryllium has a large scattering cross section for high-energy neutrons, about 6 barns for energies above ~0.01 MeV. Therefore, it works as a neutron reflector and neutron moderator, effectively slowing the neutrons to the thermal energy range of below 0.03 eV, where the total cross section is at least an order of magnitude lower – exact value strongly depends on the purity and size of the crystallites in the material.

The single primordial beryllium isotope ^{9}Be also undergoes a (n,2n) neutron reaction with neutron energies over about 1.9 MeV, to produce ^{8}Be, which almost immediately breaks into two alpha particles. Thus, for high-energy neutrons beryllium is a neutron multiplier, releasing more neutrons than it absorbs.

Cadmium - Inorganic Contaminant 0.005 mg/L MCL

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for cadmium is 0.005 mg/L or 5 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for cadmium, called a maximum contaminant level (MCL), at 0.005 mg/L or 5 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.



The Phase II Rule, the regulation for cadmium, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed cadmium as part of the Six Year Review and determined that the 0.005 mg/L or 5 ppb MCLG and 0.005 mg/L or 5 ppb MCL for cadmium are still protective of human health.

How does cadmium get into my drinking water?
The major sources of cadmium in drinking water are corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints.
A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if cadmium is in my drinking water?
When routine monitoring indicates that cadmium levels are above the MCL, your water supplier must take steps to reduce the amount of cadmium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.
How will cadmium be removed from my drinking water?
The following treatment method(s) have proven to be effective for removing cadmium to below 0.005 mg/L or 5 ppb: coagulation/filtration, ion exchange, lime softening, and reverse osmosis.

Cadmium Explained

Cadmium is a chemical element with the symbol **Cd** and atomic number 48. This soft, bluish-white metal is chemically similar to the two other stable metals in group 12, zinc and mercury. Like zinc, it prefers oxidation state +2 in most of its compounds and like mercury it shows a low melting point compared to transition metals. Cadmium and its congeners are not always considered transition metals, in that they do not have partly filled d or f electron shells in the elemental or common oxidation states. The average concentration of cadmium in the Earth's crust is between 0.1 and 0.5 parts per million (ppm). It was discovered in 1817 simultaneously by Stromeyer and Hermann, both in Germany, as an impurity in zinc carbonate.

Cadmium occurs as a minor component in most zinc ores and therefore is a byproduct of zinc production. It was used for a long time as a pigment and for corrosion resistant plating on steel while cadmium compounds were used to stabilize plastic. With the exception of its use in nickel–cadmium batteries and cadmium telluride solar panels, the use of cadmium is generally decreasing. These declines have been due to competing technologies, cadmium's toxicity in certain forms and concentration and resulting regulations. Although cadmium has no known biological function in higher organisms, a cadmium-dependent carbonic anhydrase has been found in marine diatoms.

Characteristics
Physical Properties
Cadmium is a soft, malleable, ductile, bluish-white divalent metal. It is similar in many respects to zinc but forms complex compounds. Unlike other metals, cadmium is resistant to corrosion and as a result it is used as a protective layer when deposited on other metals. As a bulk metal, cadmium is insoluble in water and is not flammable; however, in its powdered form it may burn and release toxic fumes.

Chemical Properties
Although cadmium usually has an oxidation state of +2, it also exists in the +1 state. Cadmium and its congeners are not always considered transition metals, in that they do not have partly filled d or f electron shells in the elemental or common oxidation states. Cadmium burns in air to form brown amorphous cadmium oxide (CdO); the crystalline form of this compound is a dark red which changes color when heated, similar to zinc oxide. Hydrochloric acid, sulfuric acid and nitric acid dissolve cadmium by forming cadmium chloride ($CdCl_2$), cadmium sulfate ($CdSO_4$), or cadmium nitrate ($Cd(NO_3)_2$).

The oxidation state +1 can be reached by dissolving cadmium in a mixture of cadmium chloride and aluminum chloride, forming the Cd_2^{2+} cation, which is similar to the Hg_2^{2+} cation in mercury(I) chloride.

$$Cd + CdCl_2 + 2\ AlCl_3 \rightarrow Cd_2(AlCl_4)_2$$

Chromium- Inorganic Contaminant 0.1 mg/L MCL

The Safe Drinking Water Act requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based on possible health risks from exposure over a lifetime, are called maximum contaminant level goals (MCLG).



EPA sets enforceable standards for drinking water contaminants based on the best available science to prevent potential health problems. In most cases, the enforceable standard is known as a maximum contaminant level (MCL), the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. MCLs are set as close to the health goals as possible after considering costs, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The national primary drinking water regulation that established the MCL for total chromium was promulgated in 1991. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed total chromium as part of the second six-year review that was announced in March 2010. The Agency noted in March 2010 that it had initiated a reassessment of the health risks associated with chromium exposure and that the Agency did not believe it was appropriate to revise the national primary drinking water regulation while that effort was in process. In 2008, EPA began a rigorous and comprehensive review of chromium-6 health effects based on new science. When this human health assessment is finalized EPA will carefully review the conclusions and consider all relevant information to determine if the current chromium standard should be revised

Ensuring safe drinking water for all Americans is a top priority for EPA. EPA has an enforceable drinking water standard of 0.1 milligrams per liter (mg/L) for total chromium, which includes chromium-6 and chromium-3. This standard was established in 1991 and was based on the best available science at the time which indicated that some people who use water containing chromium in excess of the drinking water standard over many years could experience allergic dermatitis (skin reactions).

EPA regularly re-evaluates drinking water standards and, based on new science on chromium-6, had begun a rigorous and comprehensive review of its health effects in 2008. In September 2010, EPA released a draft of that scientific assessment for public comment. When this human health assessment is finalized, EPA will carefully review the conclusions and consider all relevant information to determine if a new drinking water standard for chromium-6 or a revision to the current total chromium standard is warranted.

Chromium is an odorless and tasteless metallic element. Chromium is found naturally in rocks, plants, soil and volcanic dust, humans and animals.

The most common forms of chromium that occur in natural waters in the environment are trivalent chromium (chromium-3), and hexavalent chromium (chromium-6).

Chromium-3 is an essential human dietary element and occurs naturally in many vegetables, fruits, meats, grains and yeast. Chromium-6 occurs naturally in the environment from the erosion of natural chromium deposits but it can also be produced by industrial processes. There are demonstrated instances of chromium being released to the environment by leakage, poor storage, or inadequate industrial waste disposal practices.

What are some uses for Chromium?
Metallic chromium is used mainly for making steel and other alloys. Chromium compounds in either the chromium-3 or chromium-6 forms are used for chrome plating, dyes and pigments, leather and wood preservation.

What are Chromium's Health Effects?
Chromium-3 is a nutritionally essential element in humans and is often added to vitamins as a dietary supplement. Chromium-3 has relatively low toxicity and would be a concern in drinking water only at very high levels of contamination; Chromium-6 is more toxic and poses potential health risks. People who use water containing total chromium in excess of the maximum contaminant level (MCL) over many years could experience allergic dermatitis.

EPA proposed to classify chromium-6 as likely to be carcinogenic to humans when ingested. The Agency continues to work towards completing the human health assessment and making a final determination about the carcinogenicity of chromium-6. When the assessment is completed, EPA will determine whether the drinking water standard for total chromium needs to be revised.

What are EPA's drinking water regulations for Chromium?
The Safe Drinking Water Act requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based on possible health risks from exposure over a lifetime are called maximum contaminant level goals (MCLG).

The MCLG for total chromium is 0.1 mg/L or 100 parts per billion (ppb). EPA has set this level of protection based on the best available science at the time the rule was promulgated. EPA has set an enforceable regulation for total chromium, called a maximum contaminant level (MCL), at 0.1 mg/L or 100 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

States may set more stringent drinking water MCLGs and MCLs for total chromium than EPA.

Why are Chromium-6 and Chromium-3 covered in the same Standard?
Chromium-6 and chromium-3 are covered under the total chromium drinking water standard because these forms of chromium can convert back and forth in water and in the human body, depending on environmental conditions.
Measuring just one form may not capture all of the chromium that is present. In order to ensure that the greatest potential risk is addressed, EPA's regulation assumes that a measurement of total chromium is 100 percent chromium-6, the more toxic form.

How often does the EPA update the Total Chromium Drinking Water Standard?
The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed total chromium as part of the second six-year review that was announced in March 2010 . The Agency noted in March 2010 that it had initiated a reassessment of the health risks associated with chromium exposure and that the Agency did not believe it was appropriate to revise the national primary drinking water regulation while that effort was in process.

In 2008, EPA began a rigorous and comprehensive review of chromium-6 health effects based on new science. When this human health assessment is finalized EPA will carefully review the conclusions and consider all relevant information to determine if the current chromium standard should be revised.

Chromium Explained

Chromium Description
Chromium is a chemical element which has the symbol **Cr** and atomic number 24. It is the first element in Group 6. It is a steely-gray, lustrous, hard metal that takes a high polish and has a high melting point. It is also odorless, tasteless, and malleable. The name of the element is derived from the Greek word "chrōma" (χρώμα), meaning color, because many of its compounds are intensely colored.

Chromium oxide was used by the Chinese in the Qin dynasty over 2,000 years ago to coat metal weapons found with the Terracotta Army. Chromium was discovered as an element after it came to the attention of the western world in the red crystalline mineral crocoite (lead(II) chromate), discovered in 1761 and initially used as a pigment. Louis Nicolas Vauquelin first isolated chromium metal from this mineral in 1797. Since Vauquelin's first production of metallic chromium, small amounts of native (free) chromium metal have been discovered in rare minerals, but these are not used commercially. Instead, nearly all chromium is commercially extracted from the single commercially viable ore chromite, which is iron chromium oxide ($FeCr_2O_4$). Chromite is also now the chief source of chromium for chromium pigments.

Chromium metal and ferrochromium alloy are commercially produced from chromite by silicothermic or aluminothermic reactions, or by roasting and leaching processes.

Chromium metal has proven of high value due to its high corrosion resistance and hardness. A major development was the discovery that steel could be made highly resistant to corrosion and discoloration by adding metallic chromium to form stainless steel. This application, along with chrome plating (electroplating with chromium) currently comprise 85% of the commercial use for the element, with applications for chromium compounds forming the remainder.

Trivalent chromium (Cr(III)) ion is possibly required in trace amounts for sugar and lipid metabolism, although the issue remains in debate. In larger amounts and in different forms, chromium can be toxic and carcinogenic. The most prominent example of toxic chromium is hexavalent chromium (Cr(VI)). Abandoned chromium production sites often require environmental cleanup.

Characteristics

Physical

Chromium is remarkable for its magnetic properties: it is the only elemental solid which shows antiferromagnetic ordering at room temperature (and below). Above 38 °C, it transforms into a paramagnetic state.

Passivation

Chromium metal left standing in air is passivated by oxygen, forming a thin protective oxide surface layer. This layer is a spinel structure only a few atoms thick. It is very dense, and prevents the diffusion of oxygen into the underlying material. This barrier is in contrast to iron or plain carbon steels, where the oxygen migrates into the underlying material and causes rusting.

The passivation can be enhanced by short contact with oxidizing acids like nitric acid. Passivated chromium is stable against acids. The opposite effect can be achieved by treatment with a strong reducing agent that destroys the protective oxide layer on the metal. Chromium metal treated in this way readily dissolves in weak acids.

Chromium, unlike metals such as iron and nickel, does not suffer from hydrogen embrittlement. However, it does suffer from nitrogen embrittlement, reacting with nitrogen from air and forming brittle nitrides at the high temperatures necessary to work the metal parts.

Occurrence

Chromium is the 24th most abundant element in Earth's crust with an average concentration of 100 ppm. Chromium compounds are found in the environment, due to erosion of chromium-containing rocks and can be distributed by volcanic eruptions. The concentrations range in soil is between 1 and 3000 mg/kg, in sea water 5 to 800 µg/liter, and in rivers and lakes 26 µg/liter to 5.2 mg/liter. Chromium is mined as chromite ($FeCr_2O_4$) ore. About two-fifths of the chromite ores and concentrates in the world are produced in South Africa, while Kazakhstan, India, Russia, and Turkey are also substantial producers. Untapped chromite deposits are plentiful, but geographically concentrated in Kazakhstan and southern Africa.

Although rare, deposits of native chromium exist. The Udachnaya Pipe in Russia produces samples of the native metal. This mine is a kimberlite pipe, rich in diamonds, and the reducing environment helped produce both elemental chromium and diamond.

The relation between Cr(III) and Cr(VI) strongly depends on pH and oxidative properties of the location, but in most cases, the Cr(III) is the dominating species, although in some areas the ground water can contain up to 39 µg/liter of total chromium of which 30 µg/liter is present as Cr(VI).

Isotopes

Naturally occurring chromium is composed of three stable isotopes; ^{52}Cr, ^{53}Cr and ^{54}Cr with ^{52}Cr being the most abundant (83.789% natural abundance). 19 radioisotopes have been characterized with the most stable being ^{50}Cr with a half-life of (more than) 1.8×10^{17} years, and ^{51}Cr with a half-life of 27.7 days. All of the remaining radioactive isotopes have half-lives that are less than 24 hours and the majority of these have half-lives that are less than 1 minute. This element also has 2 meta states.

^{53}Cr is the radiogenic decay product of ^{53}Mn. Chromium isotopic contents are typically combined with manganese isotopic contents and have found application in isotope geology.

Mn-Cr isotope ratios reinforce the evidence from ^{26}Al and ^{107}Pd for the early history of the solar system. Variations in $^{53}Cr/^{52}Cr$ and Mn/Cr ratios from several meteorites indicate an initial $^{53}Mn/^{55}Mn$ ratio that suggests Mn-Cr isotopic composition must result from in-situ decay of ^{53}Mn in differentiated planetary bodies. Hence ^{53}Cr provides additional evidence for nucleosynthetic processes immediately before coalescence of the solar system.

What are EPA's Drinking Water Regulations for Chromium (total)?
EPA has a drinking water standard of 0.1 milligrams per liter (mg/L) or 100 parts per billion (ppb) for total chromium, which includes all forms of chromium including chromium-6. Water systems are required to test for total chromium. The current standard is based on potential adverse dermatological effects over many years, such as allergic dermatitis (skin reactions). EPA regularly re-evaluates drinking water standards and, based on new science on chromium-6, began a rigorous and comprehensive review of its health effects in 2008.

Is Total Chromium or Chromium-6 in Drinking Water a Health Concern?
The current federal drinking water standard for total chromium is 0.1 mg/L or 100 ppb. Chromium-6 and chromium-3 are covered under the total chromium drinking water standard because these forms of chromium can convert back and forth in water and in the human body, depending on environmental conditions. Measuring just one form may not capture all of the chromium that is present. In order to ensure that the greatest potential risk is addressed, EPA's regulation assumes that a measurement of total chromium is 100 percent chromium-6, the more toxic form. If tap water from a public water system exceeds this federal standard, consumers will be notified.

The MCL for total chromium was established in 1991 and is based on the best available science at the time which indicated that continued exposure to chromium-6 could result in allergic dermatitis (skin reactions). EPA is now reviewing data from a 2008 long-term animal study by the Department of Health and Human Service's National Toxicology Program, which suggested that chromium-6 may be a human carcinogen if ingested. When the review is completed, EPA will consider this and other information to determine whether the drinking water standard for total chromium needs to be revised.

If EPA decides to revise the Regulation that includes Chromium-6 in Drinking Water, what is the process the agency will follow?
Prior to EPA making any decisions about revising the chromium drinking water regulation, EPA must issue its final human health assessment for chromium-6. EPA will carefully review the final assessment and consider all other relevant information to determine if a new drinking water regulation for chromium-6 or a revision to the current total chromium standard is warranted.

How does Chromium get into my Drinking Water?
The most common forms of chromium that occur in natural waters in the environment are chromium-3 and chromium-6. Chromium-3 and chromium-6 occur naturally in the environment, and are present in water from the erosion of chromium deposits found in rocks and soils. Chromium-6 is also produced by industrial processes and manufacturing activities including discharges from steel and pulp mills among others. At many locations, chromium compounds have been released to the environment via leakage, poor storage, or improper disposal practices. Chromium compounds are very persistent in water as sediments.

A federal law called the Emergency Planning and Community Right to Know Act requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the community right-to-know hotline at (800) 424-9346.

How will I know if there is Chromium in my Drinking Water?
Your public water system's annual water quality report will provide information if total chromium is detected in the drinking water it delivers. The water quality report is sent to customers by July 1 of each year and may also be found on your public water system's website. Some water utilities have conducted monitoring specifically for chromium-6. Contact your public water system to find out if this information is available.

Consumers served by private wells can have their water tested by a state certified laboratory. You can find information on how to sample for chromium-6 and where to send samples by contacting your state water laboratory certification officer.

What should I do if I am concerned about the Presence of Chromium-6 in my Drinking Water while EPA is reviewing the Science and the Regulation?
If you remain concerned after finding out more about the chromium-6 levels in your drinking water, you may consider taking additional steps.

Can home treatment devices remove chromium-6?
Some home treatment devices are certified by organizations to remove chromium-6. Two certification organizations are: NSF International and the Water Quality Association. These certification programs are based on current drinking water standards and home treatment devices are only certified to remove chromium-6 to either 50 or 100 parts per billion. Contact the device's manufacturer for specific information about how effective the product is, given your water and treatment goal. Your public water system's water quality report and your water system's staff can help you understand the characteristics of your water.

If you choose to use a home treatment device, it is very important to follow the manufacturer's operation and maintenance instructions carefully in order to make sure the device works properly.

Consumers should be aware that the current EPA drinking water standard for chromium requires that public water systems provide drinking water that does not exceed a total chromium concentration of 100 ppb.

Can I avoid exposure to chromium-6 if I only Drink Bottled Water? (Is there Chromium-6 in bottled water?)
The Food and Drug Administration (FDA) establishes standards for bottled water and has adopted EPA's total chromium standard of 100 ppb. Contact bottled water manufacturers for specific information about levels of chromium-6 in their products.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to provide safe drinking water. Your water bill or telephone book's government listings are a good starting point for local information. Check your water system provider's website or contact your water provider. EPA requires all community water systems to prepare and deliver an annual consumer confidence report, sometimes called a water quality report, to their customers by July 1 of each year.

Copper - Inorganic Contaminant 1.3 mg/L MCLG

What are Copper's Health Effects?
Some people who drink water containing copper in excess of the action level may, with short term exposure, experience gastrointestinal distress, and with long-term exposure may experience liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level.



This health effects language is not intended to catalog all possible health effects for copper. Rather, it is intended to inform consumers of some of the possible health effects associated with copper in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Copper?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for copper is 1.3 mg/L or 1.3 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems.

For most contaminants, EPA sets an enforceable regulation called a maximum contaminant level (MCL) based on the MCLG. MCLs are set as close to the MCLGs as feasible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. However, because copper contamination of drinking water often results from corrosion of the plumbing materials belonging to water system customers, EPA established a treatment technique rather than an MCL for copper.

A treatment technique is an enforceable procedure or level of technological performance which water systems must follow to ensure control of a contaminant. The treatment technique regulation for copper (referred to as the Lead and Copper rule) requires water systems to control the corrosivity of the water. The regulation also requires systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead. If more than 10 percent of tap water samples exceed the copper action level of 1.3 milligrams per Liter (mg/L), water systems must take additional steps to reduce corrosiveness.

EPA promulgated the Lead and Copper Rule in 1991, and revised the regulation in 2000 and in 2007. States may set a more stringent regulation for copper in drinking water than EPA.

How does Copper get into my Drinking Water?
The major sources of copper in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. Copper enters the water ("leaches") through contact with the plumbing. Copper leaches into water through corrosion – a dissolving or wearing away of metal caused by a chemical reaction between water and your plumbing. Copper can leach into water primarily from pipes, but fixtures and faucets (brass), and fittings can also be a source. The amount of copper in your water also depends on the types and amounts of minerals in the water, how long the water stays in the pipes, the amount of wear in the pipes, the water's acidity and its temperature.

How will I know if Copper is in my Drinking Water?
If you are concerned about copper in your drinking water, have the water tested for copper by a certified laboratory. (Lists are available from your state or local drinking water authority.) Since you cannot see, taste, or smell copper dissolved in water, testing is the only sure way of telling whether there are harmful quantities of lead in your drinking water. You should be particularly suspicious if your home has copper pipes. If you see signs of corrosion (frequent leaks, rust-colored water, stained dishes or laundry, or if your non-plastic plumbing is less than five years old. Your water supplier may have useful information, including whether the service connector used in your home or area is made of copper. Testing is especially important in high-rise buildings where flushing might not work.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Copper be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing copper to below the action level of 1.3 mg/L or 1.3 ppm: corrosion control.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Copper Explained

Copper is a chemical element with the symbol **Cu** (from Latin: *cuprum*) and atomic number 29. It is a ductile metal with very high thermal and electrical conductivity. Pure copper is soft and malleable; a freshly exposed surface has a reddish-orange color. It is used as a conductor of heat and electricity, a building material, and a constituent of various metal alloys.

The metal and its alloys have been used for thousands of years. In the Roman era, copper was principally mined on Cyprus, hence the origin of the name of the metal as *cyprium* (metal of Cyprus), later shortened to *cuprum*.

Its compounds are commonly encountered as copper(II) salts, which often impart blue or green colors to minerals such as turquoise and have been widely used historically as pigments.

Architectural structures built with copper corrode to give green verdigris (or patina). Decorative art prominently features copper, both by itself and as part of pigments.

Copper(II) ions are water-soluble, where they function at low concentration as bacteriostatic substances, fungicides, and wood preservatives. In sufficient amounts, they are poisonous to higher organisms; at lower concentrations it is an essential trace nutrient to all higher plant and animal life. The main areas where copper is found in animals are liver, muscle and bone.

Characteristics

Physical

Copper, silver and gold are in group 11 of the periodic table, and they share certain attributes: they have one s-orbital electron on top of a filled d-electron shell and are characterized by high ductility and electrical conductivity. The filled d-shells in these elements do not contribute much to the interatomic interactions, which are dominated by the s-electrons through metallic bonds. Contrary to metals with incomplete d-shells, metallic bonds in copper are lacking a covalent character and are relatively weak. This explains the low hardness and high ductility of single crystals of copper. At the macroscopic scale, introduction of extended defects to the crystal lattice, such as grain boundaries, hinders flow of the material under applied stress thereby increasing its hardness. For this reason, copper is usually supplied in a fine-grained polycrystalline form, which has greater strength than monocrystalline forms.

The low hardness of copper partly explains its high electrical (59.6×10^6 S/m) and thus also high thermal conductivity, which are the second highest among pure metals at room temperature. This is because the resistivity to electron transport in metals at room temperature mostly originates from scattering of electrons on thermal vibrations of the lattice, which are relatively weak for a soft metal. The maximum permissible current density of copper in open air is approximately 3.1×10^6 A/m^2 of cross-sectional area, above which it begins to heat excessively. As with other metals, if copper is placed against another metal, galvanic corrosion will occur.

Together with caesium and gold (both yellow), copper is one of only three elemental metals with a natural color other than gray or silver. Pure copper is orange-red and acquires a reddish tarnish when exposed to air. The characteristic color of copper results from the electronic transitions between the filled 3d and half-empty 4s atomic shells – the energy difference between these shells is such that it corresponds to orange light. The same mechanism accounts for the yellow color of gold and caesium.

Chemical

Copper forms a rich variety of compounds with oxidation states +1 and +2, which are often called *cuprous* and *cupric*, respectively. It does not react with water, but it slowly reacts with atmospheric oxygen forming a layer of brown-black copper oxide. In contrast to the oxidation of iron by wet air, this oxide layer stops the further, bulk corrosion. A green layer of verdigris (copper carbonate) can often be seen on old copper constructions, such as the Statue of Liberty, the largest copper statue in the world built using repoussé and chasing. Hydrogen sulfides and sulfides react with copper to form various copper sulfides on the surface. In the latter case, the copper corrodes, as is seen when copper is exposed to air containing sulfur compounds.

Oxygen-containing ammonia solutions give water-soluble complexes with copper, as do oxygen and hydrochloric acid to form copper chlorides and acidified hydrogen peroxide to form copper(II) salts. Copper(II) chloride and copper comproportionate to form copper(I) chloride.

Isotopes

There are 29 isotopes of copper. ^{63}Cu and ^{65}Cu are stable, with ^{63}Cu comprising approximately 69% of naturally occurring copper; they both have a spin of 3/2. The other isotopes are radioactive, with the most stable being ^{67}Cu with a half-life of 61.83 hours. Seven metastable isotopes have been characterized, with ^{68m}Cu the longest-lived with a half-life of 3.8 minutes. Isotopes with a mass number above 64 decay by β^-, whereas those with a mass number below 64 decay by β^+. ^{64}Cu, which has a half-life of 12.7 hours, decays both ways.

^{62}Cu and ^{64}Cu have significant applications. ^{64}Cu is a radiocontrast for X-ray imaging, and complexed with a chelate can be used for treating cancer. ^{62}Cu is used in ^{62}Cu-PTSM that is a radioactive tracer for positron emission tomography.

Occurrence

Copper can be found as either native copper or as part of minerals. Native copper is a polycrystal, with the largest described single crystal measuring 4.4×3.2×3.2 cm. The largest mass of elemental copper weighed 420 tons and was found in 1857 on the Keweenaw Peninsula in Michigan, US. There are many examples of copper-containing minerals: chalcopyrite and chalcocite are copper sulfides, azurite and malachite are copper carbonates and cuprite is a copper oxide. Copper is present in the Earth's crust at a concentration of about 50 parts per million (ppm), and is also synthesized in massive stars.

Compounds

Binary Compounds

As for other elements, the simplest compounds of copper are binary compounds, i.e. those containing only two elements. The principal ones are the oxides, sulfides and halides. Both cuprous and cupric oxides are known. Among the numerous copper sulfides, important examples include copper(I) sulfide and copper(II) sulfide.

The cuprous halides with chlorine, bromine, and iodine are known, as are the cupric halides with fluorine, chlorine, and bromine. Attempts to prepare copper(II) iodide give cuprous iodide and iodine.

$$2\ Cu^{2+} + 4\ I^- \rightarrow 2\ CuI + I_2$$

Coordination Chemistry

Copper, like all metals, forms coordination complexes with ligands. In aqueous solution, copper(II) exists as $[Cu(H_2O)_6]^{2+}$. This complex exhibits the fastest water exchange rate (speed of water ligands attaching and detaching) for any transition metal aquo complex. Adding aqueous sodium hydroxide causes the precipitation of light blue solid copper(II) hydroxide. A simplified equation is:

$$Cu^{2+} + 2\ OH^- \rightarrow Cu(OH)_2$$

Aqueous ammonia results in the same precipitate. Upon adding excess ammonia, the precipitate dissolves, forming tetraamminecopper(II):

$$Cu(H_2O)_4(OH)_2 + 4\ NH_3 \rightarrow [Cu(H_2O)_2(NH_3)_4]^{2+} + 2\ H_2O + 2\ OH^-$$

Many other oxyanions form complexes; these include copper(II) acetate, copper(II) nitrate, and copper(II) carbonate. Copper(II) sulfate forms a blue crystalline pentahydrate, which is the most familiar copper compound in the laboratory. It is used in a fungicide called the Bordeaux mixture.

Polyols, compounds containing more than one alcohol functional group, generally interact with cupric salts. For example, copper salts are used to test for reducing sugars. Specifically, using Benedict's reagent and Fehling's solution the presence of the sugar is signaled by a color change from blue Cu(II) to reddish copper(I) oxide. Schweizer's reagent and related complexes with ethylenediamine and other amines dissolve cellulose. Amino acids form very stable chelate complexes with copper(II). Many wet-chemical tests for copper ions exist, one involving potassium ferrocyanide, which gives a brown precipitate with copper(II) salts.

Organocopper Chemistry

Compounds that contain a carbon-copper bond are known as organocopper compounds. They are very reactive towards oxygen to form copper(I) oxide and have many uses in chemistry. They are synthesized by treating copper(I) compounds with Grignard reagents, terminal alkynes or organolithium reagents; in particular, the last reaction described produces a Gilman reagent. These can undergo substitution with alkyl halides to form coupling products; as such, they are important in the field of organic synthesis.

Copper(I) acetylide is highly shock-sensitive but is an intermediate in reactions such as the Cadiot-Chodkiewicz coupling and the Sonogashira coupling. Conjugate addition to enones and carbocupration of alkynes can also be achieved with organocopper compounds. Copper(I) forms a variety of weak complexes with alkenes and carbon monoxide, especially in the presence of amine ligands.

Copper (III) and Copper (IV)

Copper(III) is most characteristically found in oxides. A simple example is potassium cuprate, $KCuO_2$, a blue-black solid. The best studied copper(III) compounds are the cuprate superconductors. Yttrium barium copper oxide ($YBa_2Cu_3O_7$) consists of both Cu(II) and Cu(III) centers. Like oxide, fluoride is a highly basic anion and is known to stabilize metal ions in high oxidation states. Indeed, both copper(III) and even copper(IV) fluorides are known, K_3CuF_6 and Cs_2CuF_6, respectively.

Some copper proteins form oxo complexes, which also feature copper(III). With di- and tripeptides, purple-colored copper(III) complexes are stabilized by the deprotonated amide ligands.

Complexes of copper(III) are also observed as intermediates in reactions of organocopper compounds.

Biological Role

Rich sources of copper include oysters, beef and lamb liver, Brazil nuts, blackstrap molasses, cocoa, and black pepper. Good sources include lobster, nuts and sunflower seeds, green olives, avocados, and wheat bran.

Copper proteins have diverse roles in biological electron transport and oxygen transportation, processes that exploit the easy interconversion of Cu(I) and Cu(II). The biological role for copper

commenced with the appearance of oxygen in earth's atmosphere. The protein hemocyanin is the oxygen carrier in most mollusks and some arthropods such as the horseshoe crab (*Limulus polyphemus*). Because hemocyanin is blue, these organisms have blue blood, not the red blood found in organisms that rely on hemoglobin for this purpose. Structurally related to hemocyanin are the laccases and tyrosinases. Instead of reversibly binding oxygen, these proteins hydroxylate substrates, illustrated by their role in the formation of lacquers.
Copper is also a component of other proteins associated with the processing of oxygen. In cytochrome c oxidase, which is required for aerobic respiration, copper and iron cooperate in the reduction of oxygen. Copper is also found in many superoxide dismutases, proteins that catalyze the decomposition of superoxides, by converting it (by disproportionation) to oxygen and hydrogen peroxide:

$$2\ HO_2 \rightarrow H_2O_2 + O_2$$

Several copper proteins, such as the "blue copper proteins", do not interact directly with substrates, hence they are not enzymes. These proteins relay electrons by the process called electron transfer.

Photosynthesis functions by an elaborate electron transport chain within the thylakoid membrane. A central "link" in this chain is plastocyanin, a blue copper protein.

Dietary Needs
Copper is an essential trace element in plants and animals, but not some microorganisms. The human body contains copper at a level of about 1.4 to 2.1 mg per kg of body mass. Stated differently, the RDA for copper in normal healthy adults is quoted as 0.97 mg/day and as 3.0 mg/day. Copper is absorbed in the gut, then transported to the liver bound to albumin. After processing in the liver, copper is distributed to other tissues in a second phase.

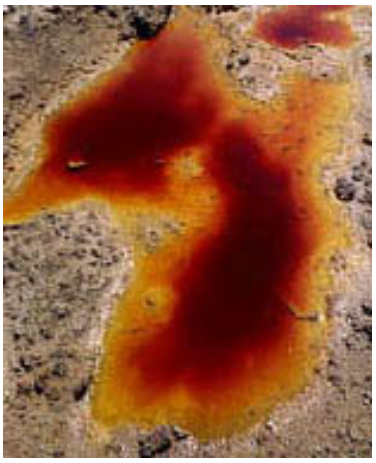
Copper transport here involves the protein ceruloplasmin, which carries the majority of copper in blood. Ceruloplasmin also carries copper that is excreted in milk, and is particularly well-absorbed as a copper source. Copper in the body normally undergoes enterohepatic circulation (about 5 mg a day, vs. about 1 mg per day absorbed in the diet and excreted from the body), and the body is able to excrete some excess copper, if needed, via bile, which carries some copper out of the liver that is not then reabsorbed by the intestine.

Copper-based Disorders
Because of its role in facilitating iron uptake, copper deficiency can produce anemia-like symptoms, neutropenia, bone abnormalities, hypopigmentation, impaired growth, increased incidence of infections, osteoporosis, hyperthyroidism, and abnormalities in glucose and cholesterol metabolism. Conversely, Wilson's disease causes an accumulation of copper in body tissues.

Severe deficiency can be found by testing for low plasma or serum copper levels, low ceruloplasmin, and low red blood cell superoxide dismutase levels; these are not sensitive to marginal copper status. The "cytochrome c oxidase activity of leucocytes and platelets" has been stated as another factor in deficiency, but the results have not been confirmed by replication.

Cyanide - Inorganic Contaminant 0.2 mg/L MCL

Cyanide is a carbon-nitrogen chemical unit which combines with many organic and inorganic compounds.



Uses for Cyanide.
The most commonly used form, hydrogen cyanide, is mainly used to make compounds and other synthetic fibers and resins.

What are Cyanide's Health Effects?
Some people who drink water containing cyanide well in excess of the maximum contaminant level (MCL) for many years could experience nerve damage or problems with their thyroid.
This health effects language is not intended to catalog all possible health effects for cyanide. Rather, it is intended to inform consumers of some of the possible health effects associated with cyanide in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Cyanide?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for cyanide is 0.2 mg/L or 200 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for cyanide, called a maximum contaminant level (MCL), at 0.2 mg/L or 200 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for cyanide, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed cyanide as part of the Six Year Review and determined that the 0.2 mg/L or 200 ppb MCLG and 0.2 mg/L or 200 ppb MCL for cyanide are still protective of human health.

States may set more stringent drinking water MCLGs and MCLs for cyanide than EPA.

How does Cyanide get into my Drinking Water?
The major source of cyanide in drinking water is discharge from industrial chemical factories.
A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Cyanide is in my Drinking Water?
When routine monitoring indicates that cyanide levels are above the MCL, your water supplier must take steps to reduce the amount of cyanide so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Cyanide be Removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing cyanide to below 0.2 mg/L or 200 ppb: granular activated carbon in combination with packed tower aeration.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Cyanide Explained

A **cyanide** is a chemical compound that contains the **cyano group**, -C≡N, which consists of a carbon atom triple-bonded to a nitrogen atom. Cyanides most commonly refer to salts of the anion CN^-, which is isoelectronic with carbon monoxide and with molecular nitrogen. Most cyanides are highly toxic.

Nomenclature and Etymology
In IUPAC nomenclature, organic compounds that have a –C≡N functional group are called nitriles. Thus, nitriles are organic compounds. An example of a nitrile is CH_3CN, acetonitrile, also known as methyl cyanide. Nitriles usually do not release cyanide ions. A functional group with a hydroxyl and cyanide bonded to the same carbon is called cyanohydrin. Unlike nitriles, cyanohydridins do release hydrogen cyanide. In inorganic chemistry, salts containing the $C{\equiv}N^-$ ion are referred to as **cyanides**.

Occurrence and Reactions
Cyanides are produced by certain bacteria, fungi, and algae and are found in a number of plants. Cyanides are found, although in small amounts, in certain seeds and fruit stones, e.g., those of apple, mango, peach, and bitter almonds. In plants, cyanides are usually bound to sugar molecules in the form of cyanogenic glycosides and defend the plant against herbivores. Cassava roots (also called manioc), an important potato-like food grown in tropical countries (and the base from which tapioca is made), also contain cyanogenic glycosides.

Fluoride - Inorganic Contaminant 4.0 mg/L MCL

Fluoride compounds are salts that form when the element, fluorine, combines with minerals in soil or rocks.



Uses for Fluoride.
Many communities add fluoride to their drinking water to promote dental health.

What are Fluoride's Health Effects?
Exposure to excessive consumption of fluoride over a lifetime may lead to increased likelihood of bone fractures in adults, and may result in effects on bone leading to pain and tenderness. Children aged 8 years and younger exposed to excessive amounts of fluoride have an increased chance of developing pits in the tooth enamel, along with a range of cosmetic effects to teeth.

This health effects language is not intended to catalog all possible health effects for fluoride. Rather, it is intended to inform consumers of some of the possible health effects associated with fluoride in drinking water.

What are EPA's Drinking Water Regulations for Fluoride?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for fluoride is 4.0 mg/L or 4.0 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for fluoride, called a maximum contaminant level (MCL), at 4.0 mg/L or 4.0 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

EPA has also set a secondary standard (SMCL) for fluoride at 2.0 mg/L or 2.0 ppm. Secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

Tooth discoloration and/or pitting is caused by excess fluoride exposures during the formative period prior to eruption of the teeth in children. The secondary standard of 2.0 mg/L is intended as a guideline for an upper bound level in areas which have high levels of naturally occurring fluoride. The level of the SMCL was set based upon a balancing of the beneficial effects of protection from tooth decay and the undesirable effects of excessive exposures leading to discoloration.

Fluoride is voluntarily added to some drinking water systems as a public health measure for reducing the incidence of cavities among the treated population.

The decision to fluoridate a water supply is made by the State or local municipality, and is not mandated by EPA or any other Federal entity. The Centers for Disease Control and Prevention (CDC) provides recommendations about the optimal levels of fluoride in drinking water in order to prevent tooth decay. Information about CDC's recommendations can be found at: http://www.cdc.gov/fluoridation/

States may set more stringent drinking water MCLGs and MCLs for fluoride than EPA.

The drinking water standards are currently under review. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. In 2003 and as part of the first Six Year Review, EPA reviewed the drinking water standard for fluoride and found that new health and exposure data were available on orally ingested fluoride. EPA requested that the National Research Council (NRC) of the National Academies of Science (NAS) conduct a review of this data and in 2006, the NRC published their evaluation in a report entitled, Fluoride in Drinking Water: A Scientific Review of EPA's Standards. The NRC recommended that EPA update its fluoride risk assessment to include new data on health risks and better estimates of total exposure.

In March 2010 and as part of the second Six Year Review, the Agency indicated that the Office of Water was in the process of developing its health and exposure assessments to address the NRC's recommendations. The Agency finalized the risk and exposure assessments for fluoride in January 2011 and announced its intent to review the drinking water regulations for fluoride to determine whether revisions are appropriate.

How does Fluoride get into my Drinking Water?
Some fluoride compounds, such as sodium fluoride and fluorosilicates, dissolve easily into ground water as it moves through gaps and pore spaces between rocks. Most water supplies contain some naturally occurring fluoride. Fluoride also enters drinking water in discharge from fertilizer or aluminum factories. Also, many communities add fluoride to their drinking water to promote dental health.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Fluoride is in my Drinking Water?
When routine monitoring indicates that fluoride levels are above the MCL, your water supplier must take steps to reduce the amount of fluoride so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household or private well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Fluoride be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing fluoride to below 4.0 mg/L or 4.0 ppm: distillation or reverse osmosis.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Fluoride Explained

Fluoride is the anion F^-, the reduced form of fluorine when as an ion and when bonded to another element. Inorganic fluorine containing compounds are called fluorides. Fluoride, like other halides, is a monovalent ion (−1 charge). Its compounds often have properties that are distinct relative to other halides. Structurally, and to some extent chemically, the fluoride ion resembles the hydroxide ion.

Occurrence
Solutions of inorganic fluorides in water contain F^- and bifluoride HF−2. Few inorganic fluorides are soluble in water without undergoing significant hydrolysis. In terms of its reactivity, fluoride differs significantly from chloride and other halides, and is more strongly solvated due to its smaller radius/charge ratio. Its closest chemical relative is hydroxide. When relatively unsolvated, fluoride anions are called "naked". Naked fluoride is a very strong lewis base. The presence of fluoride and its compounds can be detected by F NMR spectroscopy.

Natural Occurrence
Many fluoride minerals are known, but of paramount commercial importance are fluorite and fluorapatite.

Fluoride is usually found naturally in low concentration in drinking water and foods. The concentration in seawater averages 1.3 parts per million (ppm). Fresh water supplies generally contain between 0.01–0.3 ppm, whereas the ocean contains between 1.2 and 1.5 ppm. In some locations, the fresh water contains dangerously high levels of fluoride, leading to serious health problems.

Applications
Fluorides are pervasive in modern technology. Hydrofluoric acid is the fluoride synthesized on the largest scale. It is produced by treating fluoride minerals with sulfuric acid. Hydrofluoric acid and its anhydrous form hydrogen fluoride are used in the production of fluorocarbons and aluminum fluorides. Hydrofluoric acid has a variety of specialized applications, including its ability to dissolve glass.

Inorganic Chemicals
Fluoride salts are used in the manufacture of many inorganic chemicals, many of which contain fluoride covalently bonded to the metal or nonmetal in question. Some examples of these are:

- Cryolite (Na_3AlF_6) is a pesticide that can leave fluoride on agricultural commodities. Cryolite was originally utilized in the preparation of aluminum.

- Sulfuryl fluoride (SO_2F_2) is used as a pesticide and fumigant on agricultural crops. In 2010, the United States Environmental Protection Agency proposed to withdraw the use of sulfuryl fluoride on food. Sulfuryl fluoride releases fluoride when metabolized.

- Sulfur hexafluoride is an inert, nontoxic insulator gas that is used in electrical transformers and as a tracer gas in indoor air quality investigations.

- Uranium hexafluoride, although not ionic, is prepared from fluoride reagents. It is utilized in the separation of isotopes of uranium between the fissile isotope U-235 and the non-fissile isotope U-238 in preparation of nuclear reactor fuel and atomic bombs. This is due to the volatility of fluorides of uranium.

Organic Chemicals
Fluoride reagents are significant in synthetic organic chemistry. Organofluorine chemistry has produced many useful compounds over the last 50 years. Included in this area are polytetrafluorethylene (Teflon), polychlorotrifluoroethylene (moisture barriers), efavirenz (pharmaceutical used for treatment of HIV), fluoxetine (an antidepressant), 5-fluorouracil (an anticancer drug), hydrochlorofluorocarbons and hydrofluorcarbons (refrigerants, blowing agents and propellants).

Due to the affinity of silicon for fluoride, and the ability of silicon to expand its coordination number, silyl ether protecting groups can be easily removed by the fluoride sources such as sodium fluoride and tetra-n-butylammonium fluoride (TBAF). This is quite useful for organic synthesis and the production of fine chemicals. The Si-F linkage is one of the strongest single bonds. In contrast, other silyl halides are easily hydrolyzed.

Cavity Prevention
Fluoride-containing compounds are used in topical and systemic fluoride therapy for preventing tooth decay. They are used for water fluoridation and in many products associated with oral hygiene. Originally, sodium fluoride was used to fluoridate water; hexafluorosilicic acid (H_2SiF_6) and its salt sodium hexafluorosilicate (Na_2SiF_6) are more commonly used additives, especially in the United States. The fluoridation of water is known to prevent tooth decay and is considered by the U.S. Centers for Disease Control and Prevention as "one of 10 great public health achievements of the 20th century". In some countries where large, centralized water systems are uncommon, fluoride is delivered to the populace by fluoridating table salt. Fluoridation of water has its critics (see Water fluoridation controversy).

Lead- Inorganic Contaminant 0.015 Action Level

The United States Environmental Protection Agency (EPA) regulates lead in drinking water to protect public health. Lead may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.

What is Lead?
Lead is a toxic metal that was used for many years in products found in and around homes. Even at low levels, lead may cause a range of health effects including behavioral problems and learning disabilities. Children six years old and under are most at risk because this is when the brain is developing. The primary source of lead exposure for most children is lead-based paint in older homes. Lead in drinking water can add to that exposure.



Uses for Lead.
Lead is sometimes used in household plumbing materials or in water service lines used to bring water from the main to the home. A prohibition on lead in plumbing materials has been in effect since 1986. The lead ban, which was included in the 1986 Amendments of the Safe Drinking Water Act, states that only “lead free” pipe, solder, or flux may be used in the installation or repair of (1) public water systems, or (2) any plumbing in a residential or non-residential facility providing water for human consumption, which is connected to a public water system. But even “lead free” plumbing may contain traces of lead. The term “lead free” means that solders and flux may not contain more than 0.2 percent lead, and that pipes and pipe fittings may not contain more than 8.0 percent lead. Faucets and other end use devices must be tested and certified against the ANSI – NSF Standard 61 to be considered lead free.

What are Lead’s Health Effects?
Infants and children who drink water containing lead in excess of the action level could experience delays in their physical or mental development. Children could show slight deficits in attention span and learning abilities. Adults who drink this water over many years could develop kidney problems or high blood pressure.

This health effects language is not intended to catalog all possible health effects for lead. Rather, it is intended to inform consumers of the most significant and probable health effects, associated with lead in drinking water.

What are EPA’s Drinking Water Regulations for Lead?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur with an adequate margin of safety. These non-enforceable health goals, based solely on possible health risks are called maximum contaminant level goals (MCLG) The MCLG for lead is zero.

EPA has set this level based on the best available science which shows there is no safe level of exposure to lead.

For most contaminants, EPA sets an enforceable regulation called a maximum contaminant level (MCL) based on the MCLG. MCLs are set as close to the MCLGs as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. However, because lead contamination of drinking water often results from corrosion of the plumbing materials belonging to water system customers, EPA established a treatment technique rather than an MCL for lead.

A treatment technique is an enforceable procedure or level of technological performance which water systems must follow to ensure control of a contaminant. The treatment technique regulation for lead (referred to as the Lead and Copper rule) requires water systems to control the corrosivity of the water. The regulation also requires systems to collect tap samples from sites served by the system that are more likely to have plumbing materials containing lead.

If more than 10% of tap water samples exceed the lead action level of 15 parts per billion, then water systems are required to take additional actions including:

- Taking further steps optimize their corrosion control treatment (for water systems serving 50,000 people that have not fully optimized their corrosion control) .
- Educating the public about lead in drinking water and actions consumers can take to reduce their exposure to lead.
- Replacing the portions of lead service lines (lines that connect distribution mains to customers) under the water system's control.

EPA promulgated the Lead and Copper Rule in 1991 and revised the regulation in 2000 and 2007. States may set more stringent drinking water regulations than EPA.

How does Lead get into my Drinking Water?
The major sources of lead in drinking water are corrosion of household plumbing systems; and erosion of natural deposits. Lead enters the water ("leaches") through contact with the plumbing. Lead leaches into water through corrosion – a dissolving or wearing away of metal caused by a chemical reaction between water and your plumbing. Lead can leach into water from pipes, solder, fixtures and faucets (brass), and fittings. The amount of lead in your water also depends on the types and amounts of minerals in the water, how long the water stays in the pipes, the amount of wear in the pipes, the water's acidity and its temperature.

Although the main sources of exposure to lead are ingesting paint chips and inhaling dust, EPA estimates that 10 to 20 percent of human exposure to lead may come from lead in drinking water. Infants who consume mostly mixed formula can receive 40 to 60 percent of their exposure to lead from drinking water.

How will I know if Lead is in my Drinking Water?
Have your water tested for lead. A list of certified laboratory of labs are available from your state or local drinking water authority. Testing costs between $20 and $100. Since you cannot see, taste, or smell lead dissolved in water, testing is the only sure way of telling whether there are harmful quantities of lead in your drinking water. You should be particularly suspicious if your home has lead pipes (lead is a dull gray metal that is soft enough to be easily scratched with a house key) or if you see signs of corrosion (frequent leaks, rust-colored water). Your water supplier may have useful information, including whether the service connector used in your home or area is made of lead. Testing is especially important in high-rise buildings where flushing might not work.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How can I Reduce Lead in Drinking Water at Home?
Flush your pipes before drinking, and only use cold water for consumption. The more time water has been sitting in your home's pipes, the more lead it may contain. Anytime the water in a particular faucet has not been used for six hours or longer, "flush" your cold-water pipes by running the water until it becomes as cold as it will get.

This could take as little as five to thirty seconds if there has been recent heavy water use such as showering or toilet flushing. Otherwise, it could take two minutes or longer. Your water utility will inform you if longer flushing times are needed to respond to local conditions.

Use only water from the cold-water tap for drinking, cooking, and especially for making baby formula. Hot water is likely to contain higher levels of lead. The two actions recommended above are very important to the health of your family. They will probably be effective in reducing lead levels because most of the lead in household water usually comes from the plumbing in your house, not from the local water supply.

Should I be concerned about Lead in Drinking water in my child's school or child care facility?
Children spend a significant part of their days at school or in a child care facility. The faucets that provide water used for consumption, including drinking, cooking lunch, and preparing juice and infant formula, should be tested.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect and upgrade the supply of safe drinking water. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Lead Explained

Lead is a chemical element in the carbon group with symbol **Pb** (from Latin: *plumbum*) and atomic number 82. Lead is a soft, malleable poor metal. It is also counted as one of the heavy metals. Metallic lead has a bluish-white color after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air. Lead has a shiny chrome-silver luster when it is melted into a liquid.

Lead is used in building construction, lead-acid batteries, bullets and shot, weights, as part of solders, pewters, fusible alloys, and as a radiation shield. Lead has the highest atomic number of all of the stable elements, although the next higher element, bismuth, has a half-life that is so long (much longer than the age of the universe) that it can be considered stable. Its four stable isotopes have 82 protons, a magic number in the nuclear shell model of atomic nuclei.

Mercury - Inorganic Contaminant 0.002 mg/L MCL

EPA regulates mercury in drinking water to protect public health. Mercury may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.



What is Mercury?
Mercury is a liquid metal found in natural deposits such as ores containing other elements.

Uses for Mercury.
Electrical products such as dry-cell batteries, fluorescent light bulbs, switches, and other control equipment account for 50 percent of mercury used.

What are Mercury's Health Effects?
Some people who drink water containing mercury well in excess of the maximum contaminant level (MCL) for many years could experience kidney damage.

This health effects language is not intended to catalog all possible health effects for mercury. Rather, it is intended to inform consumers of some of the possible health effects associated with mercury in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Mercury?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for mercury is 0.002 mg/L or 2 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for mercury, called a maximum contaminant level (MCL), at 0.002 mg/L or 2 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for mercury, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed mercury as part of the Six Year Review and determined that the 0.002 mg/L or 2 ppb MCLG and 0.002 mg/L or 2 ppb MCL for mercury are still protective of human health.

States may set more stringent drinking water MCLGs and MCLs for mercury than EPA.

How does Mercury get into my Drinking Water?
The major sources of mercury in drinking water are erosion of natural deposits; discharge from refineries and factories; runoff from landfills; and runoff from croplands.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Mercury is in my Drinking Water?
When routine monitoring indicates that mercury levels are above the MCL, your water supplier must take steps to reduce the amount of mercury so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.
If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Mercury be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing mercury to below 0.002 mg/L or 2 ppb: coagulation/filtration, granular activated carbon, lime softening, and reverse osmosis.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information. Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Mercury Explained

Mercury is a chemical element with the symbol **Hg** and atomic number 80. It is also known as **quicksilver** or **hydrargyrum** (< Greek "hydr-" *water* and "argyros" *silver*). A heavy, silvery d-block element, mercury is the only metal that is liquid at standard conditions for temperature and pressure; the only other element that is liquid under these conditions is bromine, though metals such as caesium, gallium, and rubidium melt just above room temperature. With a freezing point of −38.83 °C and boiling point of 356.73 °C, mercury has one of the narrowest ranges of its liquid state of any metal.

Mercury occurs in deposits throughout the world mostly as cinnabar (mercuric sulfide). The red pigment vermilion is mostly obtained by reduction from cinnabar. Cinnabar is highly toxic by ingestion or inhalation of the dust. Mercury poisoning can also result from exposure to water-soluble forms of mercury (such as mercuric chloride or methylmercury), inhalation of mercury vapor, or eating seafood contaminated with mercury.

Mercury is used in thermometers, barometers, manometers, sphygmomanometers, float valves, mercury switches, and other devices though concerns about the element's toxicity have led to mercury thermometers and sphygmomanometers being largely phased out in clinical environments in favor of alcohol-filled, galinstan-filled, digital, or thermistor-based instruments. It remains in use in scientific research applications and in amalgam material for dental restoration. It

Nitrate (Measured as Nitrogen) - Inorganic Contaminant 10 mg/L MCL

EPA regulates nitrate in drinking water to protect public health. Nitrate may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.



What is Nitrate?
Nitrates and nitrites are nitrogen-oxygen chemical units which combine with various organic and inorganic compounds.

Uses for Nitrate.
The greatest use of nitrates is as a fertilizer. Once taken into the body, nitrates are converted to nitrites.

What are Nitrate's Health Effects?
Infants below six months who drink water containing nitrate in excess of the maximum contaminant level (MCL) could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.

This health effects language is not intended to catalog all possible health effects for nitrate. Rather, it is intended to inform consumers of some of the possible health effects associated with nitrate in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Nitrate?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for nitrate is 10 mg/L or 10 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for nitrate, called a maximum contaminant level (MCL), at 10 mg/L or 10 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule , the regulation for nitrate, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed nitrate as part of the Six Year Review and determined that the 10 mg/L or 10 ppm MCLG and 10 mg/L or 10 ppm MCL for nitrate are still protective of human health. States may set more stringent drinking water MCLGs and MCLs for nitrate than EPA.

How does Nitrate get into my Drinking Water?
The major sources of nitrates in drinking water are runoff from fertilizer use; leaking from septic tanks, sewage; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Nitrate is in my Drinking Water?
When routine monitoring indicates that nitrate levels are above the MCL, your water supplier must take steps to reduce the amount of nitrate so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 24 hours after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will nitrate be Removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing nitrate to below 10 mg/L or 10 ppm: ion exchange, reverse osmosis, electrodialysis.

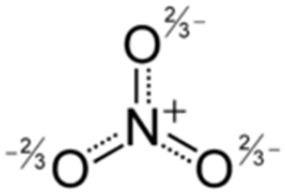
How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

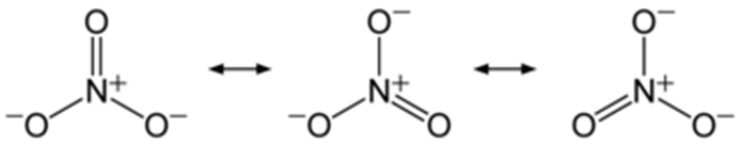
Nitrate Explained

The **nitrate ion** is a polyatomic ion with the molecular formula NO_3^- and a molecular mass of 62.0049 g/mol.

Structure
It is the conjugate base of nitric acid, consisting of one central nitrogen atom surrounded by three identically bonded oxygen atoms in a trigonal planar arrangement. The nitrate ion carries a formal charge of -1. This results from a combination formal charge in which each of the three oxygens carries a $-\frac{2}{3}$ charge, whereas the nitrogen carries a +1 charge, all these adding up to formal charge of the polyatomic nitrate ion.



The nitrate ion. The net charge of the whole ion is 1^-.
This arrangement is commonly used as an example of resonance. Like the isoelectronic carbonate ion, the nitrate ion can be represented by resonance structures:



Properties
Almost all inorganic nitrate salts are soluble in water at standard temperature and pressure. A common example of an inorganic nitrate salt is potassium nitrate (saltpeter).

In organic chemistry a nitrate (not to be confused with Nitro or Nitrite) is a relatively rare functional group with general chemical formula $RONO_2$ where R stands for any organic residue. They are the esters of nitric acid and alcohols formed by **nitroxylation**. Examples are **methyl nitrate** formed by reaction of methanol and nitric acid, the nitrate of tartaric acid, and the inaccurately named nitroglycerin (which is actually an organic *nitrate* compound, not a *nitro* compound).

Like organic nitro compounds (see below) both organic and inorganic nitrates can be used as propellants and explosives. In these uses, the thermal decomposition of the nitrate yields molecular nitrogen N_2 gas plus considerable chemical energy, due to the high strength of the bond in molecular nitrogen. Especially in inorganic nitrate reactions, oxidation from the nitrate oxygens is also an important energy-releasing process.

Occurrence
Nitrate compounds are found naturally on earth as large deposits, particularly of Chile saltpeter a major source of sodium nitrate.

Nitrites are produced by a number of species of nitrifying bacteria, and the nitrate compounds for gunpowder (see this topic for more) were historically produced, in the absence of mineral nitrate sources, by means of various fermentation processes using urine and dung.

Uses
Nitrates are mainly produced for use as fertilizers in agriculture because of their high solubility and biodegradability. The main nitrates are ammonium, sodium, potassium, and calcium salts. Several million kilograms are produced annually for this purpose.

Other Uses
The second major application of nitrates as oxidizing agents, most notably in explosives where the rapid oxidation of carbon compounds liberates large volumes of gases (see Gunpowder for an example). Sodium nitrate is used to remove air bubbles from molten glass and some ceramics. Mixtures of the molten salt are used to harden some metals.
Detection

Free nitrate ions in solution can be detected by a nitrate ion selective electrode. Such electroders analogously to the pH selective electrode. This response is partially described by the Nernst equation.

Toxicity/Toxicosis

Nitrate toxicosis can occur through enterohepatic metabolism of nitrate to nitrite being an intermediate. Nitrites oxidize the iron atoms in hemoglobin from ferrous iron (2+) to ferric iron (3+), rendering it unable to carry oxygen. This process can lead to generalized lack of oxygen in organ tissue and a dangerous condition called methemoglobinemia. Although nitrite converts to ammonia, if there is more nitrite than can be converted, the animal slowly suffers from a lack of oxygen.

Human Health Effects

Humans are subject to nitrate toxicity, with infants being especially vulnerable to methemoglobinemia due to nitrate metabolizing triglycerides present at higher concentrations than at other stages of development. Methemoglobinemia in infants is known as blue baby syndrome. Although nitrates in drinking water were once thought to be a contributing factor, there are now significant scientific doubts as to whether there is a causal link. Blue baby syndrome is now thought to be the product of a number of factors, which can include any factor which causes gastric upset, such as diarrheal infection, protein intolerance, heavy metal toxicity etc., with nitrates playing a minor role.

Nitrates, if a factor in a specific case, would most often be ingested by infants in high nitrate drinking water. However, nitrate exposure may also occur if eating, for instance, vegetables containing high levels of nitrate. Lettuce may contain elevated nitrate under growth conditions such as reduced sunlight, undersupply of the essential micronutrients molybdenum (Mo) and iron (Fe), or high concentrations of nitrate due to reduced assimilation of nitrate in the plant. High levels of nitrate fertilization also contribute to elevated levels of nitrate in the harvested plant.

Some adults can be more susceptible to the effects of nitrate than others. The methemoglobin reductase enzyme may be under-produced or absent in certain people that have an inherited mutation. Such individuals cannot break down methemoglobin as rapidly as those that do have the enzyme, leading to increased circulating levels of methemoglobin (the implication being that their blood is not as oxygen-rich). Those with insufficient stomach acid (including some vegetarians and vegans) may also be at risk. It is the increased consumption of green, leafy vegetables that typically accompany these types of diets may lead to increased nitrate intake. A wide variety of medical conditions, including food allergies, asthma, hepatitis, and gallstones may be linked with low stomach acid; these individuals may also be highly sensitive to the effects of nitrate. Methemoglobinemia can be treated with methylene blue, which reduces ferric iron (3+) in affected blood cells back to ferrous iron (2+).

Nitrate also is a by-product of septic systems. To be specific, it is a naturally occurring chemical that is left after the breakdown or decomposition of animal or human waste. Water quality may also be affected through ground water resources that have a high number of septic systems in a watershed. Septics leach down into ground water resources or aquifers and supply nearby bodies of water. Lakes that rely on ground water are often affected by nitrification through this process.

Nitrate in drinking water at levels above the national standard poses an immediate threat to young children. Excessive levels can result in a condition known as "blue baby syndrome". If untreated, the condition can be fatal. Boiling water contaminated with nitrate increases the nitrate concentration and the potential risk.

Nitrite (Measured as Nitrogen) - Inorganic Contaminant 1 mg/L MCL

EPA regulates nitrite in drinking water to protect public health. Nitrite may cause health problems if present in public or private water supplies in amounts greater than the drinking water standard set by EPA.

What is Nitrite?
Nitrates and nitrites are nitrogen-oxygen chemical units which combine with various organic and inorganic compounds.



Uses for Nitrite.
The greatest use of nitrates is as a fertilizer. Once taken into the body, nitrates are converted to nitrites.

What are Nitrite's Health Effects?
Infants below six months who drink water containing nitrite in excess of the maximum contaminant level (MCL) could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue baby syndrome.

This health effects language is not intended to catalog all possible health effects for nitrite. Rather, it is intended to inform consumers of some of the possible health effects associated with nitrite in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Nitrite?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for nitrite is 1 mg/L or 1 ppm. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for nitrite, called a maximum contaminant level (MCL), at 1 mg/L or 1 ppm. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for nitrite, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed nitrite as part of the Six Year Review and determined that the 1 mg/L or 1 ppm MCLG and 1 mg/L or 1 ppm MCL for nitrite are still protective of human health. States may set more stringent drinking water MCLGs and MCLs for nitrite than EPA.

How does Nitrite get into my Drinking Water?
The major sources of nitrite in drinking water are runoff from fertilizer use; leaching from septic tanks, sewage; and erosion of natural deposits.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals. For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Nitrite is in my Drinking Water?
When routine monitoring indicates that nitrite levels are above the MCL, your water supplier must take steps to reduce the amount of nitrite so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 24 hours after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

If your water comes from a household well, check with your health department or local water systems that use ground water for information on contaminants of concern in your area.

How will Nitrite be removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing nitrite to below 1 mg/L or 1 ppm: ion exchange, reverse osmosis.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Nitrite Explained
The **nitrite** ion, which has the chemical formula NO_2^-, is a symmetric anion with equal N-O bond lengths and a O-N-O bond angle of approximately 120°. Upon protonation, the unstable weak acid nitrous acid is produced. Nitrite can be oxidized or reduced, with the product somewhat dependent on the oxidizing/reducing agent and its strength. The nitrite ion is an ambidentate ligand, and is known to bond to metal centers in at least five different ways. Nitrite is also important in biochemistry as a source of the potent vasodilator nitric oxide. In organic chemistry the NO_2 group is present in nitrous acid esters and nitro compounds. Nitrites are also used in the food production industry for curing meat.

Selenium- Inorganic Contaminant 0.05 mg/L MCL

Selenium (Se) is an essential element for human nutrition, with the majority of our intake coming from foods such as nuts, cereals, meat, fish, and eggs. The concentration of Selenium in drinking water is usually low, and comes from natural minerals. In soils, selenium often occurs in soluble forms such as selenate, which are leached into rivers very easily by runoff increasing the amount of selenium in groundwater. Selenium in water is also a by-product of copper mining / smelting. Selenium is also used in photoelectric devises because its electrical conductivity varies with light.



Naturally occurring selenium compounds have not been shown to be carcinogenic in animals. However, acute toxicity caused by high levels of selenium in water or other sources of intake has been observed in laboratory animals and in animals grazing in areas where high selenium levels exist in the soil. The US EPA has established the MCL for selenium in water at 0.05 mg/l.

What are selenium's health effects?
Some people who drink water containing selenium well in excess of the maximum contaminant level (MCL) for many years could experience hair or fingernail losses, numbness in fingers or toes, or problems with their circulation.

This health effects language is not intended to catalog all possible health effects for selenium. Rather, it is intended to inform consumers of some of the possible health effects associated with selenium in drinking water when the rule was finalized.

What are EPA's drinking water regulations for selenium?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for selenium is 0.05 mg/L or 50 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for selenium, called a maximum contaminant level (MCL), at 0.05 mg/L or 50 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase II Rule, the regulation for selenium, became effective in 1992. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed selenium as part of the Six Year Review and determined that the 0.05 mg/L or 50 ppb MCLG and 0.05 mg/L or 50 ppb MCL for selenium are still protective of human health.

Selenium Water Treatment
Selenium contamination of water systems may result whenever new agricultural runoff courses through normally dry undeveloped lands. If you have high levels of selenium in your water the following are recommended selenium water treatment options. Anion exchange can reduce the amount of selenium in drinking water by 60 - 95%. Reverse Osmosis Systems are excellent at removing selenium in drinking water.

Selenium shows borderline metalloid or nonmetal behavior. Its most stable form, the grey trigonal allotrope, is sometimes called 'metallic' selenium. This is because its electrical conductivity is several orders of magnitude greater than that of the red monoclinic form.

The metallic character of selenium is further shown by the following properties:

- Its luster.
- Its crystalline structure, which is thought to include weakly 'metallic' interchain bonding.
- Its capacity, when molten, to be drawn into thin threads.
- Its reluctance to acquire 'the high positive oxidation numbers characteristic of nonmetals'.
- Its capacity to form cyclic polycations (such as Se2+ 8) when dissolved in oleums (an attribute it shares with sulfur and tellurium).
- The existence of a hydrolyzed cationic salt in the form of trihydroxoselenium (IV) perchlorate $[Se(OH)_3]^+.ClO– 4$.

The Non-metallic Character of Selenium is shown by:

- Its brittleness.
- Its electronic band structure, which is that of a semiconductor.
- The low electrical conductivity (~10^{-9} to 10^{-12} $S \cdot cm^{-1}$) of its highly purified form. This is comparable to or less than that of bromine (7.95×10^{-12} $S \cdot cm^{-1}$), a nonmetal.
- Its relatively high electronegativity (2.55 revised Pauling scale).
- The retention of its semiconducting properties in liquid form.
- Its reaction chemistry, which is mainly that of its nonmetallic anionic forms Se^{2-}, SeO2− 3 and SeO2− 4.

Thallium- Inorganic Contaminant 0.002 mg/L MCL

Thallium is a metal found in natural deposits such as ores containing other elements.

Uses for Thallium.
The greatest use of thallium is in specialized electronic research equipment.



What are Thallium's Health Effects?
Some people who drink water containing thallium well in excess of the maximum contaminant level (MCL) for many years could experience hair loss, changes in their blood, or problems with their kidneys, intestines, or liver problems.

This health effects language is not intended to catalog all possible health effects for thallium. Rather, it is intended to inform consumers of some of the possible health effects associated with thallium in drinking water when the rule was finalized.

What are EPA's Drinking Water Regulations for Thallium?
In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for thallium is 0.0005 mg/L or 0.5 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for thallium, called a maximum contaminant level (MCL), at 0.002 mg/L or 2 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The Phase V Rule, the regulation for thallium, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed thallium as part of the Six Year Review and determined that the 0.0005 mg/L or 0.5 ppb MCLG and 0.002 mg/L or 2 ppb MCL for thallium are still protective of human health. States may set more stringent drinking water MCLGs and MCLs for thallium than EPA.

How does Thallium get into my Drinking Water?
The major sources of thallium in drinking water are leaching from ore-processing sites; and discharge from electronics, glass, and drug factories.

A federal law called the Emergency Planning and Community Right to Know Act (EPCRA) requires facilities in certain industries, which manufacture, process, or use significant amounts of toxic chemicals, to report annually on their releases of these chemicals.
For more information on the uses and releases of chemicals in your state, contact the Community Right-to-Know Hotline: (800) 424-9346.

How will I know if Thallium is in my Drinking Water?
When routine monitoring indicates that thallium levels are above the MCL, your water supplier must take steps to reduce the amount of thallium so that it is below that level. Water suppliers must notify their customers as soon as practical, but no later than 30 days after the system learns of the violation. Additional actions, such as providing alternative drinking water supplies, may be required to prevent serious risks to public health.

How will Thallium be Removed from my Drinking Water?
The following treatment method(s) have proven to be effective for removing thallium to below 0.002 mg/L or 2 ppb: activated alumina; ion exchange.

How do I learn more about my Drinking Water?
EPA strongly encourages people to learn more about their drinking water, and to support local efforts to protect the supply of safe drinking water and upgrade the community water system. Your water bill or telephone book's government listings are a good starting point for local information.

Contact your water utility. EPA requires all community water systems to prepare and deliver an annual consumer confidence report (CCR) (sometimes called a water quality report) for their customers by July 1 of each year. If your water provider is not a community water system, or if you have a private water supply, request a copy from a nearby community water system.

Thallium Explained

Thallium is a chemical element with symbol **Tl** and atomic number 81. This soft gray poor metal is not found free in nature. When isolated, it resembles tin, but discolors when exposed to air. Chemists William Crookes and Claude-Auguste Lamy discovered thallium independently in 1861, in residues of sulfuric acid production. Both used the newly developed method of flame spectroscopy, in which thallium produces a notable green spectral line. Thallium, from Greek *θαλλός*, *thallos*, meaning "a green shoot or twig," was named by Crookes. It was isolated by electrolysis a year later, by Lamy.

Thallium tends to oxidize to the +3 and +1 oxidation states as ionic salts. The +3 state resembles that of the other elements in thallium's group (boron, aluminum, gallium, indium). However, the +1 state, which is far more prominent in thallium than the elements above it, recalls the chemistry of alkali metals, and thallium(I) ions are found geologically mostly in potassium-based ores, and (when ingested) are handled in many ways like potassium ions (K^+) by ion pumps in living cells.

Commercially, however, thallium is produced not from potassium ores, but as a byproduct from refining of heavy metal sulfide ores. Approximately 60–70% of thallium production is used in the electronics industry, and the remainder is used in the pharmaceutical industry and in glass manufacturing. It is also used in infrared detectors. The radioisotope thallium-201 (as the soluble chloride TlCl) is used in small, nontoxic amounts as an agent in a nuclear medicine scan, during one type of nuclear cardiac stress test.

Soluble thallium salts (many of which are nearly tasteless) are highly toxic in quantity, and were historically used in rat poisons and insecticides. Use of these compounds has been restricted or banned in many countries, because of their nonselective toxicity. Thallium poisoning notably results in hair loss. Because of its historic popularity as a murder weapon, thallium has gained notoriety as "the poisoner's poison" and "inheritance powder" (alongside arsenic).

SOC Section



Common water sampling bottles.

SOC/VOC bottles are the smaller, thin bottles with the septum tops. Be careful not to get any air bubbles in the SOC/VOC bottles and this may take a few weeks to learn to collect a proper sample.

SOC Introduction

Synthetic Organic Chemicals (SOCs) are organic (carbon based) chemicals that are less volatile than Volatile Organic Compounds (VOCs). SOCs are used as pesticides, defoliants, fuel additives and as ingredients for other organic compounds. They are all man made and do not naturally occur in the environment. Some of the more well-known SOCs are Atrazine, 2,4-D, Dioxin and Polychlorinated Biphenyls (PCBs).

SOCs most often enter the natural environment through application of pesticide (including runoff from areas where they are applied), as part of a legally discharged waste stream, improper or illegal waste disposal, accidental releases or as a byproduct of incineration. Some SOCs are very persistent in the environment, whether in soil or water.

SOCs are generally toxic and can have substantial health impacts from both acute (short-term) and chronic (long-term) exposure. Many are known carcinogens (cancer causing). EPA has set Maximum Contaminant Levels (MCL) for 30 SOCs under the Safe Drinking Water Act.

The Safe Drinking Water Act requires that all water sources of all public water systems be periodically monitored for regulated SOCs. The monitoring frequency can be adjusted through a waiver if SOCs are not detected.

EPA established Maximum Contaminant Levels (MCL), Maximum Contaminant Level Goals (MCLG), monitoring requirements and best available technologies for removal for 65 chemical contaminants over a five year period as EPA gathered and analyzed occurrence and health effects data. This series of rules are known as the Chemical Phase Rules and they define regulations for three contaminant groups:

- Inorganic Chemicals (IOC),
- Synthetic Organic Chemicals (SOC), and
- Volatile Organic Chemicals (VOC).

The Chemical Phase rules provide public health protection through the reduction of chronic risks from:

- cancer;
- organ damage; and
- circulatory,
- nervous, and
- reproductive system disorders.

They also help to reduce the occurrence of Methemoglobinemia or "blue baby syndrome" from ingestion of elevated levels of nitrate or nitrite. All public water systems must monitor for Nitrate and Nitrite. Community water systems and Non-transient non-community water systems must also monitor for IOCs, SOCs, and VOCs. This is a list of the organic chemicals—which include pesticides, industrial chemicals, and disinfection by-products—that are tested for in public water systems (those that provide water to the public), along with the maximum standard for the contaminant, and a brief description of the potential health effects associated with long-term consumption of elevated levels of the contaminants.

The federal standard for most contaminants is listed as a Maximum Contaminant Level (MCL), the lowest concentration at which that particular contaminant is believed to represent a potential health concern. Unless otherwise noted, the MCL is expressed as parts per billion (ppb). Also, because of technological limitations or other factors, it is not possible to test for some contaminants in a reliable fashion. Instead, public water systems are required to use specific Treatment Techniques (TT) that are designed to remove these particular contaminants from the water. In addition to the chemicals listed, monitoring is done for approximately 60 organic chemicals for which MCLs have not been established. If unacceptable levels are found of these “unregulated” contaminants—based on established state health standards and an assessment of the risks they pose—the response is the same as if an MCL has been exceeded: the public water system must notify those served by the system.

Synthetic Organic Chemicals	MCL (ppb)	Potential Health Effects
Acrylamide	TT	Cancer, nervous system effects
Alachlor	2	Cancer
Aldicarb	3	Nervous system effects
Aldicarb sulfoxide	4	Nervous system effects
Aldicarb sulfone	2	Nervous system effects
Atrazine	3	Liver, kidney, lung, cardiovascular effects; possible carcinogen
Benzo(a)pyrene (PAHs)	0.2	Liver, kidney effects, possible carcinogen
Carbofuran	40	Nervous system, reproductive system effects
Chlordane	2	Cancer
2,4-D	70	Liver, kidney effects
Di(2-ethylhexyl) adipate	400	Reproductive effects
Di(2-ethylhexyl) phthalate	6	Cancer
Dibromochloro-propane (DBCP)	0.2	Cancer
Dinoseb	7	Thyroid, reproductive effects
Diquat	20	Ocular, liver, kidney effects
Endothall	100	Liver, kidney, gastrointestinal effects
Endrin	2	Liver, kidney effects
Epichlorohydrin	TT	Cancer
Ethylene dibromide (EDB)	0.05	Cancer
Glyphosate	700	Liver, kidney effects
Heptachlor	0.4	Cancer
Heptachlor epoxide	0.2	Cancer
Hexachlorobenzene	1	Cancer
Hexachlorocyclopentadiene (HEX)	50	Kidney, stomach effects
Lindane	0.2	Liver, kidney, nervous system, immune

		system, circulatory system effects
Methoxychlor	40	Developmental, liver, kidney, nervous system effects
Oxamyl (Vydate)	200	Kidney effects
Pentachlorophenol	1	Cancer
Picloram	500	Kidney, liver effects
Polychlorinated biphenyls (PCBs)	0.5	Cancer
Simazine	4	Body weight and blood effects, possible carcinogen
2,3,7,8-TCDD (Dioxin)	0.00003	Cancer
Toxaphene	3	Cancer
2,4,5-TP (Silvex)	50	Liver, kidney effects

Volatile Organic Compounds (VOCs)

Definitions

Volatile Organic Compounds (VOCs) – "VOCs are ground-water contaminants of concern because of very large environmental releases, human toxicity, and a tendency for some compounds to persist in and migrate with ground-water to drinking-water supply well … In general, VOCs have high vapor pressures, low-to-medium water solubilities, and low molecular weights. Some VOCs may occur naturally in the environment, other compounds occur only as a result of manmade activities, and some compounds have both origins." - Zogorski and others, 2006

Volatile Organic Compounds (VOCs) – "Volatile organic compounds released into the atmosphere by anthropogenic and natural emissions which are important because of their involvement in photochemical pollution." - Lincoln and others, 1998

Volatile Organic Compounds (VOCs) – "Hydrocarbon compounds that have low boiling points, usually less than 100ºC, and therefore evaporate readily. Some are gases at room temperature. Propane, benzene, and other components of gasoline are all volatile organic compounds." - Art, 1993

Volatile Organic Compounds (VOCs) – "VOCs are organic compounds that can be isolated from the water phase of a sample by purging the water sample with inert gas, such as helium, and, subsequently, analyzed by gas chromatography. Many VOCs are human-made chemicals that are used and produced in the manufacture of paints, adhesives, petroleum products, pharmaceuticals, and refrigerants. They often are compounds of fuels, solvents, hydraulic fluids, paint thinners, and dry-cleaning agents commonly used in urban settings. VOC contamination of drinking water supplies is a human-health concern because many are toxic and are known or suspected human carcinogens." - U.S. Geological Survey, 2005

VOCs Explained

Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary, room-temperature conditions. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air. An example is formaldehyde, with a boiling point of –19 °C (–2 °F), slowly exiting paint and getting into the air.

VOCs are numerous, varied, and ubiquitous. They include both human-made and naturally occurring chemical compounds. Most scents or odors are of VOCs. VOCs play an important role in communication between plants. Some VOCs are dangerous to human health or cause harm to the environment. Anthropogenic VOCs are regulated by law, especially indoors, where concentrations are the highest. Harmful VOCs are typically not acutely toxic, but instead have compounding long-term health effects. Because the concentrations are usually low and the symptoms slow to develop, research into VOCs and their effects is difficult.

Specific Components

Paints and Coatings

A major source of man-made VOCs are coatings, especially paints and protective coatings. Solvents are required to spread a protective or decorative film. Approximately 12 billion liters of paints are produced annually. Typical solvents are aliphatic hydrocarbons, ethyl acetate, glycol ethers, and acetone. Motivated by cost, environmental concerns, and regulation, the paint and coating industries are increasingly shifting toward aqueous solvents.

Chlorofluorocarbons and Chlorocarbons

Chlorofluorocarbons, which are banned or highly regulated, were widely used cleaning products and refrigerants. Tetrachloroethene is used widely in dry cleaning and by industry. Industrial use of fossil fuels produces VOCs either directly as products (e.g., gasoline) or indirectly as byproducts (e.g., automobile exhaust).

Benzene

One VOC that is a known human carcinogen is benzene, which is a chemical found in environmental tobacco smoke, stored fuels, and exhaust from cars in an attached garage. Benzene also has natural sources such as volcanoes and forest fires. It is frequently used to make other chemicals in the production of plastics, resins, and synthetic fibers. Benzene evaporates into the air quickly and the vapor of benzene is heavier than air allowing the compound to sink into low-lying areas. Benzene has also been known to contaminate food and water and if digested can lead to vomiting, dizziness, sleepiness, rapid heartbeat, and at high levels, even death may occur.

Methylene Chloride

Methylene chloride is another VOC that is highly dangerous to human health. It can be found in adhesive removers and aerosol spray paints and the chemical has been proven to cause cancer in animals. In the human body, methylene chloride is converted to carbon monoxide and a person will suffer the same symptoms as exposure to carbon monoxide. If a product that contains methylene chloride needs to be used the best way to protect human health is to use the product outdoors. If it must be used indoors, proper ventilation is essential to keeping exposure levels down.

Perchloroethylene

Perchloroethylene is a volatile organic compound that has been linked to causing cancer in animals. It is also suspected to cause many of the breathing related symptoms of exposure to VOC's. Perchloroethylene is used mostly in dry cleaning. Studies show that people breathe in low levels of this VOC in homes where dry-cleaned clothes are stored and while wearing dry-cleaned clothing. While dry cleaners attempt to recapture perchlorothylene in the dry cleaning process to reuse it in an effort to save money, they can't recapture it all. To avoid exposure to perchlorothylene, if a strong chemical odor is coming from clothing when picked up from the dry cleaner, do not accept them and request that less of the chemical be used as well as a complete drying of the garments

MTBE

MTBE was banned in the US around 2004 in order to limit further contamination of drinking water aquifers primarily from leaking underground gasoline storage tanks where MTBE was used as an octane booster and oxygenated-additive.

Formaldehyde
Many building materials such as paints, adhesives, wall boards, and ceiling tiles slowly emit formaldehyde, which irritates the mucous membranes and can make a person irritated and uncomfortable. Formaldehyde emissions from wood are in the range of 0.02 – 0.04 ppm. Relative humidity within an indoor environment can also affect the emissions of formaldehyde. High relative humidity and high temperatures allow more vaporization of formaldehyde from wood-materials.

Health Risks
Respiratory, allergic, or immune effects in infants or children are associated with man-made VOCs and other indoor or outdoor air pollutants. Some VOCs, such as styrene and limonene, can react with nitrogen oxides or with ozone to produce new oxidation products and secondary aerosols, which can cause sensory irritation symptoms. Unspecified VOCs are important in the creation of smog.

Health effects include:

Eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system. Some organics can cause cancer in animals; some are suspected or known to cause cancer in humans. Key signs or symptoms associated with exposure to VOCs include conjunctival irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnea, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, dizziness.

The ability of organic chemicals to cause health effects varies greatly from those that are highly toxic, to those with no known health effects. As with other pollutants, the extent and nature of the health effect will depend on many factors including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics. At present, not much is known about what health effects occur from the levels of organics usually found in homes. Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans.

Reducing Exposure
To reduce exposure to these toxins, one should buy products that contain Low-VOC's or No VOC's. Only the quantity which will soon be needed should be purchased, eliminating stockpiling of these chemicals. Use products with VOC's in well ventilated areas. When designing homes and buildings, design teams can implement the best possible ventilation plans, call for the best mechanical systems available, and design assemblies to reduce the amount of infiltration into the building.

These methods will help improve indoor air quality, but by themselves they cannot keep a building from becoming an unhealthy place to breathe. While proper building ventilation is a key component to improving indoor air quality, it cannot do the job on its own. As stated earlier, awareness is the key component to improving air quality, when choosing building materials, furnishings, and decorations. When architects and engineers implement best practices in ventilation and mechanical systems, the owner must maintain good air quality levels thereafter.

Limit Values for VOC Emissions
Limit values for VOC emissions into indoor air are published by e.g. AgBB, AFSSET, California Department of Public Health, and others.

Chemical Fingerprinting
The exhaled human breath contains a few hundred volatile organic compounds and is used in breath analysis to serve as a VOC biomarker to test for diseases such as lung cancer. One study has shown that "volatile organic compounds ... are mainly blood borne and therefore enable monitoring of different processes in the body." And it appears that VOC compounds in the body "may be either produced by metabolic processes or inhaled/absorbed from exogenous sources" such as environmental tobacco smoke. Research is still in the process to determine whether VOCs in the body are contributed by cellular processes or by the cancerous tumors in the lung or other organs.

Volatile Organic Chemicals	MCL (ppb)	Potential Health Effects
Benzene	5	Cancer
Carbon tetrachloride	5	Liver effects, cancer
Chlorobenzene	100	Liver, kidney, nervous system effects
o-Dichlorobenzene	600	Liver, kidney, blood cell effects
para-Dichlorobenzene	175	Kidney effects, possible carcinogen
1,2-Dichloroethane	5	Cancer
1,1-Dichloroethylene	7	Liver, kidney effects, possible carcinogen
cis-1,2-Dichloroethylene	70	Liver, kidney, nervous system, circulatory system effects
trans-1,2-Dichloroethylene	100	Liver, kidney, nervous system, circulatory system effects
1,2-Dichloropropane	5	Cancer
Ethylbenzene	700	Liver, kidney, nervous system effects
Methylene chloride	5	Cancer
Styrene	100	Liver, nervous systems effects, possible carcinogen
Tetrachloroethylene (PCE)	5	Cancer
Toluene	1,000	Liver, kidney, nervous system, circulatory system effects
Total trihalomethanes Chloroform Bromoform Bromodichloromethane Chlorodibromomethane	100	Cancer
1,2,4-Trichlorobenzene	70	Liver, kidney effects
1,1,1-Trichloroethane	200	Liver, nervous system effects
1,1,2-Trichloroethane	5	Kidney, liver effects, possible carcinogen
Trichloroethylene (TCE)	5	Cancer
Vinyl chloride	2	Nervous system, liver effects, cancer

Xylenes (total)	10,000	Liver, kidney, nervous system effects

Disinfection By-products	MCL (ppb)	Potential Health Effects
Bromate	10	Cancer
Chlorate	1,000	Anemia, nervous system effects
Haloacetic Acids (HAA5)*	60	Cancer
Total trihalomethanes (TTHMs)**	100	Cancer

*Haloacetic acids consist of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

**Total trihalomethanes consist of chloroform, bromoform, bromodichloromethane, and chlorodibromomethane.

Metalloid Section

Drinking water contaminants that can cause health effects after continuous long-term exposure at levels greater than the maximum contaminant level (MCL) are considered “chronic” contaminants. Examples of chronic drinking water contaminants regulated by EPA include inorganic contaminants like arsenic, cadmium, and copper; organic contaminants such as pesticides and industrial chemicals; and radiological contaminants like radium and uranium.

If your water system has installed some form of inorganic contaminant or arsenic treatment, keep in mind that the treatment you installed may change the water quality in other ways. It might cause the water to react differently in the distribution system. Depending on the kind of treatment you’ve installed, consider what distribution system problems might result.

A change in the taste, odor or appearance of the water at customers’ taps may be the first indication of a problem. Some water quality parameters to consider monitoring, depending on your arsenic treatment technology, include iron, pH, manganese, alkalinity, and aluminum.

In contrast, “acute” contaminants can cause short-term health effects within hours or days of exposure. Microbes such as *E. coli* and *Cryptosporidium* are examples of contaminants that can cause an acute health risk. Some chronic-type contaminants can also fall in this category if they are present at high enough concentrations to cause immediate health effects. For example, nitrate levels over the MCL can cause “blue-baby” syndrome in children less than 6 months.

Arsenic, boron, silicon, germanium, antimony and tellurium are commonly classified as metalloids. One or more from among selenium, polonium or astatine are sometimes added to the list. Boron is sometimes excluded from the list, by itself or together with silicon. Tellurium is sometimes not regarded as a metalloid. The inclusion of antimony, polonium and astatine as metalloids has also been questioned.

A metalloid is a chemical element with properties that are in-between or a mixture of those of metals and nonmetals, and which is considered to be difficult to classify unambiguously as either a metal or a nonmetal. There is no standard definition of a metalloid nor is there agreement as to which elements are appropriately classified as such. Despite this lack of specificity the term continues to be used in the chemistry literature.

Some authors do not classify elements bordering the metal-nonmetal dividing line as metalloids noting that a binary classification can facilitate the establishment of some simple rules for determining bond types between metals and/or nonmetals. Other authors, in contrast, have suggested that classifying some elements as metalloids 'emphasizes that properties change gradually rather than abruptly as one moves across or down the periodic table. Alternatively, some periodic tables distinguish elements that are metalloids in the absence of any formal dividing line between metals and nonmetals. Metalloids are instead shown as occurring in a diagonal fixed band or diffuse region, running from upper left to lower right, centered around arsenic.

The six elements commonly recognized as metalloids are boron, silicon, germanium, arsenic, antimony and tellurium. They are metallic-looking brittle solids, with intermediate to relatively good electrical conductivities, and each having the electronic band structure of either a semiconductor or a semimetal.

Chemically, they mostly behave as (weak) nonmetals, have intermediate ionization energy and electronegativity values, and form amphoteric or weakly acidic oxides. Being too brittle to have any structural uses, the metalloids and their compounds instead find common use in glasses, alloys and semiconductors. The electrical properties of silicon and germanium, in particular, enabled the establishment of the semiconductor industry in the 1950s and the development of solid state electronics from the early 60s onwards.

Other elements less commonly recognized as metalloids include carbon, aluminum, selenium, polonium and astatine. On a standard periodic table these elements, as well as the elements commonly recognized as metalloids, occur in or near a diagonal region of the p-block, having its main axis anchored by boron at one end and astatine at the other. Some periodic tables include a dividing line between metals and nonmetals and it is generally the elements adjacent to this line or, less frequently, one or more of the elements adjacent to those elements, which are identified as metalloids.

The term *metalloid* was first popularly used to refer to nonmetals. It's more recent meaning as a category of elements with intermediate or hybrid properties did not become widespread until the period 1940–1960. Metalloids are sometimes called semimetals, a practice which has been discouraged. This is because the term *semimetal* has a different meaning in physics, one which more specifically refers to the electronic band structure of a substance rather than the overall classification of a chemical element.

There is no universally agreed or rigorous definition of a metalloid. The feasibility of establishing a specific definition has also been questioned, noting anomalies can be found in several such attempted constructs. Classifying any particular element as a metalloid has been described as 'arbitrary'.

The generic definition set out at the start of this article is based on metalloid attributes consistently cited in the literature. Illustrative definitions and extracts include:

- 'In chemistry a metalloid is an element with properties intermediate between those of metals and nonmetals.'
- 'Between the metals and nonmetals in the periodic table we find elements…[that] share some of the characteristic properties of both the metals and nonmetals, making it difficult to place them in either of these two main categories.'
- 'Chemists sometimes use the name metalloid…for these elements which are difficult to classify one way or the other.'
- 'Because the traits distinguishing metals and nonmetals are qualitative in nature, some elements do not fall unambiguously in either category. These elements…are called metalloids…'.

More Broadly, Metalloids have also been referred to as:

- 'elements that…are somewhat of a cross between metals and nonmetals' or
- 'weird in-between elements.'

The criterion that metalloids are difficult to unambiguously classify one way or the other is a key tenet. In contrast, elements such as sodium and potassium 'have metallic properties to a high degree' and fluorine, chlorine and oxygen 'are almost exclusively nonmetallic.'

Although most other elements have a mixture of metallic and nonmetallic properties most such elements can also be classified as either metals or nonmetals according to which set of properties are regarded as being more pronounced in them. It is only the elements at or near the margins, ordinarily those that are regarded as lacking a sufficiently clear preponderance of metallic or nonmetallic properties, which are classified as metalloids.

Which Elements are Metalloids?
There is no universally agreed or rigorous definition of the term metalloid. So the answer to the question "Which elements are metalloids?" can vary, depending on the author and their inclusion criteria. Emsley, for example, recognized only four: germanium, arsenic, antimony and tellurium. James et al., on the other hand, listed twelve: boron, carbon, silicon, germanium, arsenic, selenium, antimony, tellurium, bismuth, polonium, ununpentium and livermorium. As of 2011 the list of metalloid lists recorded an average of just over seven elements classified as metalloids, per list of metalloids, based on a sample size of 194 lists.

The absence of a standardized division of the elements into metals, metalloids and nonmetals is not necessarily an issue. There is a more or less continuous progression from the metallic to the nonmetallic. A specified subset of this continuum can potentially serve its particular purpose as well as any other. In any event, individual metalloid classification arrangements tend to share common ground (as described above) with most variations occurring around the indistinct margins, as surveyed later.

What Are Some Best Practices For Effective Communication About Chronic Contaminants?
If you expect that your public water system will exceed EPA's standard for a contaminant or that the costs of compliance may require public funding, communicate early and often. The most effective communication efforts follow these simple steps:

- Provide simple, straightforward, *and consistent* messages;
- Describe potential adverse health effects and populations at risk;
- Describe actions you are taking to correct the situation and when you anticipate it will be resolved;
- Describe actions the consumer can take such as using alternate water supplies and when to seek medical help;
- Provide links to useful information resources such as EPA's Web site.
- Use graphics, photographs, maps, charts, and drawings to illustrate your messages;
- Assume that consumers will only read the top half of the notice or what can be read in ten seconds;
- Display important elements in bold and/or large type in the top half of the notice;
- Communicate in multiple languages to meet the needs of your non-English speaking consumers; and Include contact information for further information in *all* communications.

Near Metalloids

The concept of a class of elements intermediate between metals and nonmetals is sometimes extended to include elements that most chemists, and related science professionals, would not ordinarily recognize as metalloids. In 1935, Fernelius and Robey allocated carbon, phosphorus, selenium, and iodine to such an intermediary class of elements, together with boron, silicon, arsenic, antimony, tellurium and polonium. They also included a placeholder for the missing element 85 (astatine), five years ahead of its synthesis in 1940.

They excluded germanium from their considerations as it was still then regarded as a poorly conducting metal. In 1954, Szabó & Lakatos counted beryllium and aluminum in their list of metalloids, as well as boron, silicon, germanium, arsenic, antimony, tellurium, polonium and astatine. In 1957, Sanderson recognized carbon, phosphorus, selenium, and iodine as part of an intermediary class of elements with 'certain metallic properties', together with boron, silicon, arsenic, tellurium, and astatine. Germanium, antimony and polonium were classified by him as metals. More recently, in 2007, Petty included carbon, phosphorus, selenium, tin and bismuth in his list of metalloids, as well as boron, silicon, germanium, arsenic, antimony, tellurium, polonium and astatine.

Elements such as these are occasionally called, or described as, *near-metalloids,* or the like. They are located near the elements commonly recognized as metalloids, and usually classified as either metals or nonmetals. Metals falling into this loose category tend to show 'odd' packing structures, marked covalent chemistry (molecular or polymeric), and amphoterism. Aluminum, tin and bismuth are examples. They are also referred to as *(chemically) weak metals, poor metals, post-transition metals,* or *semimetals* (in the aforementioned sense of metals with incomplete metallic character). These classification groupings generally cohabit the same periodic table territory but are not necessarily mutually inclusive.

Nonmetals in the 'near-metalloid' category include carbon, phosphorus, selenium and iodine. They exhibit metallic luster, semiconducting properties and bonding or valence bands with delocalized character. This applies to their most thermodynamically stable forms under ambient conditions: carbon as graphite; phosphorus as black phosphorus; and selenium as grey selenium. These elements are alternatively described as being 'near metalloidal', showing metalloidal character, or having metalloid-like or some metalloid(al) or metallic properties.

Allotropes
Some allotropes of the elements exhibit more pronounced metallic, metalloidal or nonmetallic behavior than others. For example, the diamond allotrope of carbon is clearly nonmetallic. The graphite allotrope however displays limited electrical conductivity more characteristic of a metalloid. Phosphorus, selenium, tin, and bismuth also have allotropes that display borderline or either metallic or nonmetallic behavior.

Categorization and Periodic Table Territory
Metalloids are generally regarded as a third category of chemical elements, alongside metals and nonmetals. They have been described as forming a (fuzzy) buffer zone between metals and nonmetals. The make-up and size of this zone depends on the classification criteria being used. Metalloids are sometimes grouped instead with metals, regarded as nonmetals or treated as a sub-category of same.

Metalloid Border

H								He
Li	Be		B	C	N	O	F	Ne
Na	Mg		Al	Si	P	S	Cl	Ar
K	Ca	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

Periodic table extract showing elements that have sometimes[] been classified as metalloids:

Elements that appear commonly to rarely in the list of metalloid lists.

Elements that appear still less frequently.
Outlying elements showing that the metalloid net is sometimes cast very widely. Although they do not appear in the list of metalloids lists, isolated references to their designation as metalloids can be found in the literature.

Metalloids cluster on either side of the **dividing line between metals and nonmetals**. This can be found, in varying configurations, on some periodic tables (see mini-example, right). Elements to the lower left of the line generally display increasing metallic behavior; elements to the upper right display increasing nonmetallic behavior. When presented as a regular stair-step, elements with the highest critical temperature for their groups (Li, Be, Al, Ge, Sb, Po) lie just below the line.

The diagonal positioning of the metalloids represents somewhat of an exception to the phenomenon that elements with similar properties tend to occur in vertical columns. Going across a periodic table row, the nuclear charge increases with atomic number just as there is as a corresponding increase in electrons. The additional 'pull' on outer electrons with increasing nuclear charge generally outweighs the screening efficacy of having more electrons. With some irregularities, atoms therefore become smaller, ionization energy increases, and there is a gradual change in character, across a period, from strongly metallic, to weakly metallic, to weakly nonmetallic, to strongly nonmetallic elements.

Going down a main group periodic table column, the effect of increasing nuclear charge is generally outweighed by the effect of additional electrons being further away from the nucleus. With some irregularities, atoms therefore become larger, ionization energy falls, and metallic character increases. The combined effect of these competing horizontal and vertical trends is that the location of the metal-nonmetal transition zone shifts to the right in going down a period.

A related effect can be seen in other diagonal similarities that occur between some elements and their lower right neighbors, such as lithium-magnesium, beryllium-aluminum, carbon-phosphorus, and nitrogen-sulfur.

Other Metalloids
Given there is no agreed definition of a metalloid, some other elements are occasionally classified as such. These elements include hydrogen, beryllium, nitrogen, phosphorus, sulfur, zinc, gallium, tin, iodine, lead, bismuth and radon. The term metalloid has also been used to refer to:

- Elements that exhibit metallic luster and electrical conductivity, and that are also amphoteric. Arsenic, antimony, vanadium, chromium, molybdenum, tungsten, tin, lead and aluminum are examples.

- Elements that are otherwise sometimes referred to as poor metals.

- Nonmetallic elements (for example, nitrogen; carbon) that can form alloys with, or modify the properties of, metals.

Heavy Metals
A heavy metal is a member of a loosely defined subset of elements that exhibit metallic properties. It mainly includes the transition metals, some metalloids, lanthanides, and actinides. Many different definitions have been proposed—some based on density, some on atomic number or atomic weight, and some on chemical properties or toxicity. The term *heavy metal* has been called a "misinterpretation" in an IUPAC technical report due to the contradictory definitions and its lack of a "coherent scientific basis". There is an alternative term *toxic metal*, for which no consensus of exact definition exists either. As discussed below, depending on context, heavy metal can include elements lighter than carbon and can exclude some of the heaviest metals. Heavy metals occur naturally in the ecosystem with large variations in concentration. In modern times, anthropogenic sources of heavy metals, i.e. pollution, have been introduced to the ecosystem. Waste-derived fuels are especially prone to contain heavy metals, so heavy metals are a concern in consideration of waste as fuel.

Motivations for controlling heavy metal concentrations in gas streams are diverse. Some of them are dangerous to health or to the environment (e.g. mercury, cadmium, lead, chromium), some may cause corrosion (e.g. zinc, lead), some are harmful in other ways (e.g. arsenic may pollute catalysts). Within the European community the eleven elements of highest concern are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and thallium, the emissions of which are regulated in waste incinerators. Some of these elements are actually necessary for humans in minute amounts (cobalt, copper, chromium, manganese, nickel) while others are carcinogenic or toxic, affecting, among others, the central nervous system (manganese, mercury, lead, arsenic), the kidneys or liver (mercury, lead, cadmium, copper) or skin, bones, or teeth (nickel, cadmium, copper, chromium).

Heavy metal pollution can arise from many sources but most commonly arises from the purification of metals, e.g., the smelting of copper and the preparation of nuclear fuels. Electroplating is the primary source of chromium and cadmium. Through precipitation of their compounds or by ion exchange into soils and muds, heavy metal pollutants can localize and lay dormant. Unlike organic pollutants, heavy metals do not decay and thus pose a different kind of challenge for remediation. Currently, plants or microrganisms are tentatively used to remove some heavy metals such as mercury.

Plants which exhibit hyper accumulation can be used to remove heavy metals from soils by concentrating them in their bio matter. Some treatment of mining tailings has occurred where the vegetation is then incinerated to recover the heavy metals.

One of the largest problems associated with the persistence of heavy metals is the potential for bioaccumulation and biomagnification causing heavier exposure for some organisms than is present in the environment alone. Coastal fish (such as the smooth toadfish) and seabirds (such as the Atlantic Puffin) are often monitored for the presence of such contaminants.

Living organisms require varying amounts of "heavy metals". Iron, cobalt, copper, manganese, molybdenum, and zinc are required by humans. Excessive levels can be damaging to the organism. Other heavy metals such as mercury, plutonium, and lead are toxic metals that have no known vital or beneficial effect on organisms, and their accumulation over time in the bodies of animals can cause serious illness. Certain elements that are normally toxic are, for certain organisms or under certain conditions, beneficial. Examples include vanadium, tungsten, and even cadmium.

Toxic Metals

Toxic metals are metals that form poisonous soluble compounds and have no biological role, i.e. are not essential minerals, or are in the wrong form. Often heavy metals are thought as synonymous, but lighter metals also have toxicity, such as beryllium, and not all heavy metals are particularly toxic, and some are essential, such as iron. The definition may also include trace elements when considered in abnormally high, toxic doses. A difference is that there is no beneficial dose for a toxic metal with no biological role.

Toxic metals sometimes imitate the action of an essential element in the body, interfering with the metabolic process to cause illness. Many metals, particularly heavy metals are toxic, but some heavy metals are essential, and some, such as bismuth, have a low toxicity. Most often the definition includes at least cadmium, lead, mercury and the radioactive metals. Metalloids (arsenic, polonium) may be included in the definition.

Radioactive metals have both radiological toxicity and chemical toxicity. Metals in an oxidation state abnormal to the body may also become toxic: chromium (III) is an essential trace element, but chromium (VI) is a carcinogen.

Toxicity is a function of solubility. Insoluble compounds as well as the metallic forms often exhibit negligible toxicity. The toxicity of any metal depends on its ligands. In some cases, organometallic forms, such as dimethyl mercury and tetraethyl lead, can be extremely toxic. In other cases, organometallic derivatives are less toxic such as the cobaltocenium cation.

Decontamination for toxic metals is different from organic toxins: because toxic metals are elements, they cannot be destroyed. Toxic metals may be made insoluble or collected, possibly by the aid of chelating agents. Toxic metals can bioaccumulate in the body and in the

food chain. Therefore, a common characteristic of toxic metals is the chronic nature of their toxicity. This is particularly notable with radioactive heavy metals such as thorium, which imitates calcium to the point of being incorporated into human bone, although similar health implications are found in lead or mercury poisoning. The exceptions to this are barium and aluminum, which can be removed efficiently by the kidneys.

Toxic Heavy Metals

- Antimony (a metalloid)
- Arsenic is a metalloid
- Barium
- Beryllium
- Cadmium - cadmium poisoning
- Lead - lead poisoning
- Mercury - mercury poisoning
- Osmium
- Thallium
- Vanadium
- Radioactive metals:
    - Actinium
    - Thorium
    - Uranium
    - Radium
    - The transuraniums, such as plutonium, americium, etc.
    - Polonium
    - Radioactive isotopes of metallic elements not otherwise strongly toxic, e.g. cobalt-60 and strontium-90.

Aluminum has no biological role and its classification into toxic metals is controversial. Significant toxic effects and accumulation to tissues have been observed in renally impaired patients. However, individuals with healthy kidneys can be exposed to large amounts of aluminum with no ill effects. Thus, aluminum is not considered dangerous to persons with normal elimination capacity.

Trace Elements with Toxicity

- Chromium as hexavalent Cr(VI)
- Nickel – nickel salts are carcinogenic
- Copper – copper toxicity
- Zinc - zinc toxicity
- Iron – iron poisoning
- Fluorine-fluoride poisoning

Nonmetals

Some heavy nonmetals may be erroneously called "metals", because they have some metallic properties.

- Selenium – a nonmetal; essential element
- Tellurium

Atomic Spectrometry

Atomic spectrometry converts each metal in the water sample to a particulate emission that can then be weighed. Extrapolations are made to determine each metal concentration in each water sample taken. The complicated analysis requires preserving the sample with acid, heating the sample to convert to a particulate emission and then identifying each metal and its weight.

A simple analogy is to capture the steam from a pot of water, separate every atom in the steam, identify each atom, weigh each atom and then apply these numbers back to the original volume of water contained in the pot. The result is an accurate picture of what is in the water.

Heavy Metals in Water

High heavy metals concentrations can be naturally occurring. Every geologic formation contains a certain amount of heavy metal. Mine operations extract and process these metals in areas with the highest concentrations. Water in these areas may have high metal concentrations due to the combination of naturally occurring deposits and mine waste. Water samples are usually taken randomly within a contaminated area and offsite to identify the source of contamination and the pathway it travels, into the drinkable groundwater system or away from potable water sources. Accurate determination of heavy metal contamination is important to identify cumulative risks to people drinking water derived from these areas.

Treating Heavy Metal Contamination in Water

Heavy metal water contamination is a difficult expensive problem to address. Most cleanup activities use a pump and treat system where contaminated groundwater is pumped out of the ground, treated with activated carbon to remove contaminants and then replaced into the groundwater system. Because large volumes of water must be pumped and treated over long time periods, associated operation and maintenance systems are very expensive. There are some new technologies being developed that actually treat the water in the ground which operate more efficiently and quickly, decreasing costs.

If groundwater is contaminated with heavy metals, an alternative source of drinking water must be used to prevent harmful health effects, until the water is treated to meet standards protective of human health and the environment

Health Significance of Metals in the Environment

The metallic elements can be categorized into two groups. The heavy metals are those having densities five times greater than water, and the light metals, those having lesser densities. Well-known examples of heavy metallic elements are iron, lead, and copper. Examples of light metals are sodium, magnesium, and potassium. Humans consume metallic elements through both water and food. Some metals such as sodium, potassium, magnesium, calcium, and iron are found in living tissue and are essential to human life-biological anomalies arise when they are depleted or removed. Probably less well known is that currently no less than six other heavy metals including molybdenum, manganese, cobalt, copper, and zinc, have been linked to human growth, development, achievement, and reproduction (Vahrenkamp, 1979; Friberg and others, 1979). Even these metals, however, can become toxic or aesthetically undesirable when their concentrations are too great. Several heavy metals, like cadmium, lead, and mercury, are highly toxic at relatively low concentrations, can accumulate in body tissues over long periods of time, and are nonessential for human health. Table 1 lists metals according to their toxicities.

No specific health guidelines for heavy metals associated with suspended or bed sediments have been established by the U.S. Environmental Protection Agency. This lack of national guidelines based on concise scientific criteria causes' difficulty when evaluating the environmental effects of heavy metals in sediments. Several different criteria have been defined, primarily on the basis of observed effects on aquatic life (Lyman and others, 1987). Table 2 lists criteria for open-water disposal of polluted sediments that can be used for comparison purposes.

Table 1. Classification of naturally occurring metals according to their toxicity and availability in the hydrologic environment (from Wood, 1974)

[Metals that normally do not exist as dissolved species in natural waters or are very rare in crustal rocks are in italics]

Nontoxic		Low toxicity		Moderate to high toxicity			
Aluminum	Magnesium	Barium	*Praseodymium*	*Actinium*	Indium	Polonium	Uranium
Bismuth	Manganese	*Cerium*	*Promethium*	Antimony	*Iridium*	*Radium*	Vanadium
Calcium	Molybdenum	*Dysprosium*	*Rhenium*	Beryllium	Lead	*Ruthenium*	Zinc
Cesium	Potassium	*Erbium*	*Rhodium*	Boron	Mercury	Silver	*Zirconium*
Iron	Strontium	*Europium*	*Samarium*	Cadmium	Nickel	*Tantalum*	
Lithium	Rubidium	*Gadolinium*	Scandium	Chromium	*Niobium*	Thallium	
	Sodium	*Gallium*	*Terbium*	Cobalt	*Osmium*	Thorium	
		Germanium	Thulium	Copper	Palladium	*Titanium*	
		Gold	*Tin*	*Hafnium*	Platinum	*Tungsten*	
		Holmium	*Ytterbium*				
		Neodymium	Yttrium				

Table 2. U.S. Environmental Protection Agency maximum contaminant levels for heavy-metal concentrations in drinking water and water supporting aquatic life, and criteria for open-water disposal of polluted sediments

[µg/L, microgram per liter; µg/g, microgram per gram; >, greater than; <, less than; --, no guideline available]

	Cadmium	Chromium	Copper	Lead	Mercury	Uranium
Drinking water, in µg/L[1]	5	100	[2]1,000	15	2	[3]20
Water supporting aquatic life, in µg/L[4]	12	100	20	100	0.05	–
Natural sediments, nonpolluted, in µg/g[5]	--	<25	<25	<40	<1	–
Natural sediments, moderately polluted, in µg/g[5]	--	25 to 75	25 to 50	40 to 60	--	–
Natural sediments, heavily polluted, in µg/g[5]	>6	>75	>50	>60	>1	–

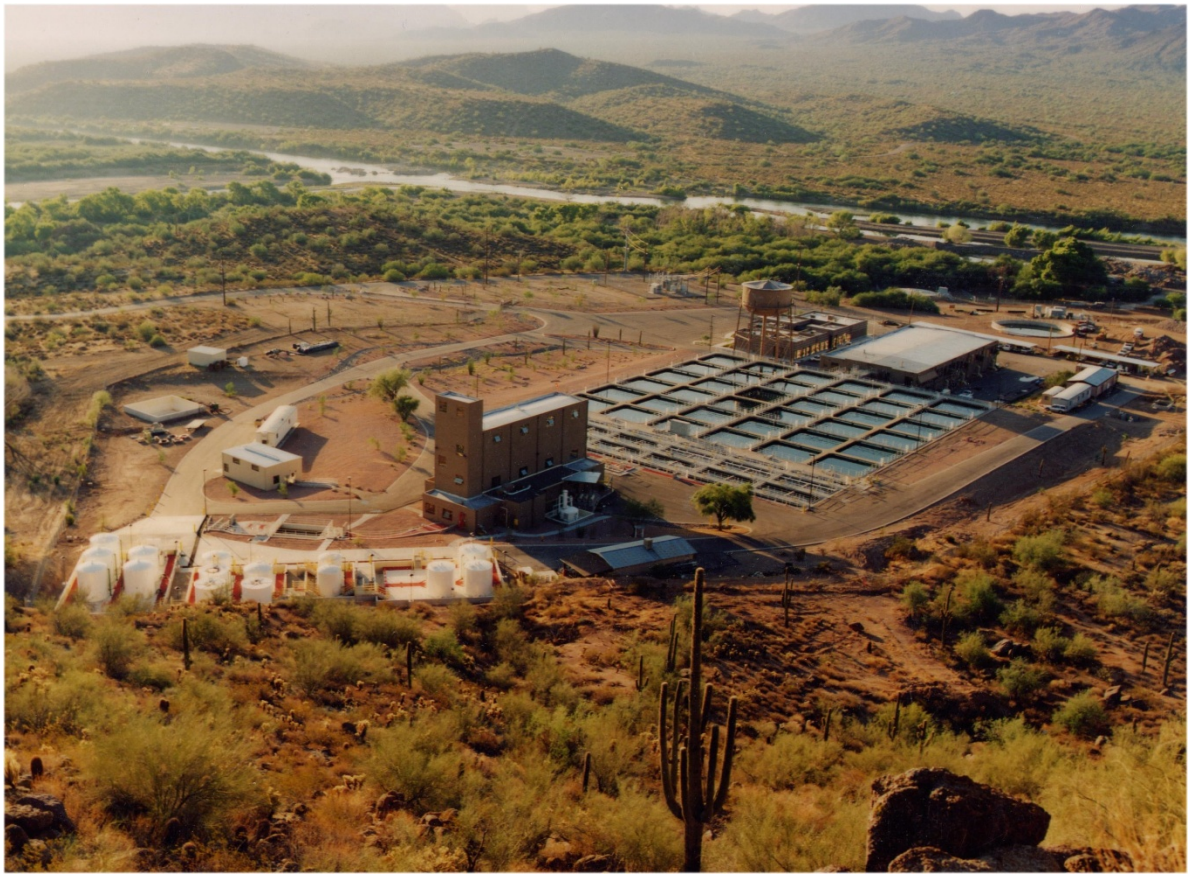
[1]U.S. Environmental Protection Agency, 1992.
[2]Secondary maximum contaminant level based on esthetic water quality.
[3]Proposed maximum contaminant level.
[4]U.S. Environmental Protection Agency, 1982.
[5]Great Lakes Water Quality Board, Dredging Subcommittee, 1982.

Water Treatment Section

For thousands of years, people have treated water intended for drinking to remove particles of solid matter, reduce health risks, and improve aesthetic qualities such as appearance, odor, color, and taste. As early as 2000 B.C., medical lore of India advised, "***Impure water should be purified by being boiled over a fire, or being heated in the sun or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool***."

The treatment needs of a water system are likely to differ depending on whether the system uses a groundwater or surface water source. Common surface water contaminants include turbidity, microbiological contaminants *(**Giardia*, **viruses and bacteria**) and low levels of a large number of organic chemicals. Groundwater contaminants include naturally occurring inorganic chemicals (such as arsenic, fluoride, radium, radon and nitrate) and a number of volatile organic chemicals (**VOCs**) that have recently been detected in localized areas.

When selecting among the different treatment options, the water supplier must consider a number of factors. These include regulatory requirements, characteristics of the raw water, configuration of the existing system, cost, operating requirements and future needs of the service area.



Here is a surface water conventional treatment facility next to a river.



Top Photograph - Final Rectangle Sedimentation Basin
Bottom - Clarifier



Preliminary Treatment

Most lakes and reservoirs are not free of logs, tree limbs, sticks, gravel, sand and rocks, weeds, leaves, and trash. If not removed, these will cause problems to the treatment plant's pumps and equipment. The best way to protect the plant is screening.

Bar screens are made of straight steel bars at the intake of the plant. The spacing of the horizontal bars will rank the size. Wire mesh screens are woven stainless steel material and the opening of the fabric is narrow. Both require manual cleaning.

Mechanical bar screens vary in size and use some type of raking mechanism that travels horizontally down the bars to scrap the debris off. The type of screening used depends on the raw water and the size of the intake.



Mechanical bar screen, above photograph.
Non-automated bar screen, below.

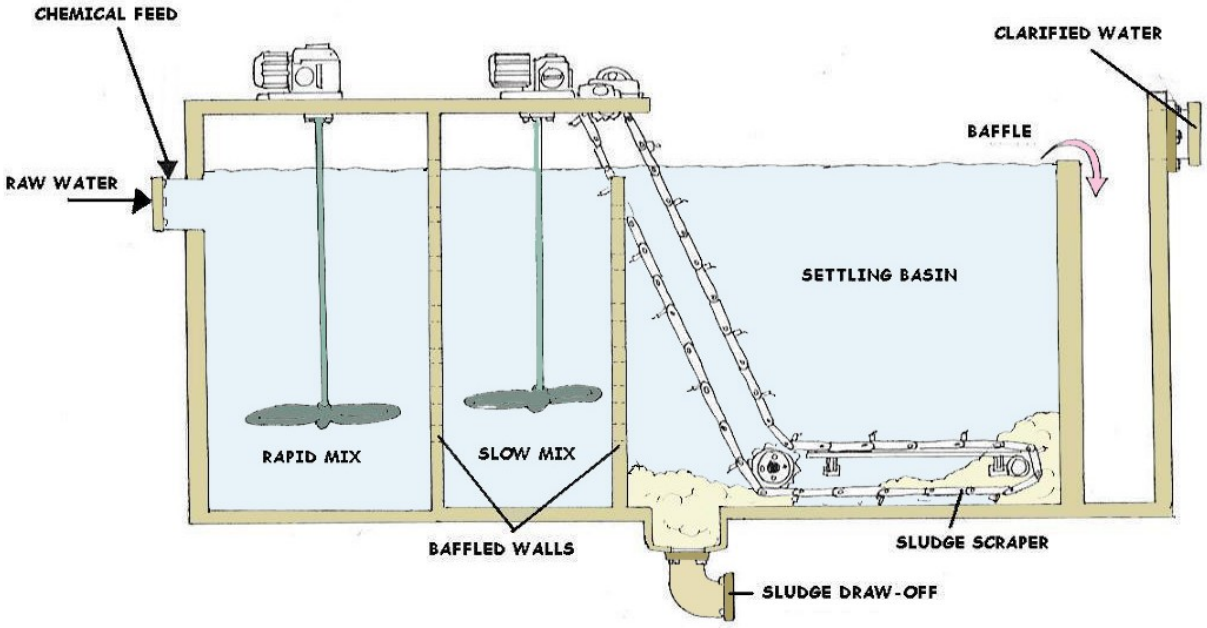


Pre-Sedimentation

Once the water passes the bar screens, sand and grit are still present. This will damage plant equipment and pipes, so it must be removed. This is generally done with either rectangular- or round-shaped clarifers. Sedimentation basins are also used after the flocculation process.



Let's first look at the components of a rectangular clarifier. Most are designed with scrapers on the bottom to move the settled sludge to one or more hoppers at the influent end of the tank. It could have a screw conveyor or traveling bridge used to collect the sludge. The most common is a chain and flight collector. Most designs will have baffles to prevent short circuiting and scum from entering the effluent.



HORIZONTAL BASIN CLARIFIER

Flights and Chains

The most important thing to consider is the sludge and scum collection mechanism known as the **"*flights and chains*".** They move the settled sludge to the hopper in the clarifier for return and they also remove the scum from the surface of the clarifier. The flights are usually wood or nonmetallic flights mounted on parallel chains. The motor shaft is connected through a gear reducer to a shaft which turns the drive chain. The drive chain turns the drive sprockets and the head shafts. The shafts can be located overhead or below.

Some clarifiers may not have scum removal equipment, so the configuration of the shaft may vary. As the flights travel across the bottom of the clarifier, wearing shoes are used to protect the flights. The shoes are usually metal and travel across a metal track.

To prevent damage due to overloads, a shear pin is used. The shear pin holds the gear solidly on the shaft so that no slippage occurs. Remember, the gear moves the drive chain. If a heavy load is put on the sludge collector system then the shear pin should break. This means that the gear would simply slide around the shaft and movement of the drive chain would stop.

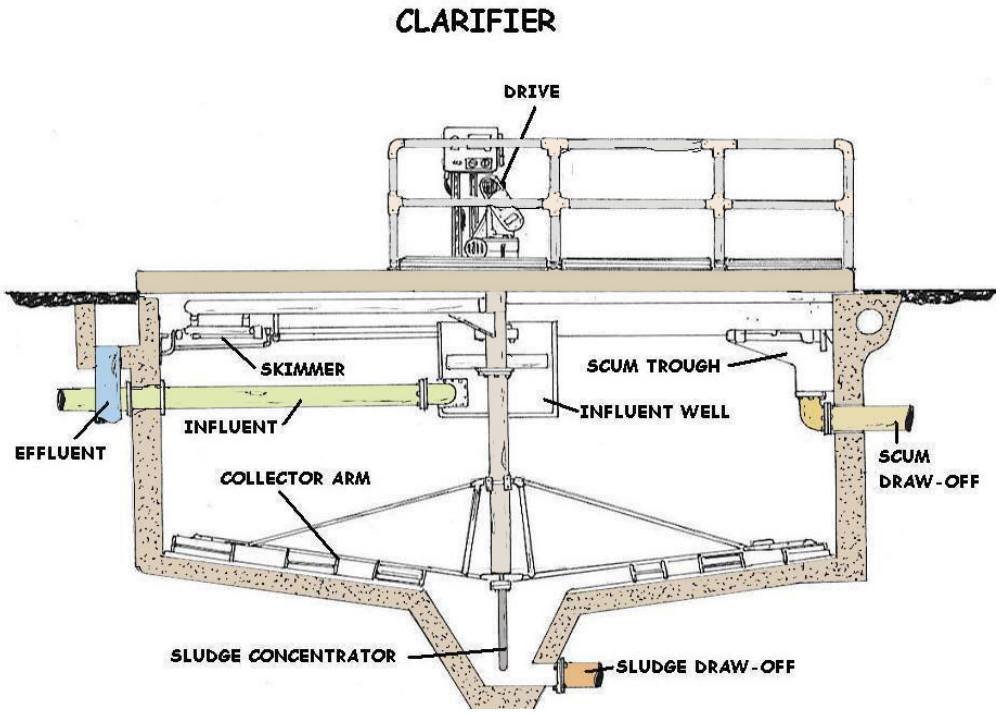


Rectangular basin flights and chains.

Circular Clarifiers

In some circular or square tanks, rotating scrapers are used. The diagram below shows a typical circular clarifier. The most common type has a center pier or column. The major mechanic parts of the clarifier are the drive unit; the sludge collector mechanism, and the scum removal system.





Circular clarifier and collector mechanism.

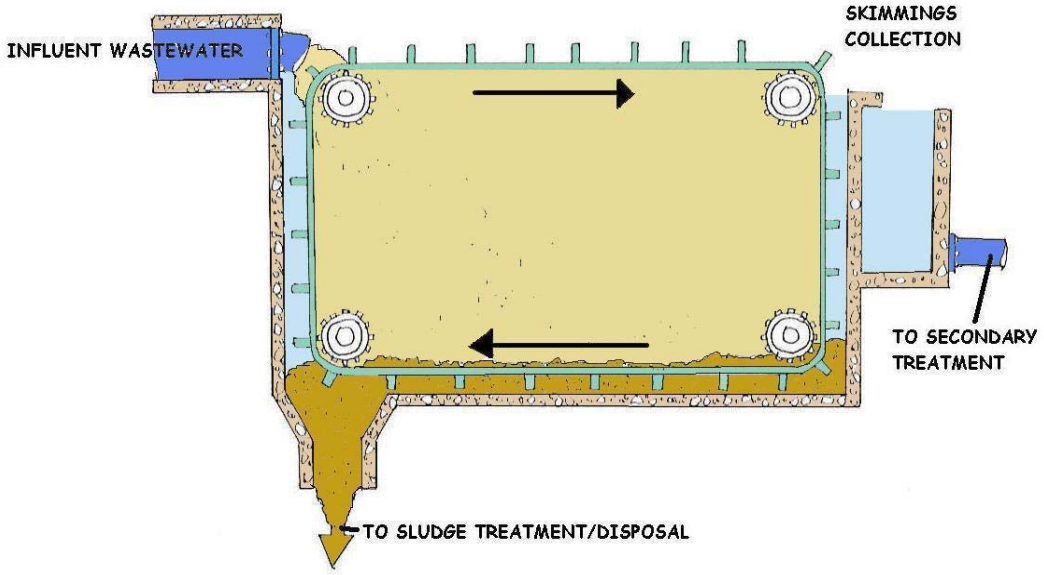
Pre-Treatment

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Clarifiers

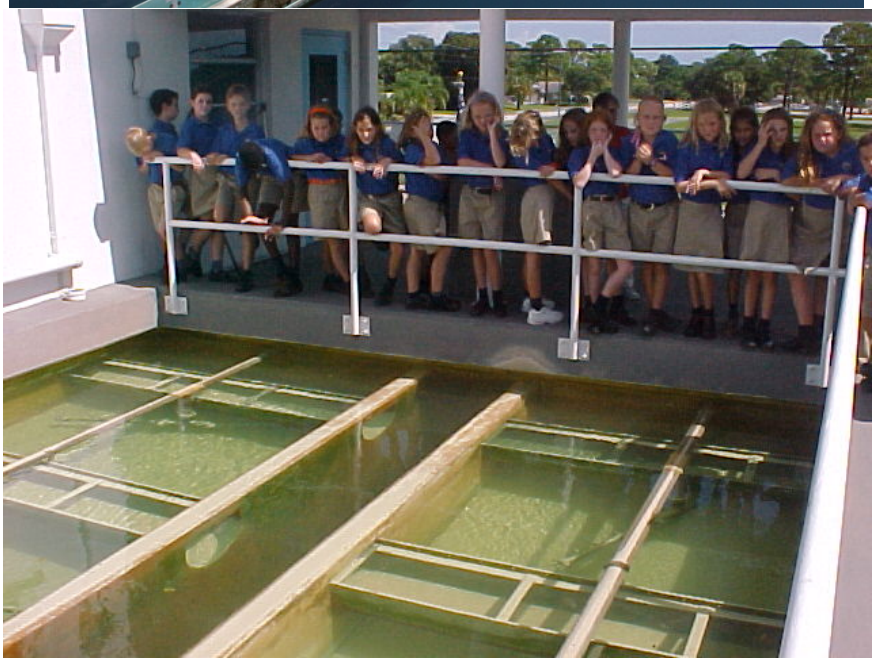
Let's first look at the components of a rectangular clarifier. Most are designed with scrapers on the bottom to move the settled sludge to one or more hoppers at the influent end of the tank. It could have a screw conveyor or traveling bridge used to collect the sludge. The most common is a chain and flight collector. Most designs will have baffles to prevent short-circuiting and scum from entering the effluent.



Direct Filtration Plant vs. Conventional Plant

The only difference is that the sedimentation process or step is omitted from the Direct Filtration plant.

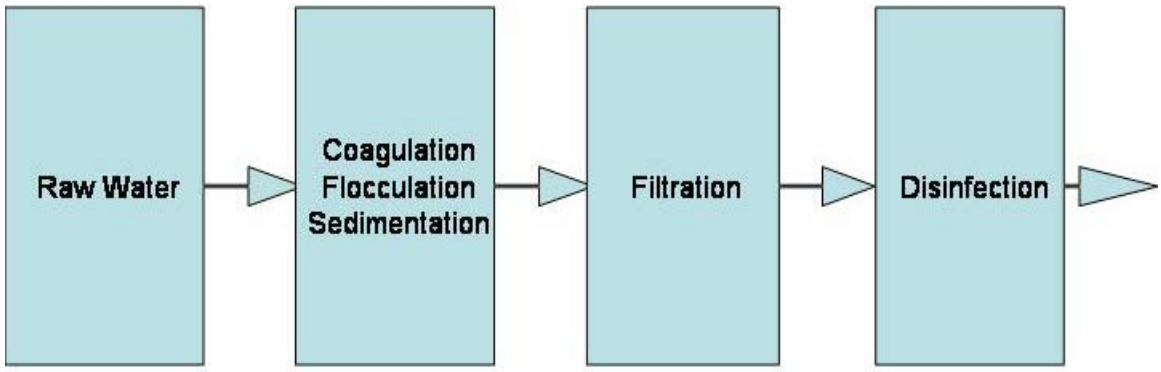




Tours of your facility are a wonderful public image tool. I know that many facilities are worried about the public and what could possibly happen, but if you can think positive, you may find more support and funding for your future projects.

Conventional Treatment Overview & Direct Filtration

Improving the clarity of surface water has always presented a challenge because source quality varies. Traditional treatments rely on expensive, construction-intensive processes with lengthy times.



Suspended particles carry an electrical charge which causes them to repel one another. The conventional process uses alum (aluminum sulfate) and cationic polymer to neutralize the charge. That allows suspended particles to clump together to form more easily filtered particles.

Alum combines with alkalinity in the raw water to form a white precipitate that neutralizes suspended particles' electrical charge and forms a base for coagulating those particles. Conventional technology uses a 30 to 50 mg/L alum dosage to form a large **floc** that requires extensive retention time to permit settling. Traditional filter systems use graded silica sand filter media. Since the sand grains all have about the same density, larger grains lay toward the bottom of the filter bed and finer grains lay at the top of the filter bed. As a result, filtration occurs only within the first few inches of the finer grains at the top of the bed.

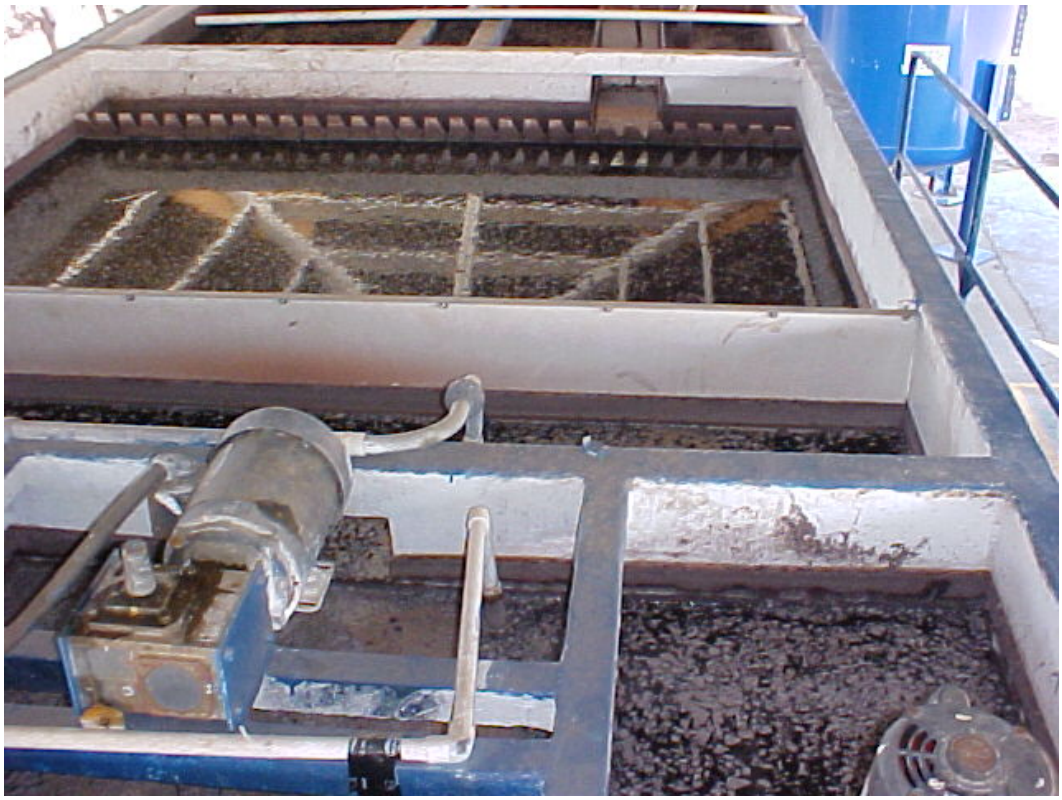
A depth filter has four layers of filtration media, each of different size and density. Light, coarse material lies at the top of the filter bed. The media become progressively finer and denser in the lower layers. Larger suspended particles are removed by the upper layers while smaller particles are removed in the lower layers. Particles are trapped throughout the bed, not in just the top few inches. That allows a depth filter to run substantially longer and use less backwash water than a traditional sand filter.

As suspended particles accumulate in a filter bed, the pressure drop through the filter increases. When the pressure difference between filter inlet and outlet increases by 5 - 10 psi (34 to 68 kPa) from the beginning of the cycle, the filter should be reconditioned. Operating beyond this pressure drop increases the chance of fouling - called ***"mud-balling"*** - within the filter.

The reconditioning cycle consists of an up-flow backwash followed by a down-flow rinse. Backwash is an up-flow operation, at about 14 gpm per square foot (34m/hr) of filter bed area that lasts about 10 minutes. Turbidity washes out of the filter bed as the filter media particles scour one another. The down-flow rinse settles the bed before the filter returns to service. Fast rinse lasts about 5 to 10 minutes.

Chemical pretreatment is often used to enhance filter performance, particularly when turbidity includes fine colloidal particles. Suspended particles are usually electrically charged. Feeding chemicals such as alum (aluminum sulfate), ferric chloride, or a cationic polymer neutralizes the charge, allowing the particles to cling to one another and to the filter media.

Chemical pretreatment may increase filtered water clarity, measured in NTU, by 90% compared with filtration alone. If an operator is present to make adjustments for variations in the raw water, filtered water clarity improvements in the range of 93 to 95% are achievable.



Example of a small water treatment package plant coagulation, flocculation and filtration all within a 20 foot area.

Package Plants

Representing a slight modification of conventional filtration technology, package plants are usually built in a factory, mounted on skids, and transported virtually assembled to the operation site.

These are appropriate for small community systems where full water treatment is desired, but without the construction costs and space requirements associated with separately constructed sedimentation basins, filter beds, clear wells, etc.

In addition to the conventional filtration processes, package plants are found as two types: tube-type clarifiers and adsorption clarifiers.

Rapid Sand Filtration

Also known as rapid-sand filtration, this is the most prevalent form of water treatment technology in use today. This filtration process employs a combination of physical and chemical processes in order to achieve maximum effectiveness, as follows:

Coagulation
At the Water Treatment Plant, aluminum sulfate, commonly called alum, is added to the water in the ***"flash mix"*** to cause microscopic impurities in the water to clump together. The alum and the water are mixed rapidly by the flash mixer. The resulting larger particles will be removed by filtration.

Coagulation is the process of joining together particles in water to help remove organic matter. When solid matter is too small to be removed by a depth filter, the fine particles must be coagulated, or ***"stuck together***" to form larger particles which can be filtered. This is achieved through the use of coagulant chemicals.

Coagulant chemicals are required since colloidal particles by themselves have the tendency to stay suspended in water and not settle out. This is primarily due to a negative charge on the surface of the particles. All matter has a residual surface charge to a certain degree. But since colloidal particles are so small, their charge per volume is significant. Therefore, the like charges on the particles repel each other, and they stay suspended in water.

Coagulant chemicals such as ***"alum***" (aluminum Sulfate) work by neutralizing the negative charge, which allows the particles to come together. Other coagulants are called "**cationic polymers**", which can be thought of as positively charged strings that attract the particles to them, and in the process, form a larger particle. Also, new chemicals have been developed which combine the properties of alum-type coagulants and cationic polymers. Which chemical is used depends on the application, and will usually be chosen by the engineer designing the water treatment system.

Aluminum Sulfate is the most widely used coagulant in water treatment. Coagulation is necessary to meet the current regulations for almost all potable water plants using surface water. Aluminum Sulfate is also excellent for removing nutrients such as phosphorous in wastewater treatment. Liquid Aluminum Sulfate is a 48.86% solution.

Large microorganisms, including algae and amoebic cysts, are readily removed by coagulation and filtration. Bacterial removals of 99% are also achievable. More than 98% of poliovirus type 1 was removed by conventional coagulation and filtration. Several recent studies have shown that bacterial and viral agents are attached to organic and inorganic particulates. Hence, removal of these particulates by conventional coagulation and filtration is a major component of effective treatment for the removal of pathogens.

Flocculation
The process of bringing together destabilized or coagulated particles to form larger masses which can be settled and/or filtered out of the water being treated. In this process, which follows the rapid mixing, the chemically treated water is sent into a basin where the suspended particles can collide, agglomerate (stick together), and form heavier particles called "**floc**". Gentle agitation of the water and appropriate detention times (the length of time water remains in the basin) help facilitate this process.

The water is slowly mixed in contact chambers allowing the coagulated particles, now called "**floc,**" to become larger and stronger. As these floc particles mix in the water, bacteria and other microorganisms are caught in the floc structure.

Pre-Sedimentation
Depending on the quality of the source water, some plants have pre-sedimentation.
A. To allow larger particles time to settle in a reservoir or lake (sand, heavy silt) reducing solid removal loads.
B. Provides an equalization basin which evens out fluctuations.

Sedimentation Basin Zones
A. Inlet Zone
B. Settling Zone
C. Sludge Zone
D. Outlet Zone



Shapes for a Sedimentation Basin
A. Rectangular Basins
B. Circular Basins
C. Square Basins
D. Double deck Basins

Sedimentation
The process of suspended solid particles settling out (going to the bottom of the vessel) in water.

Following flocculation, a sedimentation step may be used. During sedimentation, the velocity of the water is decreased so that the suspended material, including flocculated particles, can settle out by gravity. Once settled, the particles combine to form a sludge that is later removed from the bottom of the basin.

Filtration
A water treatment step used to remove turbidity, dissolved organics, odor, taste and color. The water flows by gravity through large filters of anthracite coal, silica sand, garnet and gravel. The floc particles are removed in these filters. The rate of filtration can be adjusted to meet water consumption needs. Filters for suspended particle removal can also be made of graded sand, granular synthetic material, screens of various materials, and fabrics.



The most widely used are rapid-sand filters in tanks. In these units, gravity holds the material in place and the flow is downward. The filter is periodically cleaned by a reversal of flow and the discharge of back-flushed water into a drain.

Cartridge filters made of fabric, paper, or plastic material are also common and are often much smaller and cheaper, as well as disposable. Filters are available in several ratings, depending on the size of particles to be removed. Activated carbon filters, described earlier, will also remove turbidity, but would not be recommended for that purpose only.

With most of the larger particles settled out, the water now goes to the filtration process. At a rate of between 2 and 10 gpm per square foot, the water is filtered through an approximate 36" depth of graded sand. Anthracite coal or activated carbon may also be included in the sand to improve the filtration process, especially for the removal of organic contaminants and taste and odor problems. The filtration process removes the following types of particles:

- Silts and clay
- Colloids
- Biological forms
- Floc

Four Desirable Characteristics of Filter Media

- Good hydraulic characteristics (permeable)
- Does not react with substances in the water (inert and easy to clean)
- Hard and durable
- Free of impurities and insoluble in water

Evaluation of overall filtration process performance should be conducted on a routine basis, at least once per day. Poor chemical treatment can often result in either early turbidity breakthrough or rapid head loss buildup. The more uniform the media, the slower head loss buildup. All water treatment plants that use surface water are governed by the U.S. EPA's Surface Water Treatment Rules or **SWTR**.

Declining Rate Filters

The flow rate will vary with head loss. Each filter operates at the same rate, but can have a variable water level. This system requires an effluent control structure (weir) to provide adequate media submergence.

Detention Time

The actual time required for a small amount of water to pass through a sedimentation basin at a given rate of flow, or the calculated time required for a small amount of liquid to pass through a tank at a given rate of flow.

$$\text{Detention Time} = \frac{(\text{Basin Volume, Gallons})\ (24\ \text{Hours/day})}{\text{Flow, Gallons/day}}$$

Disinfection

Chlorine is added to the water at the flash mix for pre-disinfection. The chlorine kills or inactivates harmful microorganisms. Chlorine is added again after filtration for post-disinfection.

Jar Testing (*More information later in manual. See the Water Quality Section*)

Jar testing traditionally has been done on a routine basis in most water treatment plants to control the coagulant dose. Much more information, however, can be obtained with only a small modification in the conventional method of jar testing. It is the quickest and most economical way to obtain good reliable data on the many variables which affect the treatment process. These include:

- Determination of most effective coagulant.
- Determination of optimum coagulation pH for the various coagulants.
- Evaluation of most effective polymers.
- Optimum point of application of polymers in the treatment train.
- Optimum sequence of application of coagulants, polymers, and pH adjustment chemicals.
- Best flocculation time.

pH
Expression of a basic or acid condition of a liquid. The range is from 0-14, zero being the most acid and 14 being the most alkaline. A pH of 7 is considered to be neutral. Most natural water has a pH between 6.0 and 8.5.

Caustic
NaOH (also called Sodium Hydroxide) is a strong chemical used in the treatment process to neutralize acidity, increase alkalinity, or raise the pH value.

Polymer
A type of chemical, when combined with other types of coagulants, aids in binding small suspended particles to larger particles to help in the settling and filtering processes.

Post-Chlorine
Where the water is chlorinated to make sure it holds a residual in the distribution system.

Pre-Chlorine
Where the raw water is dosed with a large concentration of chlorine.



Pre-Chlorination
The addition of chlorine before the filtration process will help:

- Control algae and slime growth
- Control mud ball formation
- Improve coagulation
- Precipate iron

Raw Turbidity
The turbidity of the water coming to the treatment plant from the raw water source.

Settled Solids
Solids that have been removed from the raw water by the coagulation and settling processes.

Hydrofluosilicic Acid
(H2SiF6) a clear, fuming corrosive liquid with a pH ranging from 1 to 1.5. Used in water treatment to fluoridate drinking water.

Corrosion Control
The pH of the water is adjusted with sodium carbonate, commonly called soda ash. Soda ash is fed into the water after filtration.

Zinc Orthophosphate
A chemical used to coat the pipes in the distribution system to inhibit corrosion.

Taste and Odor Control
Powdered activated carbon (**PAC**) is occasionally added for taste and odor control. PAC is added to the flash mix.

Water Quality
Water testing is conducted throughout the treatment process. Items like turbidity, pH, and chlorine residual are monitored and recorded continuously. Some items are tested several times per day, some once per quarter and others once per year.

Sampling
Collect the water sample at least 6 inches under the surface by plunging the container mouth down into the water and turning the mouth towards the current by dragging the container slowly horizontal. Care should be taken not to disturb the bottom of the water source or along the sides. so as not to stir up any settled solids. This would create erroneous results.

Chemical feed and rapid mix
Chemicals are added to the water in order to improve the subsequent treatment processes. These may include pH adjusters and coagulants. Coagulants are chemicals, such as alum, that neutralize positive or negative charges on small particles, allowing them to stick together and form larger particles that are more easily removed by sedimentation (**settling**) or filtration.

A variety of devices, such as baffles, static mixers, impellers, and in-line sprays can be used to mix the water and distribute the chemicals evenly.

Short-Circuiting
Short-Circuiting is a condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable, since it may result in shorter contact, reaction, or settling times in comparison with the presumed detention times.

Tube Settlers
This modification of the conventional process contains many metal ***"tubes***" that are placed in the sedimentation basin, or clarifier. These tubes are approximately 1 inch deep and 36 inches long, split-hexagonal shape, and installed at an angle of 60 degrees or less.

These tubes provide for a very large surface area upon which particles may settle as the water flows upwards. The slope of the tubes facilitates gravity settling of the solids to the bottom of the basin, where they can be collected and removed. The large surface settling area also means that adequate clarification can be obtained with detention times of 15 minutes or less. As with conventional treatment, this sedimentation step is followed by filtration through mixed media.

Adsorption Clarifiers
The concept of the adsorption clarifier package plant was developed in the early 1980's. This technology uses an up-flow clarifier with low-density plastic bead media, usually held in place by a screen. This adsorption media is designed to enhance the sedimentation/clarification process by combining flocculation and sedimentation into one step. In this step, turbidity is reduced by adsorption of the coagulated and flocculated solids onto the adsorption media and onto the solids already adsorbed onto the media.

Air scouring cleans adsorption clarifiers followed by water flushing. Cleaning of this type of clarifier is initiated more often than filter backwashing because the clarifier removes more solids. As with the tube-settler type of package plant, the sedimentation/clarification process is followed by mixed-media filtration and disinfection to complete the water treatment.

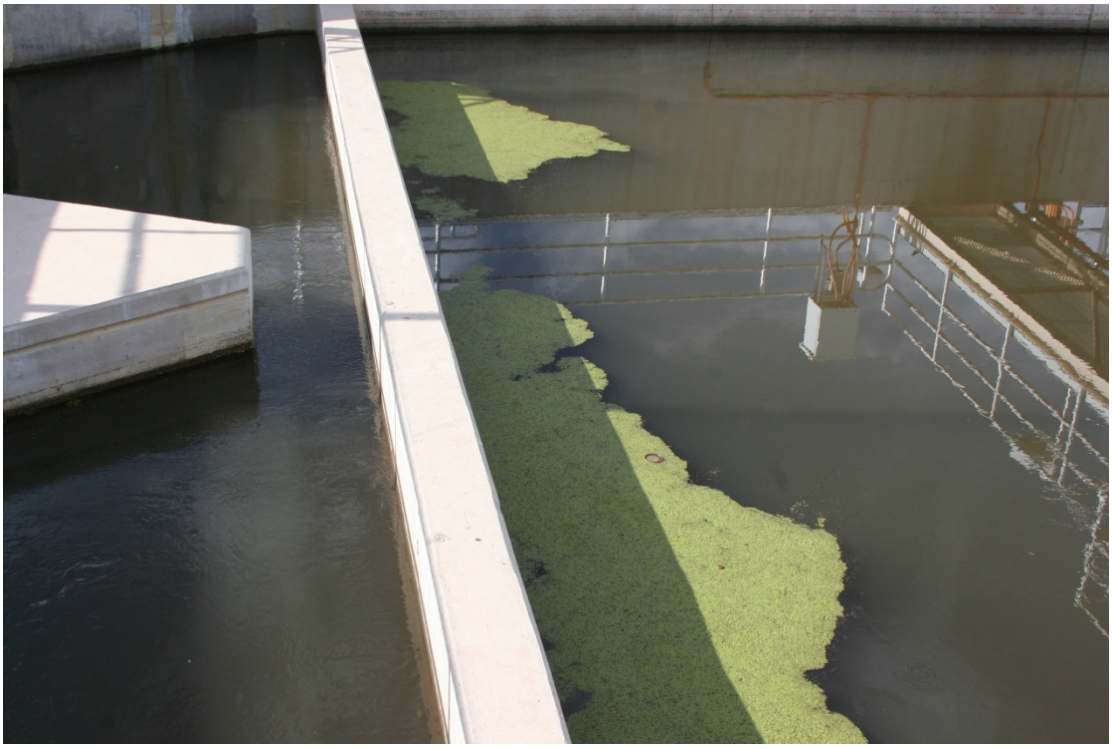
Clearwell

The final step in the conventional filtration process, the clearwell provides temporary storage for the treated water. The two main purposes for this storage are to have filtered water available for backwashing the filter, and to provide detention time (or contact time) for the chlorine (or other disinfectant) to kill any microorganisms that may remain in the water.



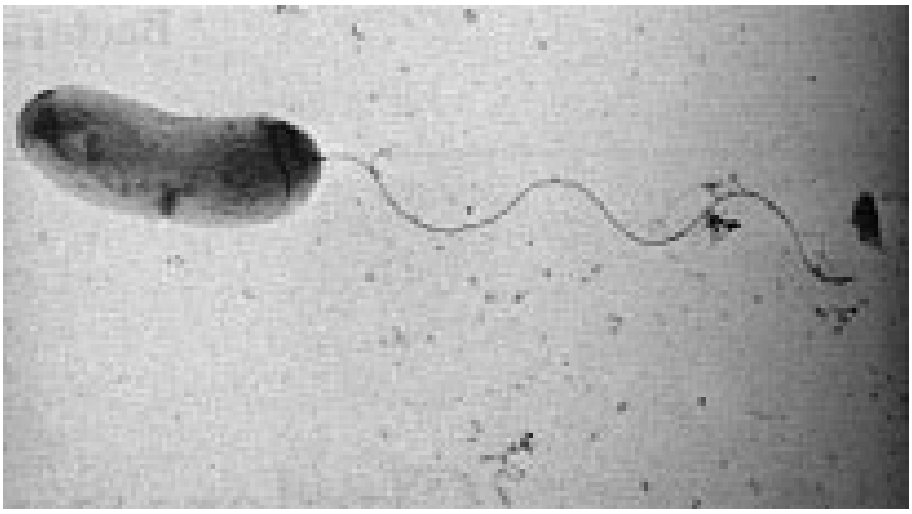
Dried backwash channels on top of a cleaned filter bed.





Pretreatment sedimentation basin, bottom photograph, sludge drying bed with new grass. Time to turn the sludge over.





Cholera, top and bottom photos



EPA Filter Backwash Rule

The U.S. Environmental Protection Agency (**EPA**) has finalized the Long Term 1 Enhanced Surface Water Treatment Rule and Filter Backwash Rule (**LT1FBR**) to increase protection of finished drinking water supplies from contamination by ***Cryptosporidium*** and other microbial pathogens.

This rule will apply to public water systems using surface water or ground water under the direct influence of surface water. This rule will extend protections against ***Cryptosporidium*** and other disease-causing microbes to the 11,500 small water systems which serve fewer than 10,000 people annually.

This rule also establishes filter backwash requirements for certain public water systems of all sizes. The filter backwash requirements will reduce the potential risks associated with recycling contaminants removed during the filtration process.

Background
The Safe Drinking Water Act (**SDWA**) requires the EPA to set enforceable standards to protect public health from contaminants which may occur in drinking water. The EPA has determined that the presence of microbiological contaminants is a health concern. If finished water supplies contain microbiological contaminants, disease outbreaks may result. Disease symptoms may include diarrhea, cramps, nausea, possibly jaundice, and headaches and fatigue. The EPA has set enforceable drinking water treatment requirements to reduce the risk of waterborne disease outbreaks. Treatment technologies such as filtration and disinfection can remove or inactivate microbiological contaminants.

Physical removal is critical to the control of *Cryptosporidium* because it is highly resistant to standard disinfection practice. Cryptosporidiosis may manifest itself as a severe infection that can last several weeks and may cause the death of individuals with compromised immune systems. In 1993, *Cryptosporidium* caused over 400,000 people in Milwaukee to experience intestinal illness. More than 4,000 were hospitalized, and at least 50 deaths were attributed to the cryptosporidiosis outbreak.

The 1996 Amendments to SDWA require the EPA to promulgate an Interim Enhanced Surface Water Treatment Rule (**IESWTR**) and a Stage 1 Disinfection Byproducts Rule (announced in December 1998). The IESWTR set the first drinking water standards to control *Cryptosporidium* in large water systems, by establishing filtration and monitoring requirements for systems serving more than 10,000 people each. The LT1FBR proposal builds on those standards by extending the requirements to small systems.

The 1996 Amendments also required the EPA to promulgate a Long Term 1 Enhanced Surface Water Treatment Rule (for systems serving less than 10,000 people) back in November, 2000 ((1412(b)(2)(C)) and also require the EPA to "***promulgate a regulation to govern the recycling of filter backwash water within the treatment process of a public water system***" back in August, 2000 ((1412(b)(14)). The current rule includes provisions addressing both of these requirements.

What will the LT1FBR require?
The LT1FBR provisions will apply to public water systems using surface water or ground water under the direct influence of surface water systems.

LT1 Provisions - Apply to systems serving fewer than 10,000 people, and fall into the three following categories:

Turbidity

- Conventional and direct filtration systems must comply with specific combined filter effluent turbidity requirements;
- Conventional and direct filtration systems must comply with individual filter turbidity requirements;

Disinfection Benchmarking

- Public water systems will be required to develop a disinfection profile unless they perform applicability monitoring which demonstrates their disinfection byproduct levels are less than 80% of the maximum contaminant levels;
- If a system considers making a significant change to their disinfection practice they must develop a disinfection benchmark and receive State approval for implementing the change.

Other Requirements

- Finished water reservoirs for which construction begins after the effective date of the rule must be covered; and
- Unfiltered systems must comply with updated watershed control requirements that add Cryptosporidium as a pathogen of concern.

FBR Provisions - Apply to all systems which recycle regardless of population served:

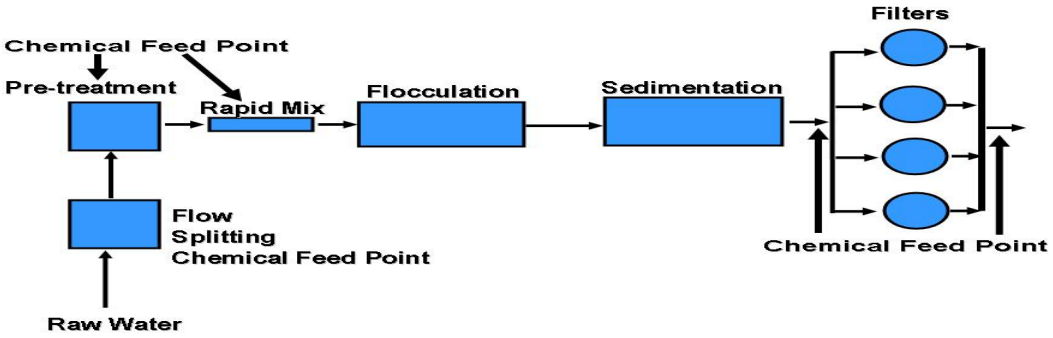
- Recycle systems will be required to return spent filter backwash water, thickener supernatant, and liquids from the dewatering process prior to the point of primary coagulant addition unless the State specifies an alternative location;
- Direct filtration systems recycling to the treatment process must provide detailed recycle treatment information to the State, which may require that modifications to the recycle practice be made, and;
- Conventional systems that practice direct recycle, employ 20 or fewer filters to meet production requirements during a selected month, and recycle spent filter backwash water, thickener supernatant, and/or liquids from the dewatering process within the treatment process must perform a one month, one-time recycle self-assessment. The self-assessment requires hydraulic flow monitoring and that certain data be reported to the State, which may require that modifications to the recycle practice be made to protect public health.



Often under the filtration basins are work tunnels, complex machinery, gauges and huge water pumps.

The Filtration Process

Removal of suspended solids by filtration plays an important role in the natural treatment of groundwater as it percolates through the soil. It is also a major part of most water treatment. Groundwater that has been softened or treated through iron and manganese removal will require filtration to remove floc created by coagulation or oxidation processes. Since surface water sources are subject to run-off and do not undergo natural filtration, it must be filtered to remove particles and impurities.



The filter used in the filtration process can be compared to a sieve or microstrainer that traps suspended material between the grains of filter media. However, since most suspended particles can easily pass through the spaces between the grains of the filter media, straining is the least important process in filtration.



The photograph on the right illustrates debris removed during the backwash process. The particles are trapped on top of the filter media and trapped within the media.

Filtration primarily depends on a combination of complex physical and chemical mechanisms, the most important being adsorption. Adsorption is the process of particles sticking onto the surface of the individual filter grains or onto the previously deposited materials. The forces that attract and hold the particles to the grains are the same as those that work in coagulation and flocculation. In fact, some coagulation and flocculation may occur in the filter bed, especially if coagulation and flocculation of the water before filtration was not properly controlled. Incomplete coagulation can cause serious problems in filter operation.



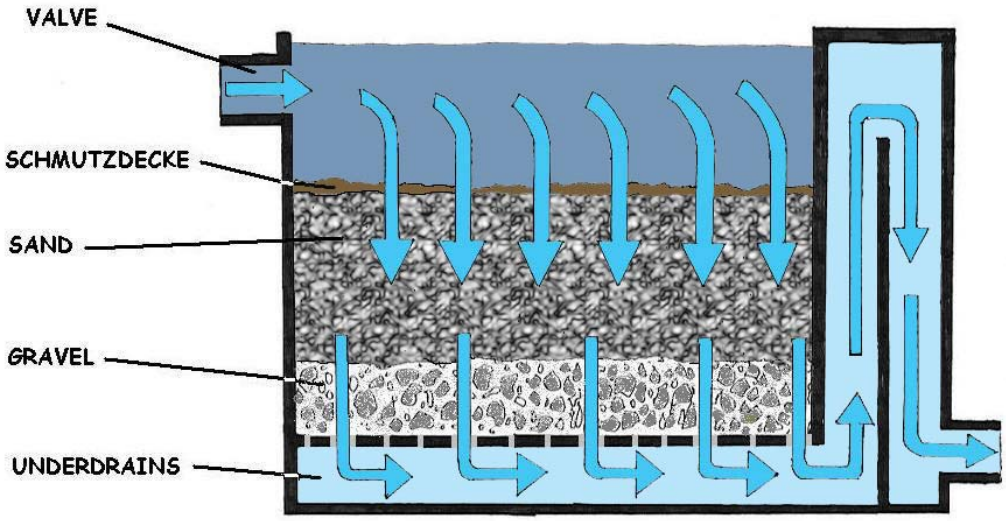
The photo on the right shows small glass beads laid on top of a sieve.



Filtration Methods: The conventional type of water treatment filtration method includes coagulation, flocculation, sedimentation, and filtration. Direct filtration method is similar to conventional except that the sedimentation step is omitted. Slow sand filtration process does not require pretreatment, has a flow of 0.1 gallons per minute per square foot of filter surface area, and is simple to operate and maintain. Diatomaceous earth method uses a thin layer of fine siliceous material on a porous plate. This type of filtration medium is only used for water with low turbidity. Sedimentation, adsorption, and biological action treatment methods are a filtration process that involves a number of interrelated removal mechanisms. Demineralization is primarily used to remove total dissolved solids from industrial wastewater, municipal water, and seawater.

Types of Filters

Several types of filters are used for water treatment. The earliest ones developed were the slow sand filters. They typically have filter rates of around 0.05 gpm/ft^2 of surface area. This type of filter requires large filter areas. The top several inches of the sand has to be removed regularly, usually by hand due to the mass of growing material ("***schmutzdecke***") that collects in the filter. The sand removed is usually washed and returned to the filter. These filters are still in use in some small plants, especially in the western United States, as well as in many developing countries. They may also be used as a final step in wastewater treatment. Most filters are classified by filtration rate, type of filter media, or type of operation into:

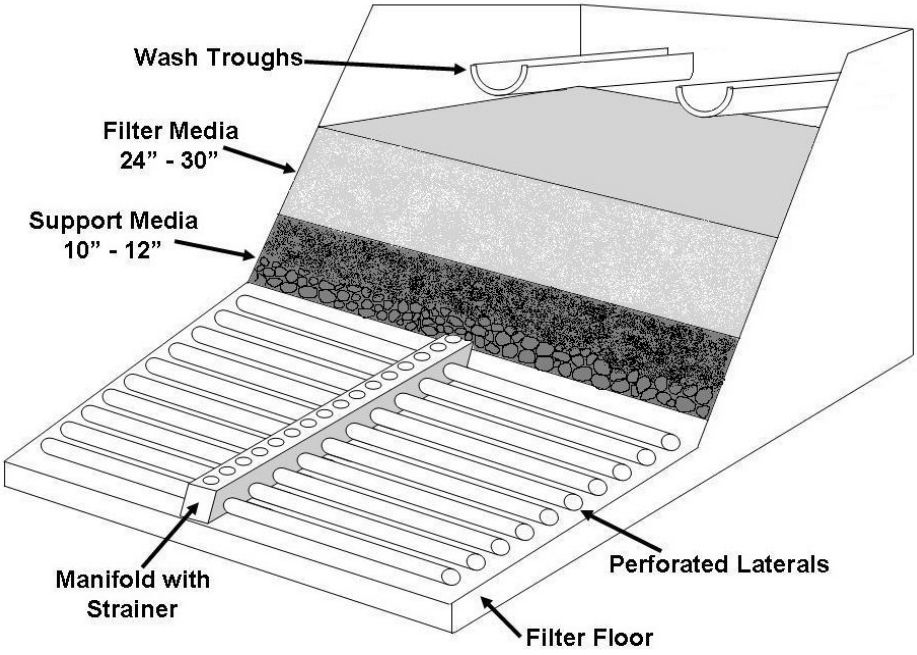


SLOW SAND FILTER

A. Gravity Filters
    1. Rapid Sand Filters
    2. High Rate Filters
        -Dual media
        -Multi-media
B. Pressure Filters
    -Sand or Multi-media

Rapid Sand Filters
Rapid sand filters can accommodate filter rates 40 times those of slow sand filters. The major parts of a rapid sand filter are:

- Filter tank or filter box
- Filter sand or mixed-media
- Gravel support bed
- Underdrain system
- Wash water troughs
- Filter bed agitators



The filter tank is generally constructed of concrete and is most often rectangular. Filters in large plants are usually constructed next to each other in a row, allowing the piping from the sedimentation basins to feed the filters from a central pipe gallery. Some smaller plants are designed with the filters forming a square of four filters with a central pipe gallery feeding the filters from a center well.

Filter Sand

The filter sand used in rapid sand filters is manufactured specifically for the purpose of water filtration. Most rapid sand filters contain 24-30 inches of sand, but some newer filters are deeper. The sand used is generally 0.4 to 0.6 mm in diameter. This is larger than the sand used in slow rate filtration. The coarser sand in the rapid filters has larger voids that do not fill as easily. The gravel installed under the sand layer(s) in the filter prevents the filter sand from being lost during the operation. The under-gravel also distributes the backwash water evenly across the total filter. This under-gravel supports the filter sand and is usually graded in three to five layers, each generally 6-18 inches in thickness, depending on the type of underdrain used.

Underdrain

The filter underdrain can be one of many types, such as:

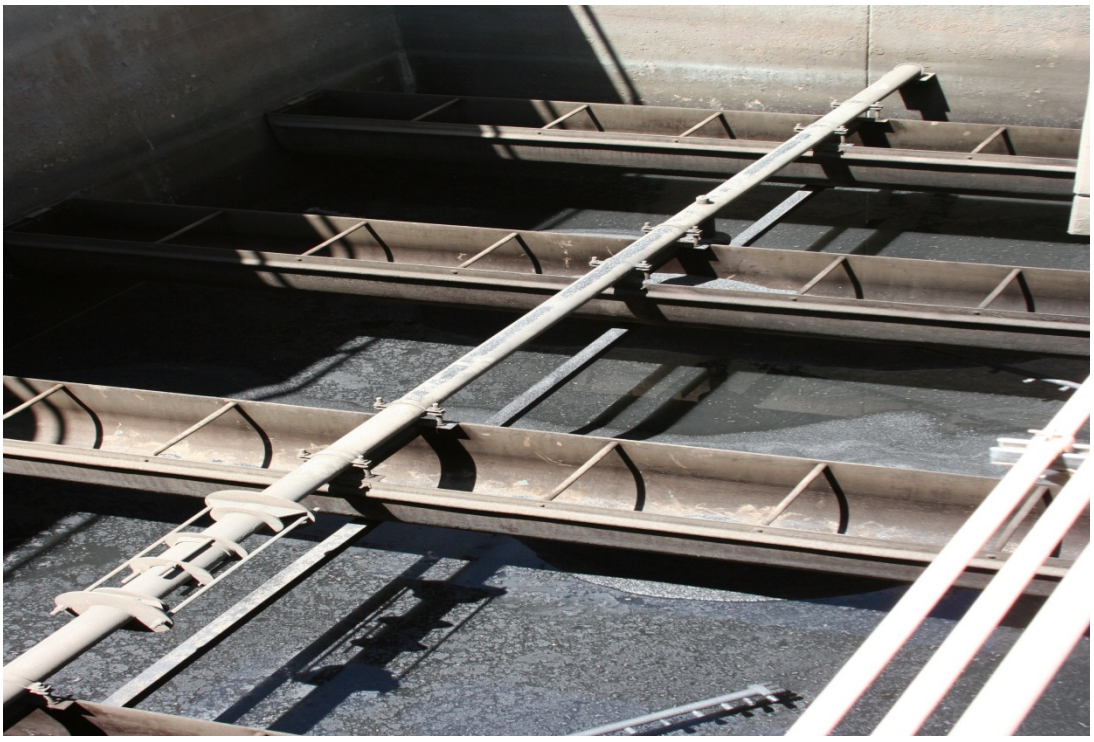
- Pipe laterals
- False floor
- Leopold system
- Porous plates or strainer nozzles
- Pipe laterals

A pipe lateral system uses a control manifold with several perforated laterals on each side. Piping materials include cast iron, asbestos cement, and PVC. The perforations are usually placed on the underside of the laterals to prevent them from plugging with sand. This also allows the backwash to be directed against the floor, which helps keep the gravel and sand beds from being directly disturbed by the high velocity water jets.

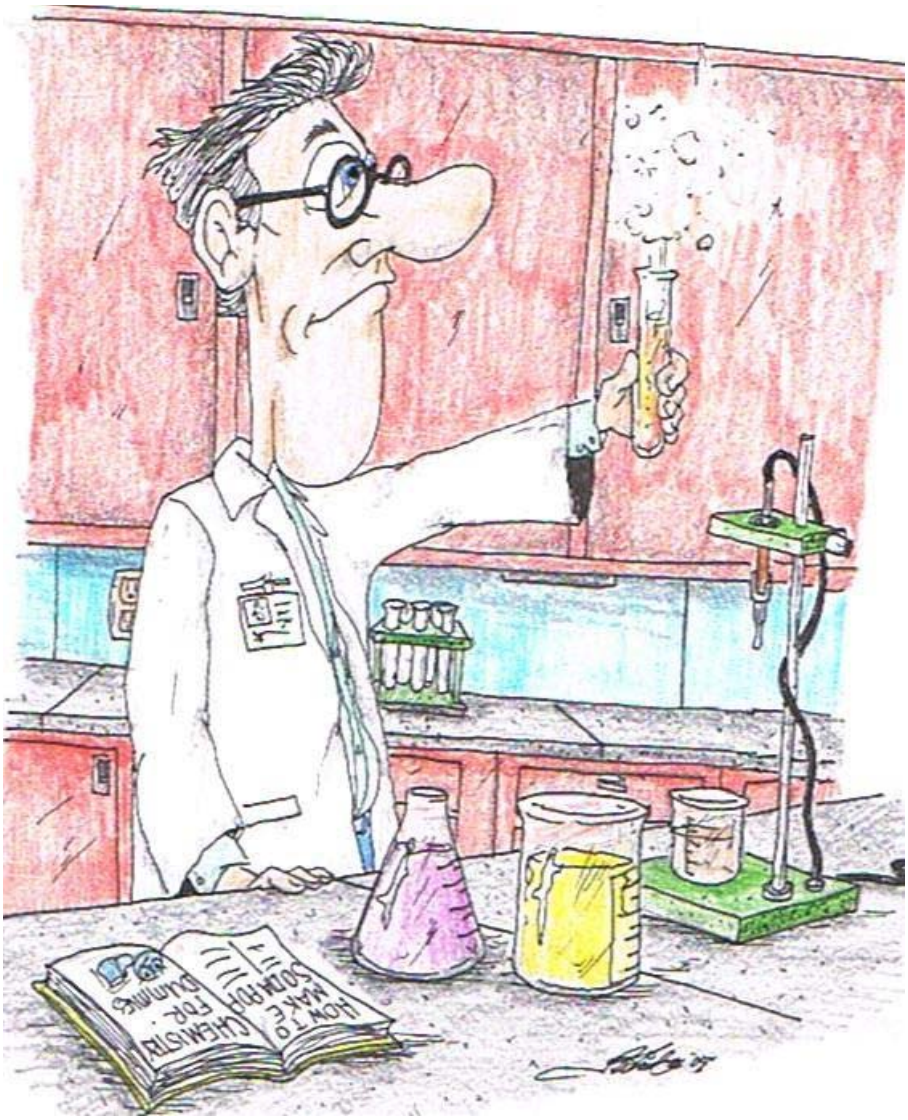
False floor
The false floor design of a filter underdrain is used together with a porous plate design or with screens that retain the sand when there is no undergravel layer. This type of underdrain allows the plenum or open space under the floor to act as the collection area for the filtered water and for the distribution of the filter backwash water.

Leopold system
The Leopold system consists of a series of clay or plastic blocks that form the channels to remove the filtered water from the filter and distribute the backwash water. This type of underdrain is generally used with an undergravel layer, although some new designs allow for sand retention without gravel.

Washwater Troughs
Washwater troughs placed above the filter media collect the backwash water and carry it to the drain system. Proper placement of these troughs is very important to ensure that the filter media is not carried into the troughs during the backwash and removed from the filter. The wash troughs must be installed at the same elevation so that they remove the backwash evenly from the filter and so that an even head is maintained across the entire filter. These backwash troughs are constructed from concrete, plastic, fiberglass, or other corrosion-resistant materials.



The photograph above shows exposed filter troughs.



Nature of turbidity: The turbidity in natural surface waters is composed of a large number of sizes of particles. The sizes of particles can be changing constantly, depending on precipitation and manmade factors. When heavy rains occur, runoff into streams, rivers, and reservoirs occurs, causing turbidity levels to increase. In most cases, the particle sizes are relatively large and settle relatively quickly in both the water treatment plant and the source of supply. However, in some instances, fine, colloidal material may be present in the supply, which may cause some difficulty in the coagulation process.

Generally, higher turbidity levels require higher coagulant dosages. However, seldom is the relationship between turbidity level and coagulant dosage linear. Usually, the additional coagulant required is relatively small when turbidities are much higher than normal due to higher collision probabilities of the colloids during high turbidities. Conversely, low turbidity waters can be very difficult to coagulate due to the difficulty in inducing collision between the colloids. In this instance, floc formation is poor, and much of the turbidity is carried directly to the filters. Organic colloids may be present in a water supply due to pollution, and these colloids can be difficult to remove in the coagulation process. In this situation, higher coagulant dosages are generally required.

Jar Test Section

Jar testing, to determine the proper coagulant dosage, continues to be one of the most effective tools available to surface water plant operators. Finished water quality, cost of production, length of filter runs, and overall filter life all depend on the proper application of chemicals to the raw water entering the treatment plant.

Instructions
The jar test, as with any coagulant test, will only provide accurate results when properly performed. Because the jar test is intended to simulate conditions in your plant, developing the proper procedure is very important. Take time to observe what happens to the raw water in your plant after the chemicals have been added, then simulate this during the jar test. **THE RPM OF THE STIRRER AND THE MINUTES TO COMPLETE THE TEST DEPEND ON CONDITIONS IN YOUR PLANT.** If, for instance, your plant does not have a static or flash mixer, starting the test at high rpm would provide misleading results. This rule applies to flocculator speed, length of settling time and floc development. Again, operate the jar test to simulate conditions in **YOUR** plant.



1. SCOPE
1.1 This practice covers a general procedure for the evaluation of a treatment to reduce dissolved, suspended, colloidal, and non-settleable matter from water by chemical coagulation-flocculation, followed by gravity settling. The procedure may be used to evaluate color, turbidity, and hardness reduction.
1.2 The practice provides a systematic evaluation of the variables normally encountered in the coagulation-flocculation process.
1.3 This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Terms **Great information for your assignment**

Flocculation - Agglomeration of particles into groups, thereby increasing the effective diameter.

Coagulation - A chemical technique directed toward destabilization of colloidal particles.

Turbidity - A measure of the presence of suspended solid material.

Colloidal – A suspension of small particles; a suspension of small particles dispersed in another substance.

Turbidity

Particles less than or about 1 to 10 μm in diameter (primarily colloidal particles) will not settle out by gravitational forces, therefore making them very difficult to remove. These particles are the primary contributors to the turbidity of the raw water causing it to be ***"cloudy".*** The most important factor(s) contributing to the stability of colloidal particles is not their mass, but their surface properties.

This idea can be better understood by relating the colloidal particles' large surface area to their small volume (**S/V**) ratio resulting from their very small size. In order to remove these small particles we must either filter the water or somehow incorporate gravitational forces such that these particles will *settle* out. In order to have gravity affect these particles, we must somehow make them larger, somehow have them come together (agglomerate); in other words, somehow make them ***"stick"*** together, thereby increasing their size and mass.

The two primary forces that control whether or not colloidal particles will agglomerate are:

Repulsive force

An electrostatic force called the **"Zeta Potential**" -

$$\zeta = \frac{4\pi q d}{D}$$

Where:

ζ = Zeta Potential
q = charge per unit area of the particle
d = thickness of the layer surrounding the shear surface through which the charge is effective
D = dielectric constant of the liquid

Attractive force

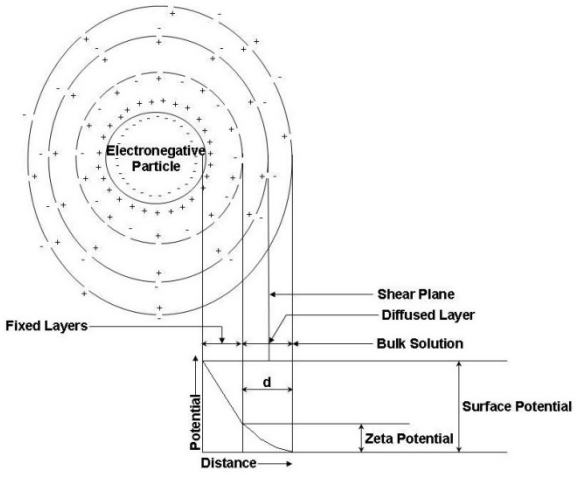
Force due to van der Waals forces

Van der Waals forces are weak forces based on a polar characteristic induced by neighboring molecules.

When two or more nonpolar molecules, such as He, Ar, H_2, are in close proximity, the nucleus of each atom will weakly attract electrons in the counter atom resulting, at least momentarily, in an asymmetrical arrangement of the nucleus.

This force, van der Waals force, is inversely proportional to the sixth power of the distance ($1/d^6$) between the particles.

As can clearly be seen from this relationship, decay of this force occurs exponentially with distance.



Ways to Measure Turbidity

1.) Jackson Candle Test
2.) Secchi Disk - a black and white disk divided like a pie in 4 quadrants about 6" in diameter.
3.) Turbidimeter - Light is passed through a sample. A sensitive photomultiplier tube at a 90^{o} angle from the incident light beam detects the light scattered by the particles in the sample. The photomultiplier tube converts the light energy into an electrical signal, which is amplified and displayed on the instrument.
    a.) *Units* - Nephelometric Turbidity Unit (**NTU**) or Formazin Turbidity Unit (**FTU**).

How to Treat Turbidity
Supercharge the water supply - By supercharging the water supply momentarily with a positive charge, we can upset the charge effect of the particle enough to reduce the Zeta potential (repulsive force), thereby allowing van der Waals forces (attractive forces) to take over.

By introducing aluminum (Al_3^+) into the water in the form of Alum ($Al_2(SO_4)_3 \bullet nH_20$) we can accomplish the supercharging of the water. This is the ***coagulation*** part of the coagulation/flocculation process; flocculation follows coagulation. During the ***flocculation*** process the particles join together to form flocs; the larger the flocs, the faster they will settle within a clarifier.

Other chemical coagulants used are Ferric Chloride and Ferrous Sulfate. Alum works best in the pH range of natural waters, 5.0 - 7.5. Ferric Chloride works best at lower pH values, down to pH 4.5. Ferrous Sulfate works well through a range of pH values, 4.5 to 9.5.

During the coagulation process, charged hydroxy-metallic complexes are formed momentarily (i.e. $Al(OH)_2^+$, $Al(OH)_2^{1+}$ etc.). These complexes are charged highly positive, and therefore upset the stable negative charge of the target particles, thereby momentarily displacing the water layer surrounding the charged particle. This upset decreases the distance “d,” in turn decreasing the Zeta potential.

The particles are then able to get close enough together for van der Waals forces to take over and the particles begin to flocculate. The chemical reaction continues until the aluminum ions (Al^+_3) reach their final form, $Al(OH)_3$ (s), and settle out (note – the flocculated particles settle out separately from the precipitated $Al(OH)_3$ (s)).

If too much alum is added, then the opposite effect occurs--the particles form sub complexes with the Al^+_3 and gain a positive charge about them, and the particles re-stabilize.

The final key to obtaining good flocs is the added energy put into the system by way of rotating paddles in the flocculator tanks. By ***“pushing”*** (adding energy) the particles together we can aid in the flocculation process, forming larger flocs.

It is important to understand that too much energy, i.e. rotating the paddles too fast, would cause the particles to shear (breakup), thereby reducing the size of the particles and increasing the settling time in the clarifier.

Key Equations

$$Al_2(SO_4)_3 \bullet 14.3H_2O + 6H_2O \rightarrow 2Al(OH)_3(s) + 14.3H_2O + 3H_2SO_4 \quad (2)$$

$$Al_2(SO_4)_3 \bullet 14.3H_2O + 6Na(HCO_3) \rightarrow 2Al(OH)_3(s) + 3Na_2SO_4 + 14.3H_2O + 6CO_2 \quad (3)$$

$$Al_2(SO_4)_3 \bullet 14.3H_2O + 6Na(OH) \rightarrow 2Al(OH)_3(s) + 3Na_2SO_4 + 14.3H_2O \quad (4)$$

Apparatus

- Jar Test Apparatus
- 6 1500 mL Beakers
- pH meter
- Pipettes
- Conductivity Meter
- Turbidimeter

Procedure

- Make up a 10-g/L solution of alum.
- Make up a 0.1 N solution of NaOH (buffer). (Na^{+1} = 23 mg/mmol, O^{-2} = 16 mg/mmol, H^{+} = 1 mg/mmol)
- Fill each of the six 1500 mL beakers with one-liter of river water.
- Measure the temperature and conductivity.
- Measure the initial pH
- Add alum and NaOH solutions in equal portions as specified by instructor.
- Mixing protocol:
    - rapid mix - 1 minute (100 rpm)
    - slow mix - 15 minutes (20 rpm)
    - off, settling - 30 minutes
- Measure final turbidity. Take the sample from the center, about 2" down for each one liter sample. Be careful not to disturb the flocs that have settled.
- Measure final pH



Information to be Recorded

Initial Turbidity = ? NTU Alum - g/L Buffer - 0.1 N

Beaker	Alum (ml)	Buffer (ml)	Turbidity (NTU)	pH-Before	pH-After	Temp. ^{o}C

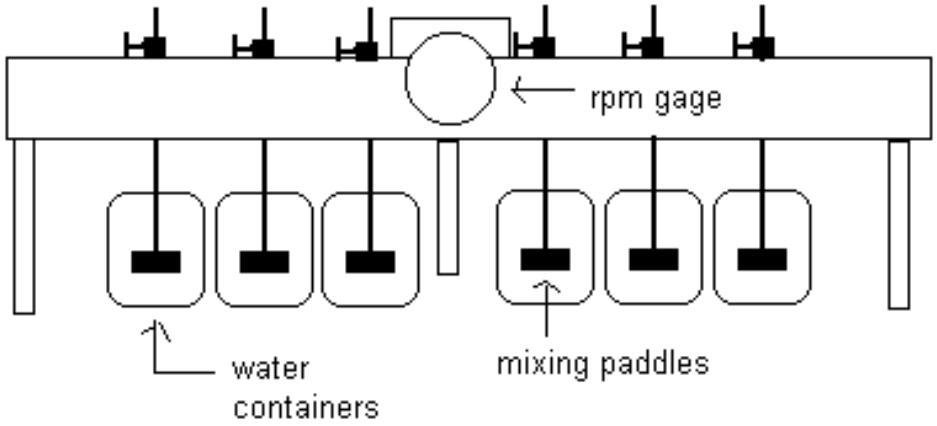
Preparing Polymers for the Jar Test

A successful Jar Test is very reliant upon the proper preparation of the polymers being tested. Dilution technique ***("make down")*** is especially critical, since it involves compactly coiled large molecules in emulsions, prior to activation. The polymer must be uncoiled to provide maximum contact with the colloidal particles to be flocculated. If the following procedures are not followed, the Jar Test results will be very unreliable.

Required Equipment:
- 250 mL bottles with lids.
- High speed hand mixer (for emulsion polymers).
- Syringes (1cc, 5cc, 10cc).
- 250 and 500 mL beakers.
- Water (it is recommended that the make-down water from the plant be used).
- Graduated cylinder (100 mL).

Emulsion Polymers (Prepare 1.0% solution.)
- Add 198 mL of water to a beaker.
- Insert Braun mixer into water and begin mixing.
- Using a syringe, inject 2 mL of neat polymer into vortex.
- Mix for 20 seconds. Do not exceed 20 seconds!
- Allow dilute polymer to age for at least 20 minutes, but preferably overnight. Prepare 0.1% solution.
- Add 180 mL of water to 250 mL bottle.
- Add 20 mL of 1.0% polymer solution.
- Shake vigorously for at least one minute.

Solution Polymers and Inorganics (Prepare a 1.0% solution.)
- Add 198 mL of water to 250 mL bottle.
- Using a syringe, add 2 mL of neat product to bottle.
- Shake vigorously for at least 1 minute.
- Prepare 0.1% solution.
- Add 180 mL to 250 mL bottle.
- Add 20 mL of 1 % solution.
- Shake vigorously for at least one minute.



Potassium Permanganate Jar Test

Potassium Permanganate has been used for a number of years in both water and wastewater treatment. $KMnO_4$ is a strong oxidizer which can be used to destroy many organic compounds of both the natural and man-made origin. $KMnO_4$ is also used to oxidize iron, manganese and sulfide compounds and other taste and odor producing substances usually due to the presence of very small quantities of secretions given off by microscopic algae, which develop on the surface waters and on beds of lakes and rivers under certain conditions of temperature and chemical composition.

$KMnO_4$ must be used with caution, as this material produces an intense purple color when mixed with water. As the permanganate ion is reduced during its reaction with compounds that it oxidizes, it changes color from purple, to yellow or brown. The final product formed is manganese dioxide (MnO_2), an insoluble precipitate that can be removed by sedimentation and filtration.

All $KMnO_4$ applied must be converted to manganese dioxide (MnO_2) prior to filtration. If it is not all converted and is still purple or pink, it will pass through the filter into the clearwell or distribution system. This may cause the customer to find pink tap water, or the reaction may continue in the system and the same conditions as exist with naturally occurring manganese may cause staining of the plumbing fixtures.

Stock Solutions
(Strong Stock Solution)
5 grams potassium permanganate dissolved in 500 ml distilled water.
(Test Stock Solution)
4 ml strong stock solution thoroughly mixed in 100 ml distilled water.
Each 5 ml of the test stock solution added to a 2000 ml sample equals 1 mg/l.



Jar Testing Example
If you have a six position stirrer:
Using a graduated cylinder, measure 2000 ml of the sample to be tested into each of the six beakers. Dose each beaker to simulate plant practices in pre-treatment, pH adjustment, coagulant,- etc. Do not add carbon or chlorine. Using a graduated pipette, dose each beaker with the test stock solution in the following manner.

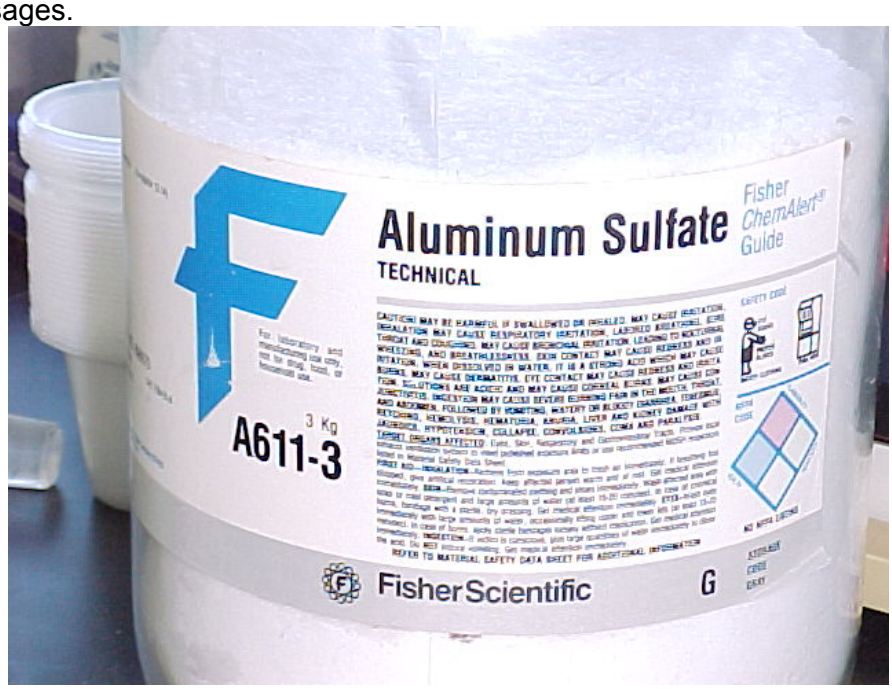
Jar #	$KMnO_4$	ml KMnO4 mg/l	Color
1	0.50	0.10	no pink
2	0.75	0.15	no pink
3	1.00	0.20	no pink
4	1.25	0.25	no pink
5	1.50	0.30	pink
6	1.75	0.35	pink

Stir the beakers to simulate the turbulence where the $KMnO_4$ is to be added and observe the color change.

As the iron and manganese begin to oxidize, the sample will turn varying shades of brown, indicating the presence of oxidized iron and or manganese. Samples which retain a brown or yellow color indicate that the oxidation process is incomplete and will require a higher dosage of $KMnO_4$.

The end point has been reached when a pink color is observed and remains for at least 10 minutes. In the preceding table a pink color first developed in beaker #5 which had been dosed with 1.5 ml/ 0.3 mg/l. If the first jar test does not produce the correct color change, continue with increased dosages.

When applying potassium permanganate to raw water, care must be taken not to bring pink water to the filter unless you have "***greensand***". Also, permanganate generally reacts more quickly at pH levels above 7.0.



Quick Test
A quick way to check the success of a $KMnO_4$ application is by adding 1.25 ml of the test stock solution to 1000 ml finished water. If the sample turns brown there is iron or manganese remaining in the finished water. If the sample remains pink, oxidation is complete.

With proper application, potassium permanganate is an extremely useful chemical treatment.

As well as being a strong oxidizer for iron and manganese, $KMnO_4$ used as a disinfectant in pre-treatment could help control the formation of trihalomethanes by allowing chlorine to be added later in the treatment process or after filtration. Its usefulness also extends to algae control, as well as many taste/odor problems.

To calculate the dosage of $KMnO_4$ for iron and manganese removal, here is the formula to use.

$KMnO_4$ Dose, mg/l = 0.6(iron, mg/l) + 2.0(Manganese, mg/l)

Example:
Calculate the $KMnO_4$ dose in mg/l for a water with 0.4 of iron. The manganese concentration is 1.2 mg/l.

Known Unknown
Iron, mg/l = 0.4 mg/l $KMnO_4$ Dose, mg/l
Manganese, mg/l = 1.2 mg/l

Calculate the $KMnO_4$ dose in mg/l.

$KMnO_4$ Dose, mg/l = 0.6(Iron, mg/l) + 2.0(Manganese, mg/l)
= 0.6(0.4 mg/l) + 2.0(1.2 mg/l)
= 2.64 mg/l

Note: The calculated 2.64 mg/l KMnO4 dose is the minimum dose. This dose assumes there are no oxidizable compounds in the raw water. Therefore, the actual dose may be higher. Jar testing should be done to determine the required dose.

Alkalinity

Introduction
Alkalinity of water is its acid-neutralizing capacity. It is the sum of all the titratable bases. The measured value may vary significantly with the end-point pH used. Alkalinity is a measure of an aggregate property of water and can be interpreted in terms of specific substances only when the chemical composition of the sample is known.

Alkalinity is significant in many uses and treatments of natural waters and wastewaters. Because the alkalinity of many surface waters is primarily a function of carbonate, bicarbonate, and hydroxide content, it is taken as an indication of the concentration of these constituents. The measured values also may include contributions from borates, phosphates, silicates or other bases if these are present. Alkalinity in excess of alkaline earth metal concentrations is significant in determining the suitability of water for irrigation. Alkalinity measurements are used in the interpretation and control of water and wastewater treatment processes.

Titration Method
a. Principle
Hydroxyl ions present in a sample, as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end-point pH used.

b. Reagents
i) Standard Hydrochloric Acid – 0.02 N.
ii) Methyl Orange Indicator – Dissolve 0.1 g of methyl orange in distilled water and dilute to 1 liter.
iii) Sodium carbonate solution, 0.02 N : Dry 3 to 5 g primary standard Na_2CO_3 at 250^oC for 4 h and cool in a desiccator. Weigh 1.03 gm.
(to the nearest mg), transfer to a 1-L volumetric flask, fill flask to the mark with distilled water, dissolve and mix reagent. Do no keep longer than 1 week.

c. Procedure
Titrate over a white surface 100 ml of the sample contained in a 250-ml conical flask with standard hydrochloric acid using two or three drops of methyl orange Indicator.
(**NOTE** – If more than 30 ml of acid is required for the titration, a smaller suitable aliquot of the sample shall be taken.)

d. Calculation
Total alkalinity (as $CaCO_3$), mg/l = 10 V or NxVx50x1000

T.A. (as $CaCO_3$) = ----------
Sample Amount
Where N = Normality of HCl used
V = volume in ml of standard hydrochloric acid used in the titration.

Alkalinity to Phenolphthalein
The sample is titrated against standard acid using phenolphthalein indicator.

a. Reagents
i) Phenolphthalein Indicator Solution :
Dissolve 0.1 g of phenolphthalein in 60 ml of ETHANOL and dilute with Distilled water to 100 ml.
ii) Standard hydrochloric Acid – 0.02 N.

b. Procedure
Add 2 drops of phenolphthalein indicator solution to a sample of suitable size, 50 or 100 ml, in a conical flask and titrate over a while surface with standard hydrochloric acid.

c. Calculation

Alkalinity to phenolphthalein (as $CaCO_3$), mg/l = $\frac{1000\ V_1}{V_2}$

Where
V_1 = volume in ml of standard hydrochloric acid used in the titration , and
V_2 = Volume in ml of the sample taken for the test.

Caustic Alkalinity
a. General
Caustic alkalinity is the alkalinity corresponding to the hydroxides present in water and is calculated from total alkalinity (T) and alkalinity to phenolphthalein (P).

b. Procedure Determine total alkalinity and alkalinity to phenolphthalein and calculate caustic alkalinity as shown in Table below. Result of Titration Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$ Carbonate Alkalinity as $CaCO_3$ Bicarbonate Concentration as $CaCO_3$ **Result of Titration**	**Caustic Alkalinity or Hydroxide Alkalinity as $CaCO_3$**	**Carbonate Alkalinity as $CaCO_3$**	**Bicarbonate Concentration as $CaCO_3$**
P=0	0	0	0
P<1/2T	0	2P	T-2P
P=1/2T	0	2P	0
P>1/2T	2P-T	2(T-P)	0
P=T	T	0	0

The alkalinity of water is a measure of its capacity to neutralize acids. The alkalinity of natural water is due to the salts of carbonate, bicarbonate, borates, silicates and phosphates along with the hydroxyl ions in free state. However, the major portion of the alkalinity in natural waters is caused by hydroxide, carbonate, and bicarbonates which may be ranked in order of their association with high pH values. Alkalinity values provide guidance in applying proper doses of chemicals in water and waste water treatment processes, particularly in coagulation and softening.

Alkalinity (total)

References: ASTM D 1067-92, Acidity or Alkalinity of Water.
APHA Standard Methods, 19th ed., p. 2-26, method 2320B (1995).
EPA Methods for Chemical Analysis of Water and Wastes, method 310.1 (1983).

The alkalinity of water is a measurement of its buffering capacity or ability to react with strong acids to a designated pH. Alkalinity of natural waters is typically a combination of bicarbonate, carbonate, and hydroxide ions. Sewage and wastewaters usually exhibit higher alkalinities either due to the presence of silicates and phosphates or to a concentration of the ions from natural waters.

Alkalinity inhibits corrosion in boiler and cooling waters and is therefore a desired quality which must be maintained. It is also measured as a means of controlling water and wastewater treatment processes or the quality of various process waters. In natural waters, excessive alkalinity can render water unsuitable for irrigation purposes and may indicate the presence of industrial effluents. *The Titrimetric Method.* CHEMetrics' tests determine total or "M" alkalinity using an acid titrant and a pH indicator. The end point of the titration occurs at pH 4.5. Results are expressed as ppm (mg/L) CaCO3.

Hardness (calcium)

Reference: West, T. S., DSC, Ph.D., Complexometry with EDTA and Related Reagents, 3rd ed., p. 46, 164 (1969).

Originally described as water's capacity to precipitate soap, hardness is one of the most frequently determined qualities of water. It is a composite of the calcium, magnesium, strontium, and barium concentrations in a sample. The current practice is to assume total hardness refers to the calcium and magnesium concentrations only.

Completely de-hardened water, resulting from sodium zeolite or other suitable ion exchange treatment, is required for various processes-including power generation, printing and photo finishing, pulp and paper manufacturing, and food and beverage processing. Hard water can cause scale formation on heat exchange surfaces, resulting in decreased heat transfer and equipment damage.

The Titrimetric Method. This method is specific for calcium hardness. The EGTA titrant in alkaline solution is employed with zincon indicator. Results are expressed as ppm (mg/L) $CaCO_3$.

Shelf-life. 8 months. Although the reagent itself is stable, the end point indicator has a limited shelf-life. We recommend stocking quantities that will be used within 7 months.

Hardness (total)

References: Colorimetric-Calcichrome chemistry--Method developed by CHEMetrics, Inc.
Titrimetric--APHA Standard Methods, 19th ed., p. 2-36, method 2340 C (1995).
EPA Methods for Chemical Analysis of Water and Wastes, method 130.1 (1983).

For a discussion of hardness, see Hardness (calcium).

The colorimetric method is applicable to monitoring boiler feedwater and other industrial waters. The titrimetric method is applicable to drinking, surface, and brine waters. *The Colorimetric Method.* CHEMetrics developed the sensitive Calcichrome reagent, which is a dark purple color. It reacts to form a light purple color at the lower end of the range, and forms a light blue color at the end of the range. Results are expressed as ppm (mg/L) or ppb (µg/L) $CaCO_3$. *The Titrimetric Method.* The EDTA titrant is employed in alkaline solution with a calmagite indicator. This method determines the combined calcium and magnesium concentration of a sample. If no magnesium is present, the end point of the titration normally appears sluggish. However, the reagent has been specially formulated to ensure a sharp end point, regardless of the presence of magnesium. Results are expressed as ppm (mg/L) $CaCO_3$.

Iron (total)

Reference: J. A. Tetlow and A. L. Wilson, "Determination of Iron in Boiler Feedwater", Analyst, 1958. See discussion under Iron (total & soluble). CHEMetrics' colorimetric method for determining total iron uses thioglycolic acid to dissolve particulate iron and to reduce any iron from the ferric to the ferrous state. Ferrous iron then reacts with PDTS in acid solution to form a purple-colored chelate. Results are expressed as ppm (mg/L) Fe.

Manganese

Reference: APHA Standard Methods, 14th ed., p. 227, method 314C (1975).
Surface and ground waters rarely contain more than 1 mg/L of soluble or suspended manganese. Manganese can act as an oxidizing or reducing agent, depending on its valence state. In various forms, it is used as a pigment or a bleaching agent. Manganese concentrations in potable water should not exceed 0.05 mg/L. Concentrations greater than 0.1 mg/L will impart a foul taste to water and discolor laundry and porcelain surfaces. Levels higher than 1 mg/l in surface waters can result from mining operations or excessive discharging from domestic waste treatment facilities or industrial plants.

The Colorimetric Method

CHEMetrics' tests measure soluble manganese compounds but do not differentiate the various valence states. Manganese is oxidized in the presence of periodate to form a deep-red reaction product. Reducing agents will interfere. Results are expressed as ppm (mg/L) Mn.

Fluorides

Fluoride ions have dual significance in water supplies. High concentration of F- causes dental fluorisis (disfigurement of the teeth). At the same time, a concentration less than 0.8 mg/l results in `dental caries'. Hence it is essential to maintain the F- conc. between 0.8 to 1.0 mg/L in drinking water. Among the many methods suggested for the determination of fluoride ion in water, the colormetric method (SPADNS) & the ion selective electrode method are the most satisfactory and applicable to variety of samples. Because all of the colorimetric methods are subject to errors due to the presence of interfering ions, it may be necessary to distill the sample before making the fluoride estimation, while addition of the

prescribed buffer frees the electrode method from the interference, caused by such relatively common ions as aluminum hexametaphosphate and orthophosphate which adversely affect the colorimetric methods. However, samples containing fluoroborate ion (BF_4), must be subject to a preliminary distillation step in either of the methods. Both the methods and the preliminary distillation step are discussed below.

1. SPADNS METHOD

Principle

Under acid condition fluorides (**HF**) react with zirconium SPADNS solution and the `Lake' (color of SPADNS reagent) gets bleached due to formation of ZrF_6. Since bleaching is a function of fluoride ions, it is directly proportional to the concentration of F. It obeys Beer's law in a reverse manner.

Interference

Alkalinity 5000 mg/L, aluminum 0.1 mg/L, chlorides 7000 mg/L, Fe 10 mg/L, PO_4 16 mg/L, SO_4 200 mg/L, and hexametaphosphate 1.0 mg/L interfere in the bleaching action. In presence of interfering radicals distillation of sample is recommended.

Apparatus

1. Distillation apparatus (as shown in the Fig. 3)
2. Colorimeter for use at 570 nm.
3. Nessler's tubes cap. 100 ml.

Reagents

1. Sulphuric acid H_2SO_4 concentration.
2. Silver Sulfate Ag_2SO_4 crystals.
3. SPADNS solution : Dissolve 958 mg SPADNS and dilute to 500 ml.
4. Ziroconyl acid reagent : Dissolve 133 mg $ZrOCl_2$ $8H_2O$ in 25 ml water. Add 350 ml. conc. HCl and dilute to 500 ml.
5. Mix equal volume of 3 and 4 to produce a single reagent. Protect from direct light.
6**. Reference solution:** Add 10 ml SPADNS solution to 100 ml distilled water. Dilute 7 ml concentration HCl to 10 ml and add to diluted SPADNS solution.
7. **Sodium arsenite solution:** Dissolve 5.0 g $NaAsO_2$ and dilute to 1000 ml.
8. **Stock F- solution:** Dissolve 221.0 mg anhydrous NaF and dilute to 1000 ml. 1 ml = 100 mg F-.
9**. Standard F :** Dilute stock solution 10 times to obtain 1 ml = 10mg F.

A. Preliminary Distillation Step

Place 400 ml distilled water in the distilling flask and carefully add 200 ml conc. H_2SO_4. Swirl until the flask contents are homogenous, add 25 to 30 glass beads and connect the apparatus as shown in Fig 1. Begin heating slowly at first and then rapidly until the temperature of the flask reaches exactly 180^{o}C. Discard the distillate. This process removes fluoride contamination and adjusts the acid-water ratio for subsequent distillations. After cooling, the acid mixture remaining after above step or previous distillation to 120^{o}C or below add 300 ml of sample, mix thoroughly, and distill as before until the temperature reaches 180^{o}C. Do not heat above 180^{o}C to prevent Sulfate carryover.

Add Ag_2SO_4 to distilling flask at the rate of 5 mg/mg Cl when high chloride samples are distilled. Use the sulphuric acid solution in the flask repeatedly until the contaminants from the samples accumulate to such an extent that recovery is affected or interferences appear in the distillate. After the distillation of high fluoride samples, flush the still with 300 ml. distilled water and combine the two fluoride distillates. After periods of inactivity, similarly flush the still, discard the distillate.

B. Procedure

1. Prepare standard curve in the range 0.0 to 1.40 mg/L by diluting appropriate volume of standard F solution to 50 ml in Nessler's tubes.
2. Add 10.0 mL mixed reagent prepared as in 5 above to all the samples, mix well and read optical density of bleached color at 570 nm using reference solution for setting zero absorbance.
3. Plot conc. Vs. % transmission or absorbance.
4. If sample contains residual chlorine, remove it by adding 1 drop (0.05ml) $NaAsO_2$ solution 0.1 mg Cl_2 and mix. $NaAsO_2$ conc. should not exceed 1300 mg/L to avoid error due to $NaAsO_2$. Take suitable aliquot & dilute it to 50 mL.
5. Add acid Zirconyl - SPADNS reagent 10 ml; Mix well and read % transmission or absorbance.
6. Take suitable aliquots of sample either direct or after distillation in Nessler's tubes. Follow the step 5.
7. Calculate the mg F present in the sample using standard curve.

2. Ion Selective Electrode Method

Principle

The fluoride sensitive electrode is of the solid state type, consisting of a lanthanum fluoride crystal; in use it forms a cell in combination with a reference electrode, normally the calomel electrode. The crystal contacts the sample solution at one face and an internal reference solution at the other. A potential is established by the presence of fluoride ions across the crystal, which is measured by a device called ion meter, or by a moder pH meter having an expanded millivolt scale.

The fluoride ion selective electrode can be used to measure the activity or concentration of fluoride in an aqueous sample by use of an appropriate calibration curve. However, fluoride activity depends on the total ionic strength of the sample. The electrode does not respond to bound or complex fluoride. Addition of a buffer solution of high total ionic strength containing a chelate to complex aluminum preferentially overcomes these difficulties.

Interference

Polyvalent cations such as Al (III), Fe (III) and Si (IV) will complex fluoride ions. However, the addition of CDTA (Cyclohexylene diamine tetra acetic acid) preferentially will complex concentrations of aluminum up to 5 mg/L. Hydrogen ion forms complex with fluoride, while hydroxide ion interferes with electrode response. By adjusting the pH between 5 to 8 no interference occurs.

Apparatus

1. Ion meter (field / laboratory model) or pH/mV meter for precision laboratory measurements.
2. Reference electrode (calomel electrode)
3. Fluoride sensitive electrode.
4. Magnetic stirrer.
5. Plastic labware (Samples and standards always be stored in plastic containers as fluoride reacts with glass).

Reagents

1. Standard fluoride solution prepared as directed in SPADNS method.
2. Total Ionic strength adjustment buffer (TISAB).

Place approximately 500 ml distilled water in a 1 - L beaker add 57 mL glacial acetic acid, 58 gm NaCl and 4.0 gm 1, 2 cyclohexylene diamine tetraacetic acid. Stir to dissolve. Place beaker in a cool water bath and add slowly 6 N NaOH (About 125 ml) with stirring, until pH is between 5 and 5.5. Transfer to a 1 - L volumetric flask and make up the volume to the mark.

Procedure

1. For connecting the electrodes to meter, and for further operation of the instrument, follow the instruction manual supplied by the manufacturer.
2. Check the electrode slope with the ion meter (59.16 mV for monovalent ions and 29.58 mV for diavalent ions at 25^{o}C)
3. Take 50 ml of each 1 ppm and 10 ppm fluoride standard. Add 50 ml TISAB (or 5 ml if conc. TISAB is used) and calibrate the instrument.
4. Transfer 50 to 100 ml of sample to a 150 ml plastic beaker. Add TISAB as mentioned in (3).
5. Rinse electrode, blot dry and place in the sample. Stir thoroughly and note down the steady reading on the meter.
6. Recalibrate every 1 or 2 hours.
7. Direct measurement is a simple procedure for measuring a large number of samples. The temperature of samples and standard should be the same and the ionic strength of standard and samples should be made the same by addition of TISAB to all solutions.
8. Direct measurement results can be verified by a known addition procedure. The known addition procedure involves adding a standard of known concentration to a sample solution. From the change in electrode potential before and after addition, the original sample concentration is determined.

Fluoride SPADNS Method

References:
APHA Standard Methods, 20th ed., p. 4-82, method 1500 F-(1998).
EPA Methods for Chemical Analysis of Water and Wastes, method 340.1 (1974,1978).
Thomas and Chamberlain, 1974, Colorimetric Analytical Methods, pp 186-193.

The Fluoride Vacu-vials® test method is based on the reaction between fluoride and a red zirconium-dye lake that has been formed with SPADNS. The loss of color resulting from the reaction of the fluoride with the dye lake is a function of the fluoride concentration. Results are expressed in ppm (mg/Liter) F-.

This method is approved by the EPA for NPDES and NPDWR reporting purposes when the samples have been distilled from an acid solution. Seawater and wastewater samples must be pre-distilled. Distillation removes most contaminating interferences except chlorine. Sodium Arsenite has been added to remove up to 5 mg/L chlorine.

Oxygen (dissolved)

References: Indigo Carmine--ASTM D 888-87, Colorimetric Indigo Carmine, Test Method A.
Gilbert, T.W., Behymer, T.D., Castaneda, H.B., "Determination of Dissolved Oxygen in Natural and Wastewaters," *American Laboratory*, March 1982, pp. 119-134.
Rhodazine D method--(Method developed by CHEMetrics, Inc.) Power Plant Manual, First ed., p. 169 (1984).

ASTM D 5543-94, Standard Test Methods for Low Level Dissolved Oxygen in Water.
The level of dissolved oxygen in natural waters is often a direct indication of quality, since aquatic plants produce oxygen, while microorganisms generally consume it as they feed on pollutants. At low temperatures the solubility of oxygen is increased, so that in winter, concentrations as high as 20 ppm may be found in natural waters; during summer, saturation levels can be as low as 4 or 5 ppm. Dissolved oxygen is essential for the support of fish and other aquatic life and aids in the natural decomposition of organic matter. Waste treatment plants which employ aerobic digestion must maintain a level of at least 2 ppm dissolved oxygen. This is usually accomplished by mechanical aeration.

At elevated temperatures, oxygen is highly corrosive to metals, causing ***"pitting"*** in ferrous systems such as high-pressure boilers and deep well oil recovery equipment. To prevent costly corrosion damage, the liquids in contact with the metal surfaces must be treated, usually by a combination of physical and chemical means. De-aeration can reduce the dissolved oxygen concentration of boiler feedwater from several ppm to a few ppb. Chemical reducing agents such as hydrazine or sodium sulfite are sometimes used instead of de-aeration, but more often are used to react with residual oxygen which remains after the de-aeration process.

The Colorimetric Methods.
Test kits for environmental and drinking water applications (ppm range) employ the indigo carmine method. The reduced form of indigo carmine reacts with D.O. to form a blue product. The indigo carmine methodology is not subject to interferences from temperature, salinity or dissolved gases such as sulfide, which plague users of D.O. meters. Results are expressed as ppm (mg/L) O_2.

Test kits for boiler waters and applications requiring trace levels of D.O. (ppb range) employ the Rhodazine D methodology. Developed by CHEMetrics, Inc., the Rhodazine D compound in reduced form reacts with dissolved oxygen to form a bright pink reaction product. This method is not subject to the temperature, salinity, or dissolved gas interferences which plague dissolved oxygen meters. Oxidizing agents, including benzoquinone, can cause high results. Reducing agents such as hydrazine and sulfite do not interfere. Results are expressed as ppm (mg/L) or ppb (µg/L) O_2.

The dissolved oxygen products provide fast, accurate colorimetric oxygen determination. Test kit K-7512 is used to monitor surface waters. ULR CHEMets™ ampoules detect oxygen to 1 ppb. Test kit K-7540 is widely used to monitor boiler feedwater.

Boiler feedwater testing: Low range dissolved oxygen test kits include a special "***sampling tube***" (see diagram) for use with boiler feedwater. This device allows the user to break the tip of the ampoule in a flowing sample stream in order to preclude error from contamination by atmospheric oxygen.

Total Dissolved Solids (Filterable)

The dissolved (Filterable) solids can be determined from the difference between the residue on evaporation and total suspended solids, but if the dissolved solids content is low and the suspended solids high, a direct determination is better. It is preferable to adopt the centrifugal method of separating suspended matter in order that a sufficiently large volume of separated liquid is available for the determination.

Principle
A known volume of filtered sample is evaporated and dried in a weighed dish at 105^{o}C to constant weight; the increase in weight over the empty dish represents the dissolved solids.

Apparatus
1. Evaporating dishes, 50, 100 mL capacity (Preferably porcelain or silica).
2. Pipettes 25, 50 ml capacity
3. Water bath & Oven
4. Balance to weigh up to 4th decimal.

Procedure
The known volume (V) of filtered sample in a previously ignited and weighed basin (W_1). Evaporate to dryness on a steam bath and further dry at 105^{o}C for one or two hours in an oven. Cool in dessicator and weight (W_2). Repeat by further heating for 15 minutes and cooling until successive results do not differ by more than about 0.4 mg.

Calculation

$$\text{Dissolved solids mg/L} = \frac{(W_2 - W_1) \times 1000}{V}$$

Where
W_2 = Weight of residue and dish
W_1 = Weight of empty and dry dish
V = Weight of sample

Ozone

Reference:
DDPD method: Developed by CHEMetrics, Inc.
Indigo method: Bader, H. and Hoigne, J., "Determination of Ozone in Water by the Indigo Method," Water Research, Vol. 15, 449-456, 1981. APHA Standard Methods, 20th ed., p. 4-137, Method 4500-03 B (1998).

Ozone is a strong oxidizing agent. Ozonation is used as an alternative biocide and disinfectant to chlorination of drinking water. Ozone is used to remove odor, decolorize, and to control algae and other aquatic growths. Because ozone is unstable in water, monitoring ozone residuals is important to ensure that proper treatment levels are maintained.

The Colorimetric Methods
The DDPD chemistry employs a methyl substituted form of the DPD reagent. The A-7400 activator solution (potassium iodide) is added to the sample before analysis. Ozone reacts with the iodide to liberate iodine. The iodine then reacts with the reagent to give a blue-violet

color. Various free halogens and halogenating agents produce color with the reagent. Chromate in test samples below 25 ppm will not interfere with results. Results are expressed as ppm (mg/L) O_3.The new ozone method employs the indigo trisulfonate reagent, which reacts instantly and quantitatively with ozone, bleaching the blue color in direct proportion to the amount of ozone present. Malonic acid is included in the formulation to prevent interference from chlorine. Results are expressed as ppm (mg/L) O_3.

Turbidity

Suspension of particles in water interfering with passage of light is called turbidity. Turbidity is caused by wide variety of suspended matter which range in size from colloidal to coarse dispersions, depending upon the degree of turbulence, and also ranges from pure inorganic substances to those that are highly organic in nature. Turbid waters are undesirable from an aesthetic point of view in drinking water supplies and may also affect products in industries. Turbidity is measured to evaluate the performance of water treatment plants.

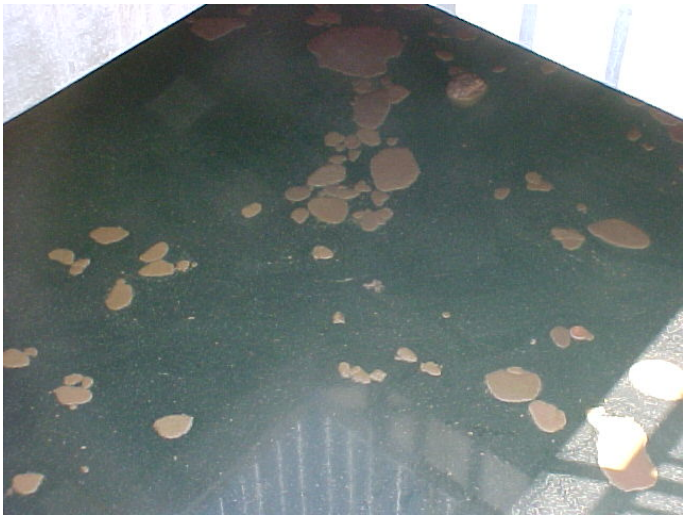
Principle
Turbidity can be measured either by its effect on the transmission of light, which is termed as Turbidimetry, or by its effect on the scattering of light, which is termed as Nephelometry. A Turbidimeter can be used for samples with moderate turbidity, and a Nephelometer for samples with low turbidity. The higher the intensity of scattered light, the higher the turbidity.

Interference
Color is the main source of interference in the measurement of turbidity.

Apparatus : Turbidimeter or Nephelometer.

Reagents
1. Solution I : Dissolve 1.0 gm Hydrazine Sulfate and dilute to 100 mL.
2. Solution II : Dissolve 10.0 gm Hexamethylene tetramine and dilute to 100 mL.
3. Mix 5 mL of I with 5 mL of II. Allow to stand for 24 hrs. at 25 $\pm$ 3^{o}C and dilute to 100 mL. This solution (III) will have turbidity of 400 units (N.T.U.)
4. Standard turbidity suspension: Dilute 10 mL of solution III as prepared above to 100 mL to have solution of the turbidity of 40 units. (N.T.U.)

Procedure
1. Prepare calibration curve in the range of 0-400 units by carrying out appropriate dilutions of solutions III and IV above taking readings on turbidimeter.
2. Take sample or a suitably diluted aliquot and determine its turbidity either by visual comparison with the diluted standards or by reading on turbidimeter.
3. Read turbidity from the standard curves and apply correction due to dilution, if necessary.
4. Report the readings in turbidity units.



Standard Operating Procedure for the Determination of Total Organic Carbon in Water

1.0 Scope and Application
This method is used to determine total organic carbon (**TOC**) in water. A concentration of 0.01 mg/L can be measured by some instruments if scrupulous attention is given to minimizing sample contamination and method background.

2.0 Summary of Method
There are two different ways to determine total organic carbon (TOC). The first way is by the TOC mode. The inorganic carbon (IC) is first removed from the sample by acidification and sparging and then the organic carbon (OC) is oxidized to carbon dioxide (CO_2) by sodium persulfate in the presence of ultraviolet light. The CO_2 produced is purged from the sample, dried, and transferred with a carrier gas to a non-dispersive infrared (NDIR) analyzer that is specifically tuned to the absorptive wavelength of CO_2. The instrument's microprocessor converts the detector signal to organic carbon concentrations in mg/L based on stored calibration data. The second way is TOC by difference. This is just total carbon (TC) minus inorganic carbon. The TC is all the carbon in the sample, both IC and OC. The IC is determined in the same manner as in the TOC mode.

3.0 Definitions
3.1 The definitions and purposes below are specific to this method, but have been conformed to common usage as much as possible.
3.2 Liter: L
Milliliter: mL
Grams: g
Total Organic Carbon: TOC
Total Carbon: TC
Inorganic Carbon: IC
Organic Carbon: OC
Carbon Dioxide: CO_2
Non dispersive infrared: NDIR
Dissolved organic carbon: DOC
3.3 May: This action, activity, or procedural step is neither required nor prohibited. **May not**: This action, activity, or procedural step is prohibited. **Must**: This action, activity, or procedural step is required. **Shall**: This action, activity, or procedural step is required. **Should**: This action, activity, or procedural step is suggested, but not required

4.0 Interferences
4.1 Removal of carbonate and bicarbonate by acidification and purging with purified gas results in the loss of volatile organic substances. The volatiles also can be lost during sample blending, particularly if the temperature is allowed to rise. Another important loss can occur if large carbon-containing particles fail to enter the needle used for injection.

Filtration, although necessary to eliminate particulate organic matter when only dissolved organic carbon (DOC) is to be determined, can result in loss or gain of DOC, depending on the physical properties of the carbon-containing compounds and adsorption and desorption of the carbon matter on the filter. Avoid contaminated glassware, plastic containers, and rubber tubing. Insufficient acidification will result in incomplete release of CO_2.

4.2 The intensity of the ultraviolet light reaching the sample matrix may be reduced by highly turbid samples or with aging of the ultraviolet source, resulting in sluggish or incomplete oxidation. Large organic particles or very large or complex organic molecules such as tannins, lignins, and humic acid may be oxidized slowly because persulfate oxidation is rate-limited. However, oxidation of many large biological molecules such as proteins and monoclonal antibodies proceeds rapidly.
4.3 Persulfate oxidation of organic molecules is slowed in samples containing sufficient concentrations of chloride by the preferential oxidation of chloride; at concentrations above 0.05% chloride, oxidation of organic matter may be inhibited. To remove this interference add mercuric nitrate to the persulfate solution in UV-persulfate instruments, or extend reaction time and/or increase amount of persulfate solution in heated persulfate instruments.
4.4 With any organic carbon measurement, contamination during sample handling and treatment is a likely source of interference. This is especially true of trace analysis. Take extreme care in sampling, handling and analysis of samples below 1 mg/L TOC.

5.0 Safety
5.1 This method does not address all safety issues associated with its use. The laboratory is responsible for maintaining a safe work environment and a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of Safety Data Sheets (SDS)s for each chemical used in this method should be available to all personnel involved in these analyses.
5.2 Each chemical should be treated as a potential health hazard. Exposure to these chemicals should be reduced to the lowest possible level. It is suggested that the laboratory perform personal hygiene monitoring of each analyst using this method and that the results of this monitoring be made available to the analyst.
5.3 Unknown samples may contain high concentrations of volatile compounds. Sample containers should be opened in a hood and handled with gloves to prevent exposure.

6.0 Equipment and Supplies
Note: Brand names, suppliers, and part numbers are cited for illustrative purposes only. No endorsement is implied. Equivalent performance may be achieved using equipment and materials other than those specified here, but demonstration of equivalent performance that meets the requirements of this method is the responsibility of the laboratory.
6.1 Tekmar-Dohrman Phoenix 8000 TOC uv-persulfate analyzer or other comparable brand with autosampler.
6.2 0-14 pH paper.
6.3 10 ml syringe.
6.4 0.45 micron glass fiber filters.
6.5 125 ml sample bottles:
6.6 Autosampler vials: 40 mL amber glass vials with Teflon-faced septa. These vials should be washed with laboratory detergent and thoroughly rinsed with tap water followed by reverse osmosis water and allowed to dry. The vials should then be rinsed with acetone followed by hexane and allowed to dry. Finally, the vials should be dried in the drying oven used for drying vials used for the analysis of volatile organic compounds.

7.0 Reagents and Standards
7.1 Reagent water: ultrapure from the spectroscopy lab.
7.2 21% phosphoric acid: add 37 ml of 85% phosphoric acid to 188 ml of reagent water. Always add acid to water.

7.3 LabChem Inc. Catalog number LC12910-1 Organic carbon stock solution. 1000 parts per million. Primary standard grade. 1mL=1mg. If it is prepared in the laboratory, it should be preserved by adding phosphoric acid until the pH is <2.
This stock standard solution is used with drinking water samples.
7.4 Inorganic carbon stock solution: Dissolve 4.4122 g anhydrous sodium carbonate, in reagent water, add 3.4970 g anhydrous sodium bicarbonate and dilute to 1000 mL; 1mL=1mg carbon. Keep tightly stoppered. Do not acidify. Used for analysis of surface waters in determining TOC by difference. To make the standards use 4 mL to make 20 ppm, 20 mL for 100 ppm, and 40 mL for 200 ppm. There are different methods in the Phoenix 8000 that can be used. Choose the one that best suits the samples involved.
7.5 Carrier gas. This lab uses nitrogen, CO_2-free and containing less than 1 ppm hydrocarbon.
7.6 Purging gas. Any gas free of CO_2 and hydrocarbons. This lab uses nitrogen.
7.7 Persulfate solution. Acros. 98+ %. Add 25 g of sodium persulfate to 213 mL of reagent water and add 9 mL of phosphoric acid.

8.0 Sample Collection, Preservation, and Storage
8.1 If possible, rinse bottles with sample before filling.
8.2 Collect and store samples in glass bottles protected from sunlight and seal with TFE-backed septa. Preferably use thick silicone rubber-backed TFE septa with open ring caps to produce a positive seal. Before use, wash bottles with laboratory detergent, rinse thoroughly with tap and reverse osmosis water and allow to dry. Then rinse with acetone and hexane and dry in the oven used for drying vials used for analysis of volatile organic carbon compounds. Analyze a bottle blank with each set of sample bottles to determine effectiveness or necessity of cleaning. This can be done by filling a sample bottle (bottle blank) with reagent water in the laboratory when the sample containers are shipped out and holding the sample bottle at 0-4 degrees C until the associated samples are analyzed.
8.3 Drinking water-related samples must either be analyzed or must be acidified to achieve pH <2.0 by addition of minimal phosphoric or sulfuric acid as soon as practical after sampling, not to exceed 24 hours. Check pH before analysis by using a stirring rod to dip in the container and then touch it to the pH paper. If the sample is a groundwater sample, it should not be acidified because there would be a loss of inorganic carbon from the sample in the form of CO2. Regardless of what is being analyzed, all samples must be stored at 0 - 4 degrees C from the
time of collection until analysis.
8.4 All samples must be analyzed within 28 days of the date and time collected.

9.0 Quality Control
9.1 For every set of ten samples, analyze a reagent blank, a known-value check sample, and a duplicate. Analysis of blanks is to show freedom from contamination.
9.2 Analyze a sample bottle blank with each set of samples. See section 8.2 for details.

10.0 Calibration and Standardization
10.1 Use the standard described in section 7.4 for finding TC. If only TOC is to be found, there is a stock solution of organic carbon. The same concentrations can be made up for the organic carbon.
10.2 Depending on whether TC-IC is to be found or TOC is to be found, will determine what curve or curves need to be set active. If just TOC is to be found, then choose SETUP, CALIBRATION, SET ACTIVE, then choose TOC. It will then give ranges of different values.

The choice that has been used is 20ppm-200ppm for most samples. If TOC is found by way of TC-IC, both curves for TC and IC must be set active. They also must have the same range of calibration. The TOC range should not be set active.

10.3 Once the calibration curve is formed, stop the run and go to the calibration results. Choose the standards that have just been run and click on the RECALC button. If you want to keep the curve, click on OK and then start the run again. The curve is supposed to be linear, so the closer to 1.0000 the better the curve.

11.0 Procedure

11.1 Filtration of drinking water-related samples prior to TOC analysis is not permitted as this could result in removal of organic carbon. Where turbidity interferes with TOC analysis, samples should be homogenized and, if necessary, diluted with organic-free reagent water.

11.2 Bring the analytical batch of samples to room temperature. Make sure the samples are homogenized and pour into labeled amber 40 mL vials. Put on a new septa and place on the rack.

11.3 Check the carbonate and bicarbonate levels of the samples to be analyzed. If they are over 800 mg/L then dilute.

11.4 Make up the reagents weekly. Make up new standards when quality control checks start to fail.

11.5 Warm up the instrument at least one-half hour before use. This means just switch from standby to run, and make sure that the gas flow is 200 cc/min. Make sure the baseline has stabilized.

11.6 Create a file and label it according to the current date. An easy way to do this is to load an old file from the setup menu and change the samples that are in it to go along with the new run. Go to the file and use the “save as” and then type in the day of the run. Put the year first then the month and then day. Example: the date of January 21st, 2012 should be read as 120121.

11.7 Set the curve for the desired analysis. The TOC curve should be set for analyzing drinking water-related samples. The TC and IC curve needs to be set active for analysis of TOC by difference. Make sure that all other curves that are not used are not active.

11.8 Put the samples on and select run.

11.9 The calibration curve should be checked after the first standard is run. This will ensure the correct calibration is made. The analyst can choose the points on the calibration menu. The more linear the line the better, so if the r-squared number is close to one, and the check sample is in the tolerance limits, let the rest of the samples run.

11.10 Only TOC results will be displayed for the drinking water-related samples; whereas the TOC by difference will be shown as TC, IC, and TOC on the results portion of the screen.

12.0 Data Analysis, Calculations, and Reporting Results

12.1 Calculations

If the instrument does not already do this, calculate corrected instrument response of standards and samples by subtracting the reagent-water blank instrument response vs. TOC concentration. Subtract procedural blank from each sample instrument response and compare to standard curve to determine carbon content. Apply appropriate dilution factor when necessary. Subtract inorganic carbon form total carbon when TOC is determined by difference.

12.2 Reporting Results

The results can be hand entered or electronically transferred to the Laboratory Information Management System (LIMS). The units should be mg/L.

13.0 Method Performance

Interlaboratory studies of persulfate and/or UV with NDIR detection methods have been conducted in the range of 0.1 mg/L to 4,000 mg/L of carbon. The resulting equation for organic carbon single-operator precision is :

So= 0.04 x + 0.1

Overall precision is expressed as: St = 0.08x + 0.1

where:

So = single-operator precision

St = overall precision, and

x = TOC concentration, mg/L

14.0 Pollution Prevention

If mercuric nitrate is used to complex the chloride, use an appropriate disposal method for the treated waste to prevent mercury contamination.

15.0 Waste Management

15.1 Disposal of any hazardous waste from this method must be done in accordance with appropriate regulations.

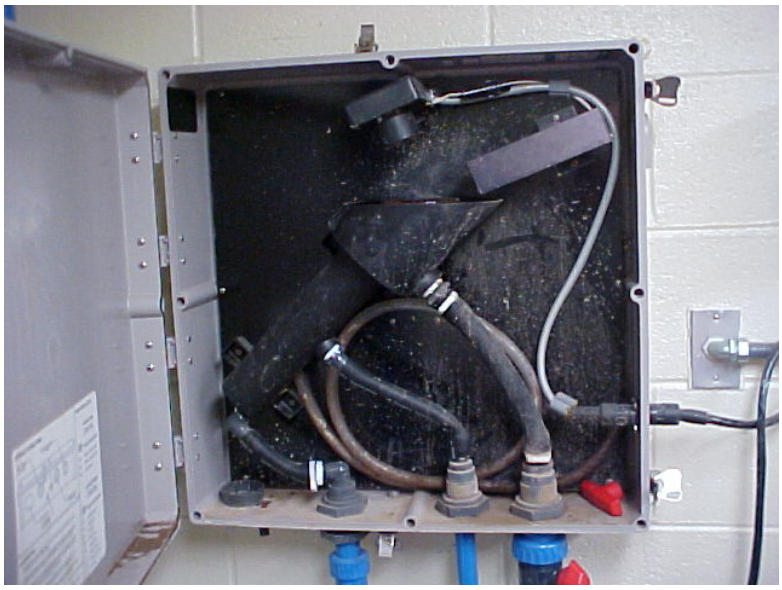
15.2 For further information on waste management, consult *The Waste Management Manual for Laboratory Personnel and Less is Better: Laboratory Chemical Management for Waste Reduction*, both available from the American Chemical society's Department of Government Relations and Science Policy, 1155 16th Street N.W., Washington D.C. 20036

16.0 References

16.1 Method 5310 C: Total Organic Carbon(TOC), Persulfate-Ultraviolet or Heated-Persulfate Oxidation Method, *Standard Methods for the Examination of Water and Wastewater,* 19th edition supplement, 1996, pp.9-14.

16.2 "Dohrman Phoenix 8000 User Manual", 7413 East Kemper Road, Cincinnati, Ohio 45242-9576.

16.3 *Federal Register*, Wednesday, December 16, 1998, p 69417.



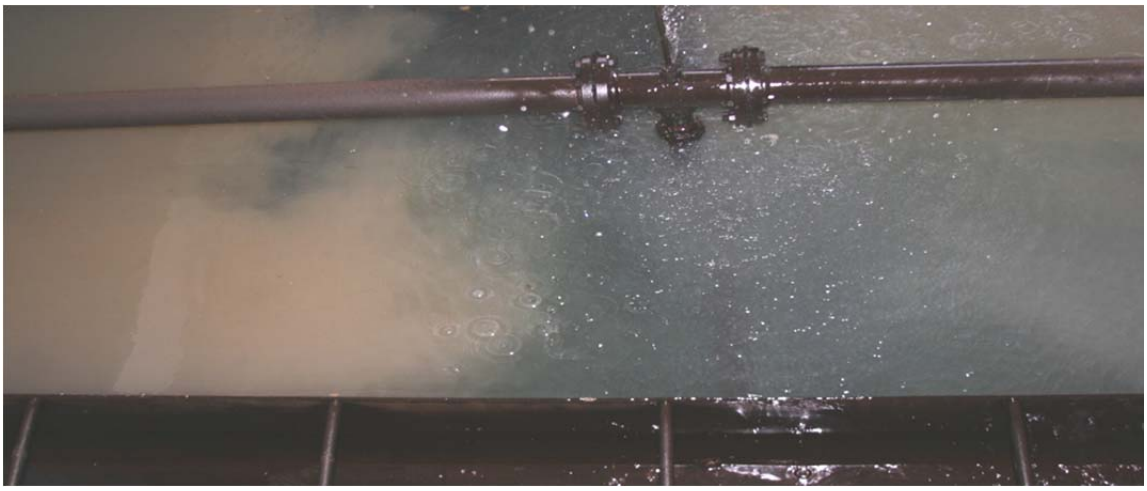
Inside a Turbimeter.

Surface Wash



The photograph above shows a drained filter with the agitator and nozzles exposed. During operation these will spin, spraying water during the water backwash.

During the operation of a filter, the upper six-to-ten inches of the filter media remove most of the suspended material from the water. It is important that this layer be thoroughly cleaned during the backwash cycle. Normal backwashing does not, in most cases, clean this layer completely; therefore, some method of agitation is needed to break up the top layers of the filter and to help the backwash water remove any material caught there.

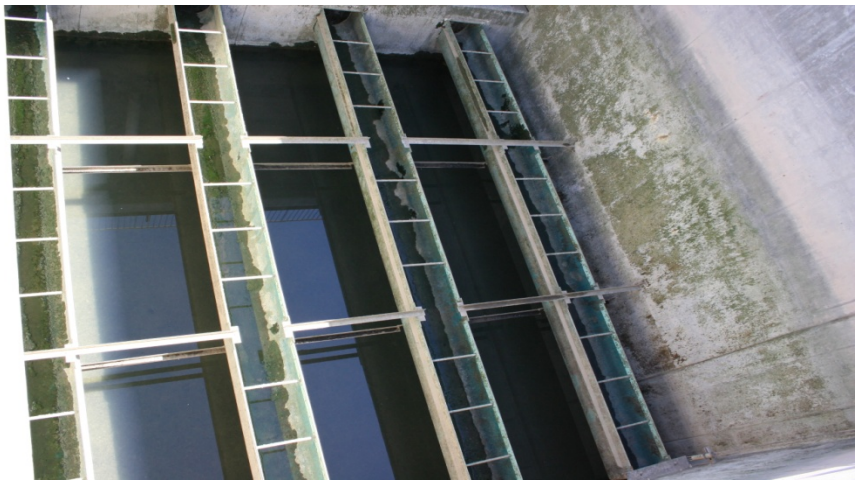


The surface wash system consists of a series of pipes installed in the filter that introduce high velocity water or air jet action into the upper layer of the filter. This jet action will generally be supplied by rotating arms that are activated during the backwashing of the filter.

A newer design of surface wash uses compressed air to mix the upper layer and loosen the particles from the sand so that the backwash water can remove the particles more easily. This air wash generally is turned on before the backwash cycle. If both are used at the same time, some sand may be washed away. The compressed air rate can be two-to-five cubic feet per minute per square foot (cfm/ft^2) of filter surface, depending on the design of the filter.

High Rate Filters

High rate filters, which operate at a rate three-to-four times that of rapid sand filters, use a combination of different filter media, not just sand. The combinations vary with the application, but generally they are sand and anthracite coal. Multi-media or mixed-media filters use three or four different materials, generally sand, anthracite coal, and garnet.

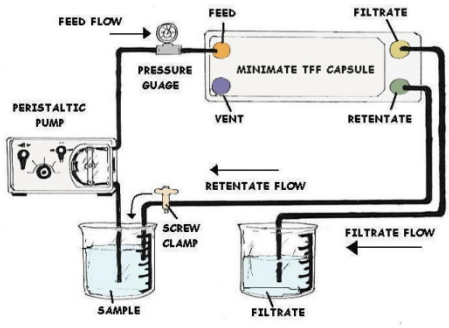


In this photograph you can see the water lines on the wall of the filter. The deeper the water the more head pressure exerted on the filter media.

In rapid sand filters, finer sand grains are at the top of the sand layer with larger grains farther down into the filter. As a result, the filter removes more suspended material in the first few inches of the filter. In the high rate filter, the media size decreases. The top layers consist of a coarse material with the finer material farther down, allowing the suspended material to penetrate deeper into the filter.

The material in a filter bed forms layers in the filter, depending on their weight and specific gravities. In the coarse layer at the top, the larger suspended particles are removed first, followed by the finer materials. This allows for longer filter runs at higher rates than is possible with rapid sand filters.

The type of filter media used in a high rate filter depends on many factors, including the raw-water quality, raw-water variations, and the chemical treatment used. Pilot studies help the operator evaluate which material, or combination of materials, will give the best result.



LABORATORY FILTRATION SYSTEM

Pressure Filters

Pressure filters fall into two categories: pressure sand and diatomite filters.

Pressure Sand Filters



This type of filter is used extensively in iron and manganese removal plants.

A pressure sand filter is contained under pressure in a steel tank, which may be vertical or horizontal, depending on the space available. As with gravity filters, the media is usually sand or a combination of media. Filtration rates are similar to gravity filters.

These filters are commonly used for iron and manganese removal from groundwater, which is first aerated to oxidize the iron or manganese present, then pumped through the filter to remove the suspended material.



Filter Media

Because the water is under pressure, air binding will not occur in the filter. However, pressure filters have a major disadvantage in that the backwash cannot be observed; in addition, cracking of the filter bed can occur quite easily, allowing the iron and manganese particles to go straight through the filter. When using pressure filters for iron and manganese removal, the operator must regularly measure the iron and manganese concentration of the filter effluent and backwash the filter before breakthrough occurs. Because of these limitations, pressure filters must not be used to treat surface water.

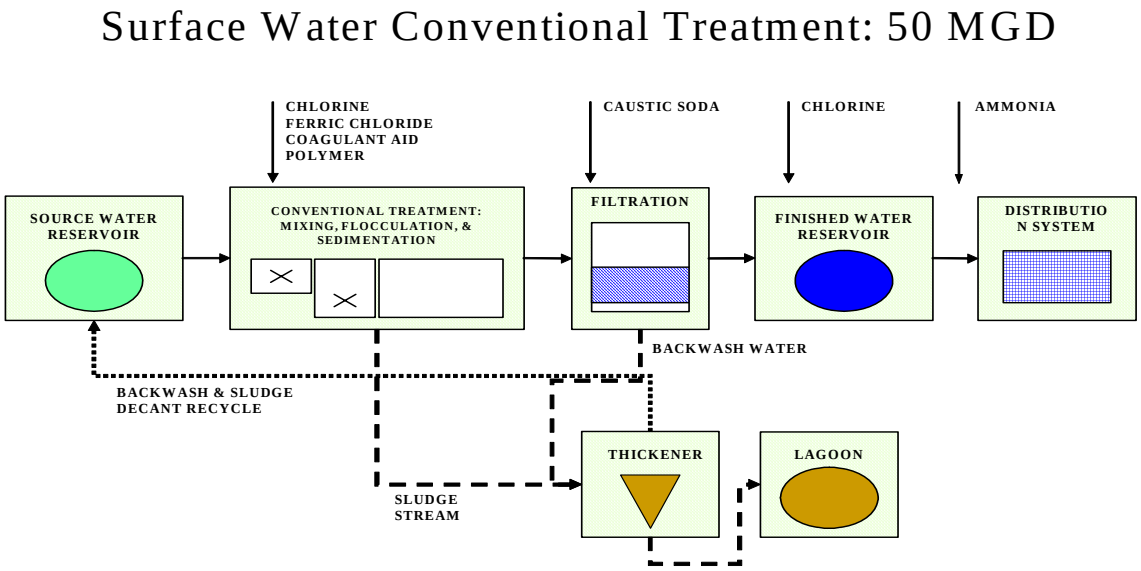


Diatomaceous Earth Filter

This type of filter is commonly used for the treatment of swimming pools. The process was developed by the military during World War II to remove microorganisms that cause amoebic dysentery from water used in the field.

Filtration Processes

Two basic types of filtration processes are currently used in the United States. Conventional filtration, the traditional design for many years, provides effective treatment for just about any range of raw-water turbidity. Its success is due partially to the sedimentation that precedes filtration and follows the coagulation and flocculation steps. Sedimentation, if operated properly, should remove most of the suspended material.



After sedimentation, the water passing through to the filters should not have turbidity higher than 10-to-15 NTU. Rapid sand filters were once used in the conventional process, but many have been converted to multi-media filters in an attempt to increase plant capacity.

In the other type of filtration process--direct filtration--no sedimentation follows the coagulation phase. Direct filtration is designed to filter water with an average turbidity of less than 25 NTU. Dual and multi-media filters are used with direct filtration. They are able to remove more suspended material per cubic foot of filter media than sand filters. Direct filtration plants have a lower capital cost. However, the process cannot handle large variations in raw water turbidity.



Filtration Operation

Filtration operation is divided into three steps: filtering, backwashing, and filtering to waste.

Filter Control of the filter operation requires the following equipment:

- Rate of flow controller
- Loss of head indicator
- On-line turbidimeter

Rate of Flow Controllers
Flow rates through filters are controlled by one of two different methods:

Declining rate
This method of control is used where the head loss through the plant is quite large. It allows the filter head to increase until the filter becomes plugged with particles and the head loss is too great to continue operation of the filter. The rate through the filter is much greater in the beginning of a filter run than at the end when the filter is dirty. This method tends to be the most commonly installed in new filter plants.



The photograph on right shows operators walking through the filter gallery of a plant that uses declining rate filters. This is also showing pipelines to and from the filter boxes.

Constant rate
This type of control monitors the level of water on the top of the filter and attempts to control this level from the start of the operation to the end. This is accomplished by the controller operating a valve on the effluent of the filter. The valve will be nearly closed at the start of the filter run and fully open at the end. This design is used when the head or pressure on the filter is limited.



The photograph above shows the overflow in case the filter level gets too high.

Both controllers consist of a venturi tube or some other type of metering device, as well as a valve to control the flow from the filter. In most cases, the valve is controlled by an automatic control device, often an air-actuated type valve that is controlled by the flow tube controller.

Loss of head indicator

As filtration proceeds, an increasing amount of pressure, called head loss across the filter, is required to force the water through the filter. The head loss should be continuously measured to help determine when the filter should be backwashed.



Usually the difference in the head is measured by a piezometer connected to the filter above the media and the effluent line.

In-line turbidimeter

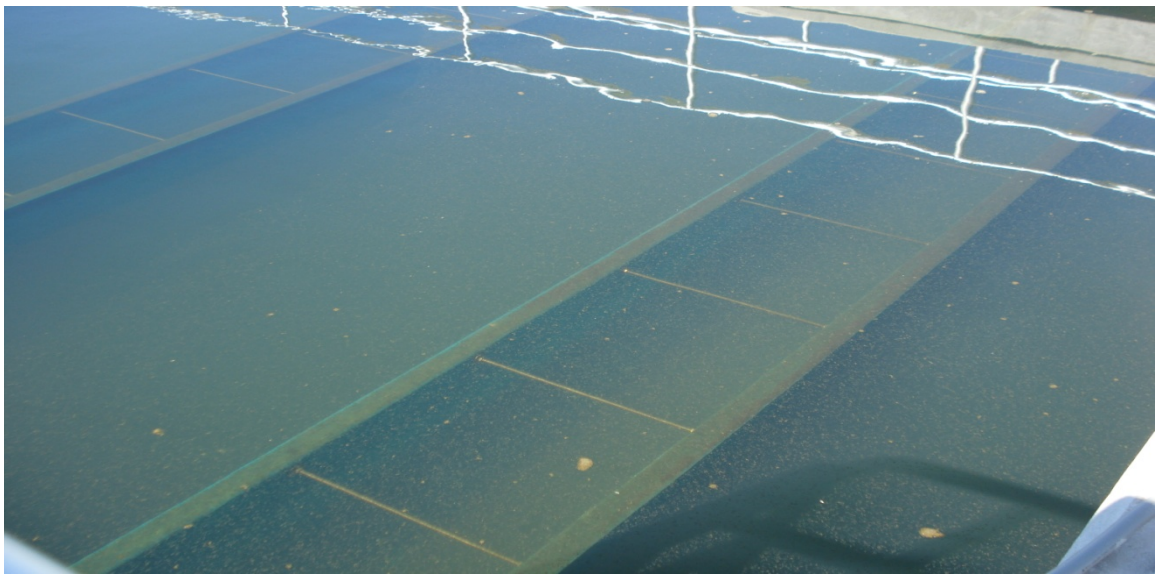
Turbidity in water is caused by small suspended particles that scatter or reflect light so that the water appears to be cloudy. Turbidity of the filtered water may shelter bacteria, preventing chlorine from reaching it during the final disinfection process. The turbidity of the filtered water is one of the factors that determine the length of a filter run. At some point, the suspended material will start to break through the filter media and increase the turbidity of the filter effluent. At this time, the filter should be backwashed. Continuous turbidity monitors provide information about when the filter is approaching this point so that the operators can start the backwash before the turbidity is too great. Turbidity measurements will also indicate whether the coagulation and other treatment processes are operating properly.



Filtration Process

Water from the source or, more commonly, from pre-treatment processes, is applied to the top of the filter; it then flows downward. The water level above the filter bed is usually kept at two-to-six feet. When the filtration is started after being backwashed, there will be little head loss. In filters with a control valve installed on the filter effluent pipe, the filter flow is restricted during this time. The control valve also has the important function of preventing filter surges, which could disturb the media and force floc through the filter.

The rate of flow on a filter depends on the type of filter. A rapid sand filter will have a flow of two-to-three gpm/square foot of filter area. The high rate filter may have four-to-six gpm/square foot applied to the surface. A constant rate flow valve is almost fully closed when a filter is clean so that the desired water level on top of the filter is maintained. As the filter becomes dirty with suspended material, the valve opens gradually until the increase in the water level above the filter indicates that the filter needs backwashing.



The above photograph is a filter from a direct filtration plant; notice the size of the floc.

In filters with variable declining rate flow control, the filters are allowed to take on as much water as they can handle. As the filters become dirty, both the headloss and the depth of the water on the surface increase until the filters need backwashing. This method is generally preferred because it requires less operator attention. With this method, a filter accepts as much flow as it can handle. As the filter becomes dirty, the flow through the filter becomes less and, if the plant has more than one filter, additional flow redistributes across the other filters. A flow restrictor is placed in the filter effluent pipe to prevent a filter inflow that is too great for the filter.

Regardless of the method of control, the filter eventually fills with suspended material. At some time, usually after 15 to 30 hours, it will need to be backwashed to clean the media.

Back Washing



Proper backwashing is a very important step in the operation of a filter. If the filter is not backwashed completely, it will eventually develop additional operational problems. If a filter is to operate efficiently, it must be cleaned before the next filter run. Treated water from storage is used for the backwash cycle. This treated water is generally taken from elevated storage tanks or pumped in from the clear well.

During filtration, the filter media becomes coated with the floc, which plugs the voids between the filter grains, making the filter difficult to clean. The media must be expanded to clean the filter during the backwash. This expansion causes the filter grains to violently rub against each other, dislodging the floc from the media.

The filter backwash rate has to be great enough to expand and agitate the filter media and suspend the flocs in the water for removal. However, if the filter backwash rate is too high, media will be washed from the filter into the troughs and out of the filter. A normal backwash rate is between 12 to 15 gpm per square foot of filter surface area.

In most cases the filter backwash rate will not break up the mass on the top of the filter. The design engineer will recommend the installation of a surface wash of some type, the most common being a set of rotary arms that are suspended above the media during filtration. During filter backwash, the media expands upwards and around the washing arms. A newer method of surface wash involves using air scour before the water wash. This is a very efficient method, but requires the installation of a large air blower to produce the air. The normal design for the air wash will be two-to-five cubic feet of air per square foot of filter area.



Both photographs are part of the backwash equipment for the water plant.

The filter should be backwashed when the following conditions have been met:

- The head loss is so high that the filter no longer produces water at the desired rate; and/or
- Floc starts to break through the filter and the turbidity in the filter effluent increases; and/or
- A filter run reaches a given hour of operation.
- If a filter is taken out of service for some reason, it must always be backwashed prior to be putting on line.



The decision to backwash the filter should not be based on only one of the above conditions. If a filter is not backwashed until the headloss exceeds a certain number of feet, the turbidity may break through and cause the filter to exceed the standard of 0.5 NTU of turbidity.

Similarly, depending on filter effluent-turbidity alone can cause high head loss and decreased filter flow rate, which can cause the pressure in the filter to drop below atmospheric pressure and cause the filter to air bind and stop filtering.

If the water applied to a filter is very good quality, the filter runs can be very long. Some filters can operate longer than one week before needing to be backwashed. However, this is not recommended as long filter runs can cause the filter media to pack down so that it is difficult to expand the bed during the backwash.

Backwashing Process

The normal method for backwashing a filter involves draining the water level above the filter to a point six inches above the filter media. The surface wash is then turned on and allowed to operate for several minutes to break up the crust on the filter.

After that, the backwash valve is opened, allowing backwash water to start flowing into the filter and start carrying suspended material away from the filter. For a filter with an air wash instead of a water-surface wash, the filter backwash water and the air wash should not be used together. This would be possible only if some means of controlling the media carryover is installed.



This is a filter control panel.

The time elapsed from when the filter wash is started until full flow is applied to the filter should be greater than one minute. After a few minutes, the filter backwash valve should be fully opened to allow full expansion of the filter media. Generally, this expansion will be from 20 to 40 percent over the normal filter bed volume. The expansion needed will depend on how much agitation is needed to suspend the filter media to remove to suspended material trapped in the filter. With a multi-media filter, the rate must be high enough to scrub the interface between the coal and the sand, where the highest amount of suspended solids will be removed from the media. The filter will be washed for 10 to 15 minutes, depending on the amount of solids that must be removed. The best way to determine how long the filter should be washed is to measure the turbidity of the backwash water leaving the filter. In most cases, a filter is washed too long. This could be costly. Too much backwash water is used, and it must be treated after use. Backwash valves must be opened slowly. Opening the valves too rapidly can cause serious damage to the filter underdrain, filter gravel, and filter media.

Disposal of Filter Backwash Water

Water from the filter backwash cannot be returned directly to the environment. Normally the water is discharged into a backwash tank and allowed to settle. The supernatant, or cleared liquid, is then pumped back to the head of the treatment plant at a rate not exceeding ten percent of the raw water flow entering the plant. The settled material is pumped to a sewer or is treated in the solids-handling process of the plant. This conserves most of the backwash water and eliminates the need to obtain a pollution discharge permit for the disposal of the filter backwash water.



Since backwash is a very high flow operation, the surges that are created from the backwash coming from the filter must not be allowed to enter the head of the plant. Therefore, the spent backwash water must be stored in storage tanks and returned slowly to the treatment process.

Filter to Waste

When filtration is started after backwash, filtered water should be wasted until the turbidity in the effluent meets standards. Depending on the type of filter, this may last from two to 20 minutes. This wasting is needed as some suspended material remains in the filter media following the backwash. The media needs to become somewhat sticky again to start to capture the suspended material.

Also, the filtration rate is higher in a clean filter, causing more material to be swept from the filter during the start-up. Filtration should always be started slowly after a backwash to prevent breakthrough of suspended material.



Filter Aids

Sometimes, when water passes through a filter, the floc is torn apart into smaller particles that will penetrate deeply into the filter media, causing premature turbidity breakthrough. This will require more frequent filter backwashing of the filter and use of large volumes of backwash water to be able to remove the floc that has penetrated deeply into the filter bed. A filter aid is a material that adds strength to the floc and prevents its breakup. Generally, a polymer is used as a filter aid because it creates strong bonds with the floc. Polymers are water-soluble, organic compounds that can be purchased in either wet or dry form.







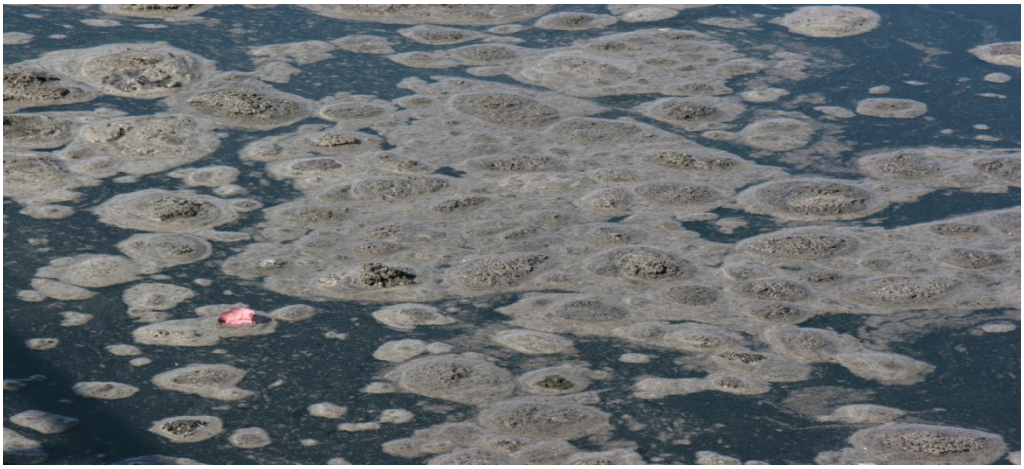
The photograph on the right is showing dry Polymer and on the left side is liquid.

Polymers have very high molecular weight and cause the floc to coagulate and flocculate quickly. Polymers can have positive or negative charges, depending on the type needed to cause attraction to the specific floc filtered.

When used as a filter aid, the polymer strengthens the bonds and prevents the shearing forces in the filter from breaking the floc apart. For best results, the polymer should be added just ahead of the filter. A normal dose of polymer for filter aiding will be less than 0.1 ppm, but the exact dose will be decided by the result of a jar test and by experimentation in the treatment plant. Too much polymer will cause the bonds to become too strong, which may then cause the filter to plug, especially the top few inches of the filter media.

Filter Operating Problems

There are three major types of filter problems. They can be caused by chemical treatment before the filter, control of filter flow rate, and backwashing of filters.



The above photograph shows clumps formed by Powder Activated Carbon.

Chemical Treatment before the Filter

The coagulation and flocculation stages of the water treatment must be monitored continuously. Adjustments in the amount of coagulant added must be made frequently to prevent the filter from becoming overloaded with suspended material. This overload may cause the filter to prematurely reach its maximum headloss.

If there is early turbidity breakthrough in the filter effluent, more coagulant may have to be added to the coagulation process. There may be a need for better mixing during the coagulation or the addition of more filter aid.

If there is a rapid increase in filter head loss, too much coagulant may be clogging the filter. Less coagulant or less filter aid should be used. The operator needs to learn to recognize these problems and choose the proper corrections.



Filter aid being fed at the weirs of sedimentation.

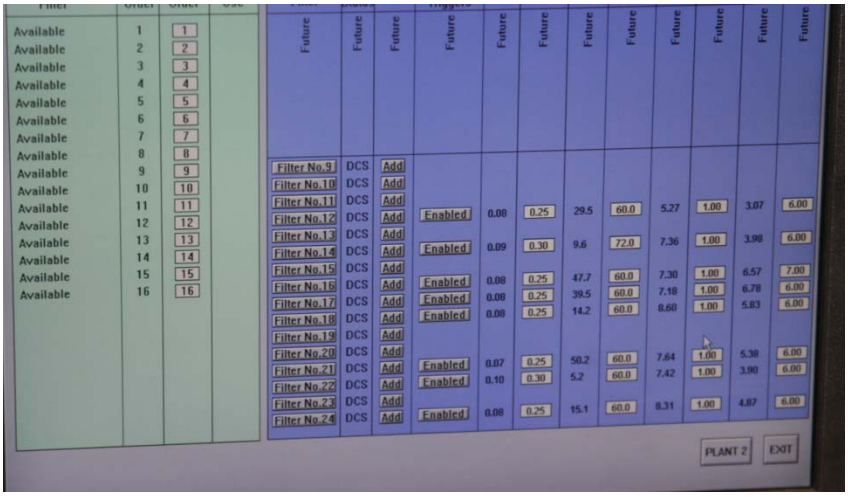


In the photograph above, overfeeding flocculants to meet federal regulations caused Iron to precipitate on the filter walls.

Control of Filter Flow Rate
When a filter is subjected to rapid changes in flow rate, the turbidity of the effluent may be affected; the dirtier the filter media, the greater the effect.

When a plant flow changes, the filter flow also has to change to produce the water needed. If an increase is necessary, the flow should, if possible, be increased gradually over a ten-minute period to reduce the impact on the filter. Addition of filter aids may also reduce the impact on the filter effluent.

When backwashing a filter and therefore temporarily taking it out of service, the remaining filter(s) must pick up the additional flow. This can cause an abrupt change in flow that will cause turbidity breakthrough. This problem can be avoided by keeping one filter in reserve to accept this additional flow. If the plant has a backwash storage basin, this will also prevent surges to the filters.



Many plants are not operated continuously, and the start-up at the beginning of the day will cause a surge to the filter(s). The filters should be backwashed before putting them back into operation or operated to waste until the effluent meets the standards.

Backwashing of Filters
Backwashing of the filters is the single most important operation in the maintenance of the filters. If the filter is not backwashed effectively, problems may occur that may be impossible to correct without totally replacing the filter media. These problems could be caused by improper backwashing procedures:

- Mud balls are formed by the filter media cementing together with the floc that the filter is supposed to remove. If the filter is backwashed effectively, the mud balls are broken apart and removed. As the balls gain weight, they will settle to the bottom of the filter and occupy valuable filter volume. This will cause the flow to increase in the areas of the filter that have not been plugged. Additional problems, such as filter cracking and separation of the media from the filter walls may also be the result of mud-ball formation.

- Filter bed shrinkage or compaction can result from ineffective backwashing. Media grains in a clean filter rest directly against each other with very little compaction.

- Filter media in a dirty filter are surrounded by a soft layer which causes it to compact. This causes filter bed cracking and separation of the filter media from the walls of the filter. When the filter is cracked, it is obvious that the filter will short circuit. The flow will seek the crack and go straight through, resulting in excessive turbidity in the effluent.



A photograph of a backwash basin that has media caked on the bottom.

- Separation of the gravel is caused by the backwash valve opening too quickly; as a result, the supporting gravel is forced to the top of the filter. This could also be caused by the filter underdrain being plugged, causing uneven distribution of the backwash water. When this happens, a boil occurs from the increased velocity in the filter. The filter media will start washing into the filter underdrain system and be removed from the filter. If displacement has occurred, the filter media must be removed from the filter and the filter rebuilt by the placement of each grade of media in its proper place.

- Air binding of the filter is not common as long as the filter is washed regularly. Air binding is the result of pressure in the filter becoming negative during operation. This causes the air dissolved in the water to come out of the solution and become trapped in the filter, resulting in resistance and short filter runs. This negative head generally occurs in a filter that has less than five feet of head above the unexpanded filter bed. If a filter head of five feet is not possible, filter backwash should be started at a lower head loss than normal.



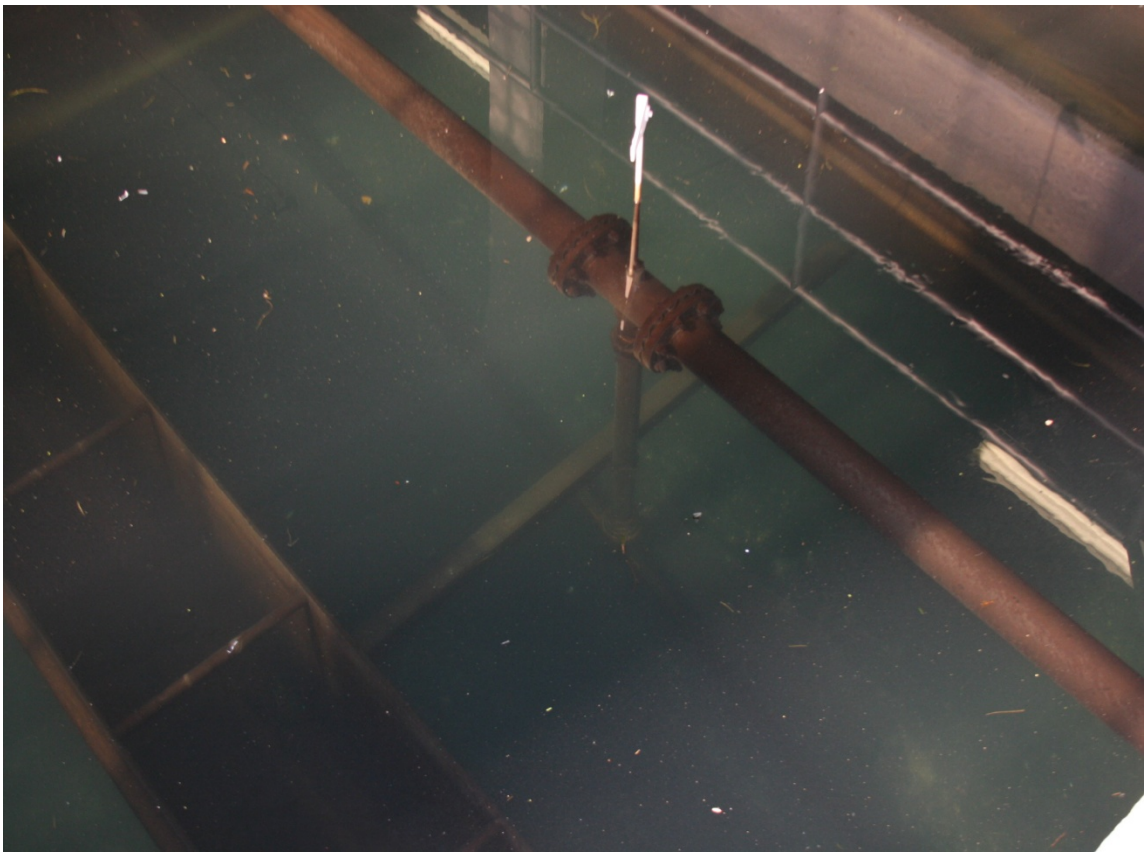
The photograph on the right shows a filter support bed under construction.

Air binding can also be caused by the water being cold and super-saturated with air. This air bubbles out as the water warms up. It is not possible for the operator to control this situation. If it happens, the filter must be backwashed more frequently to correct the filter air binding.

- Media loss is normal in any filter. Some are lost each time the filter is backwashed, especially if the filter surface wash is used. If a large amount of media is being lost, the method of washing should be inspected and corrected. The bed should not have to be expanded more than 20 percent during the backwash cycle. It may help to turn off the surface wash approximately two minutes before the end of the backwash. If this does not correct the problem, the filter troughs may have to be raised to prevent the excessive media loss.

Filter On-Line

After a well-operated filter backwash, the filter should be level and smooth with no cracks or mud balls at the surface. A good bed will appear to move laterally during the backwash and there will be no boils at the surface. The filter should clear up evenly cleaning. If some areas are not clean, there could be an under-drain problem.



Mudballs can be seen on the top layer of the media bed or during the backwash water cycle. Typically, these will not flow over into the filter troughs.

More on Water Treatment Chemicals

Similar chemicals are used for process control, odor control and sludge conditioning in Water and Wastewater Treatment. Students will learn about the types of chemicals used and how they react in the process. Students will also learn about chemical safety and perform on-site equipment assessment.

The table below is a list of **general** chemicals used in Water and Wastewater. They may vary by the manufacture; a perfect example would be Thioguard®, which is Magnesium Hydroxide. In this class we will discuss the chemical name and compound and leave out manufacture trade names.

Common Water/Wastewater Treatment Chemicals

Chemical Name	Common Name	Chemical Formula	pH (Raise or Lowers)
Aluminum hydroxide		$Al(OH)_3$	
Aluminum sulfate	Alum, liquid	$AL_2(SO_4)3 . 14(H_2O)$	
Ammonia		NH_3	
Ammonium		NH_4	
Bentonitic clay	Bentonite		
Calcium bicarbonate		$Ca(HCO_3)2$	
Calcium carbonate	Limestone	$CaCO_3$	
Calcium chloride		CaCl2	
Calcium Hypochlorite	HTH	$Ca(OCl)_2 . 4H_2O$	
Calcium hydroxide	Slaked Lime	$Ca(OH)_2$	
Calcium oxide	Unslaked (Quicklime)	CaO	
Calcium sulfate	Gypsum	$CaSO_4$	
Carbon	Activated Carbon	C	
Carbon dioxide		CO_2	
Carbonic acid		$H2CO_3$	
Chlorine gas		Cl2	
Chlorine Dioxide		ClO_2	
Copper sulfate	Blue vitriol	$CuSO_4 . 5H_2O$	
Dichloramine		NHCl2	
Ferric chloride	Iron chloride	$FeCl_3$	
Ferric hydroxide		$Fe(OH)_3$	
Ferric sulfate	Iron sulfate	$Fe_2(SO_4)_3$	
Ferrous bicarbonate		$Fe(HCO_3)_2$	
Ferrous hydroxide		$Fe(OH)_3$	
Ferrous sulfate	Copperas	$FeSO_4.7H_20$	
Hydrofluorsilicic acid		H_2SiF_6	
Hydrochloric acid	Muriatic acid	HCl	
Hydrogen sulfide		H_2S	

Chemical Name	Common Name	Chemical Formula	pH (Raise or Lowers)
Hypochlorus acid		HOCL	
Magnesium bicarbonate		$Mg(HCO_3)2$	
Magnesium carbonate		$MgCO_3$	
Magnesium chloride		MgCl2	
Magnesium hydroxide		$Mg(OH)_2$	
Magnesium dioxide		MgO_2	
Manganous bicarbonate		$Mn(HCO_3)2$	
Manganous sulfate		$MnSO_4$	
Monochloramine		NH_2Cl	
Potassium bicarbonate		$KHCO_3$	
Potassium permanganate		$KMnO_4$	
Sodium carbonate	Soda ash	Na_2CO_3	
Sodium chloride	Salt	NaCl	
Sodium chlorite		$NaClO_2$	
Sodium fluoride		NaF	
Sodium fluorsilicate		Na_2SiF_6	
Sodium hydroxide	Lye	NaOH	
Sodium hypochlorite		NaOCl	
Sodium Metaphosphate	Hexametaphosphate	$NaPO_3$	
Sodium phosphate	Disodium phosphate	Na_3PO_4	
Sodium sulfate		Na_2SO_4	
Sulfuric acid		H_2SO_4	



Solubility of Substances in Water

Water is an excellent solvent for many compounds. Some dissolve in it as molecules while others, called electrolytes, dissociate and dissolve not as neutral molecules but as charged species called ions. Compounds which exist as solid ionic crystals dissolve in water as ions, and most of them are highly soluble in water. “Highly soluble” is a somewhat elastic description, but generally means soluble to at least the extent of forming 0.1 to 1.0 molar aqueous solutions. Salts which are less soluble in water than this at room temperature are called slightly soluble salts.

The solubility of an ionic salt depends both upon its cations and its anions, but for simple salts in aqueous solution at room temperature the following general observations are useful. Almost all sodium, potassium, and ammonium salts are highly soluble; the only significant exception is $KClO_4$, which is moderately soluble almost without exception. Metal carbonates and phosphates are generally insoluble or slightly soluble, with the exception of those of sodium, potassium, and ammonium which are highly soluble; magnesium ammonium phosphate is used for the precipitation of magnesium ion.

Metal halides are generally highly soluble, with the exception of those of silver, lead, and mercury (I). Lead chloride is slightly soluble while silver and mercury (I) chlorides are much less soluble. Sulfate salts are generally highly soluble as well, with more exceptions; calcium, barium, strontium, lead, and mercury (I) sulfates are almost insoluble while silver sulfate is slightly soluble. Metal sulfides are generally insoluble in water.

Solid-Solution (Solubility) Reactions
When solids dissolve, the solutes are no longer pure substances and their activity can no longer be taken as unity. In dilute solutions, aqueous or otherwise, activities of solutes are often taken as equal to their molar concentrations. These equilibria are called solubility equilibria and are taken up under the following main heading. The example below shows how the form in which they are written compares to other equilibrium constants.

Example. The equilibrium constant for the reaction AgCl(s) <--> Ag+(aq)+Cl-(aq) is written as K= a(Ag+)a(Cl-)/a(AgCl); more commonly, it is written in the form Ka(AgCl)=a(Ag+)a(Cl-)=K_{sp}. If the molar concentrations are taken as good approximations to the activities, which in dilute solutions they are, then K_{sp}=[Ag+][Cl].

Example. Let us write and simplify to the extent possible the equilibrium constant for the equilibrium $Al^{3+}(aq) + 3OH^{-}(aq)$ <--> $A1(OH)_3(s)$ For this equilibrium $K= 1/[Al^{3+}][OH^{-}]^3 = 1/K_{sp}$. where K has the units dm^{12}/mol^4, or $(dm^3)^4/mol^4$.

The form of equilibrium constant indicated as K_{sp} is called the solubility product constant or, more commonly, the solubility product. This constant therefore must refer to the process of a solid going into solution (solubility) rather than the reverse, precipitation of solid from solution. As a consequence, the ions are products and appear in the numerator.

The value of the solubility product is temperature-dependent and is generally found to increase with increasing temperature. As a consequence, the molar solubility of ionic salts generally increases with increasing temperature. The extent of this increase varies from one salt to another.

It is sometimes possible to take advantage of the difference in the effect of temperature to separate mixtures of different soluble salts. As the chart in the following Figure shows, a solution originally of equal concentration in $KClO_3$ and KNO_3 should upon heating and evaporation of water precipitate $KClO_3$ because KNO_3 is by far the more soluble near the boiling point of water.

The solubility of solid salts in water, and in most other solvents, increases with temperature while that of gases decreases. The heat or enthalpy change of the dissolution reaction for most solids is positive so the dissolution reaction is endothermic. For some solids, such as NaCl, the heat of solution is very small and so the effect of temperature is small also. For other salts, such as KNO_3, the effect of temperature is much larger:

$NaCl(c) <--> Na^+(aq) + Cl^-(aq)$; H0 = (-240.12-167.159) – (-411.153) = +3.87 kJ/mol

$KNO_3(c) <--> K^+(aq) + NO_3^-(aq)$; H0 = (-252.38-205.0)-(-494.63) = +37.3kJ/mol

Chemical coagulation in the water/wastewater treatment is the process of bringing suspended matter in untreated water together for the purpose of settling and for the preparation of the water for filtration.

Coagulation involves three specific steps, which are:

- Coagulation
- Flocculation
- Sedimentation



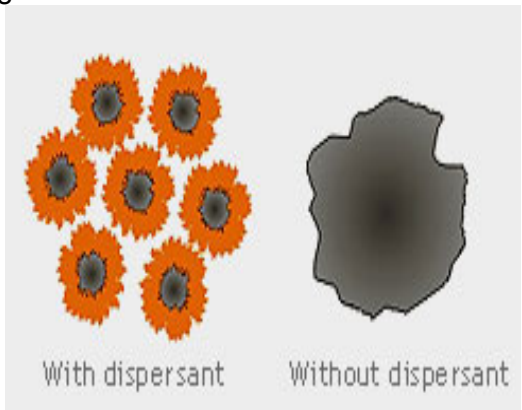
Primary Clarifier

Purpose of Coagulation

Untreated surface waters contain clay, minerals, bacteria, inert solids, microbiological organisms, oxidized metals, organic color producing particles, and other suspended materials. Some of the microbiological organisms can include Giardia cysts, pathogenic bacteria, and viruses. Oxidized metals include iron and manganese. All of these materials can inhibit disinfection, cause problems in the distribution system, and leave the water cloudy rather than clear. The purpose of coagulation is to remove these particles.

The ability of particles to remain suspended in water is a function of both the particle size and specific gravity. Turbidity particles can range in size from molecular to 50 microns. Particles which are greater than one micron in diameter are considered silt, and settle out due to their relatively large size and density without the need to coagulate in a matter of seconds or minutes.

Colloidal material ranges in size from 0.001 to one micron in diameter. These materials require days to months for complete settling. Since detention times in the water treatment process are generally less than twelve hours, the rate of settling of these colloidal particles must be increased in the water treatment process. This is accomplished in the coagulation process when tiny particles agglomerate into larger, denser particles which will settle more quickly as shown in the picture on the right.



These tiny colloidal particles have a very large surface area to mass ratio, and this factor is important in keeping the particles suspended for long periods of time. In fact, the surface area to mass ratio is so high that electric charges and ionic groups become important in keeping the particles suspended. Two types of colloids exist. These are hydrophobic or water hating colloids, and hydrophilic or water loving colloids. Hydrophilic colloids form suspensions easily, and can be difficult to remove. These colloids can, however, react chemically with the coagulants commonly added to water under proper conditions. Examples of hydrophilic colloids would be organic color forming compounds. Hydrophobic colloids do not easily form suspensions. The reactions between hydrophobic colloids and the coagulants commonly added to water are largely physical rather than chemical. Examples of hydrophobic colloids would be clays and metal oxides.

The Coagulation Process

Coagulation is accomplished by the addition of ions having the opposite charge to that of the colloidal particles. Since the colloidal particles are almost always negatively charged, the ions which are added should be cations or positively charged. The coagulating power of an ion is dependent on its valency or magnitude of charge. A bivalent ion (+2 charge) is 30 to 60 times more effective than a monovalent ion (+l charge). A trivalent ion (+3 charge) is 700 to 1000 times more effective than a monovalent ion.

Typically, two major types of coagulants are added to water. These are aluminum salts and iron salts. The most common aluminum salt is aluminum sulfate, or alum.

When aluminum sulfate is added to water, the aluminum ions enter into a series of complicated reactions. The aluminum ions become hydrated, meaning that water molecules attach themselves to the aluminum ions. In addition, anions present in the water, such as hydroxide and sulfate ions can attach to the aluminum ions.

These reactions result in large, positively charged molecules having aluminum ions at their center. These particles may have charges as high as +4. Following these reactions, a second type of reaction occurs, called Olation. This reaction involves the bridging of two or more of these large molecules to form even larger, positively charged ions. A typical molecule can contain eight aluminum ions, twenty hydroxide ions, and will have a +4 charge. Iron salts behave in a similar manner when added to water.

Once these large polymeric aluminum or iron compounds are formed, the magnitude of their high positive charge allows these species to rapidly move toward the colloid, where they are adsorbed onto the negatively charged surface of the turbidity particle. The coagulant compounds can penetrate the bound water layer because of their high positive charge.

This rapid adsorption results in the compression of the electrical double layer, and results in the colloid becoming coated with the coagulant compounds. The net result of this process is that the electrical charges on the particle are reduced. The suspension is now considered to be destabilized, and the particles can be brought together through, among other forces, Brownian Movement, and will be held together by the Van der Waals forces.

An additional process occurs which assists this process. As the coagulant continues to undergo the hydrolyzation and olation reactions, progressively larger masses of flocculent material are formed. These compounds can become large enough to settle on their own, and tend to trap turbidity particles as they settle. This is commonly referred to as sweep floc.

As the coagulation reactions and destabilization are occurring, the Zeta Potential at the surface of the colloid is also found to be reducing. Typically, the Zeta Potential for a naturally occurring water may be in the range of -10 to -25 millivolts. As the reactions occur, this Zeta Potential will be reduced to approximately -5 millivolts. These figures are only examples of what might be considered typical waters. Since all waters exhibit a specific set of characteristics, these numbers will vary. It is interesting to note that the Zeta Potential does not have to be reduced to zero in order for coagulation to occur, because the forces of attraction can become predominant before complete destabilization occurs.

Hydrophilic colloids participate in the coagulation process in a slightly different way. These colloids tend to attract water molecules and attach these water molecules to their surfaces. This is also a hydration process, and the water molecules act as a barrier to contact between particles. Also attached to the surfaces are hydroxyl, carboxyl, and phosphate groups, all to which are negatively charged. Coagulant products react chemically with the negatively charged groups attached to the hydrophilic colloids, forming an insoluble product which is electrically neutral and destabilized.

Factors Influencing Coagulation

Effects of pH: The pH range in which a coagulation process occurs may be the single most important factor in proper coagulation. The vast majority of coagulation problems are related to improper pH levels. Whenever possible, coagulation should be conducted in the optimum pH zone. When this is not done, lower coagulation efficiency results, generally resulting in a waste of chemicals and a lowered water quality. Each of the inorganic salt coagulants has its own characteristic optimum pH range. In many plants, it is necessary to adjust the pH level in the coagulation process. In most cases this involves the addition of lime, caustic soda, or soda ash to maintain a minimum pH level. In some cases, however, acids may be necessary to lower the pH level to an optimum range. In some water plants, the acidic reactions of the inorganic salts are taken advantage of when the raw water pH levels are higher than desired. In these instances, overfeed of the coagulant is intentionally induced in order for the coagulation process to occur in the optimum range.

Effects of salts: Since no natural waters are completely pure, each will have various levels of cations and anions such as calcium, sodium, magnesium, iron, manganese, sulfate, chloride, phosphate, and others. Some of these ions may affect the efficiency of the coagulation process. Generally, mono and divalent cations such as sodium, calcium, and magnesium have little or no effect on the coagulation process. Trivalent cations do not have an adverse effect on the process in most instances. In fact, significant concentrations of naturally occurring iron in a water supply has resulted in the ability to feed lower than normal dosages of inorganic salt coagulants.

Some anions can have a more pronounced effect. Generally, monovalent anions such as chloride have little effect on the coagulation process. As the concentration of the divalent anion sulfate in a water supply increases, the optimum pH range of the inorganic salt coagulants tends to broaden, generally toward the lower pH levels. As the concentration of phosphate ions increase, the optimum range of pH tends to shift to lower pH levels, without broadening. These effects could cause a disruption of the coagulation process if abrupt changes in the concentrations of these anions occur in the water supply.

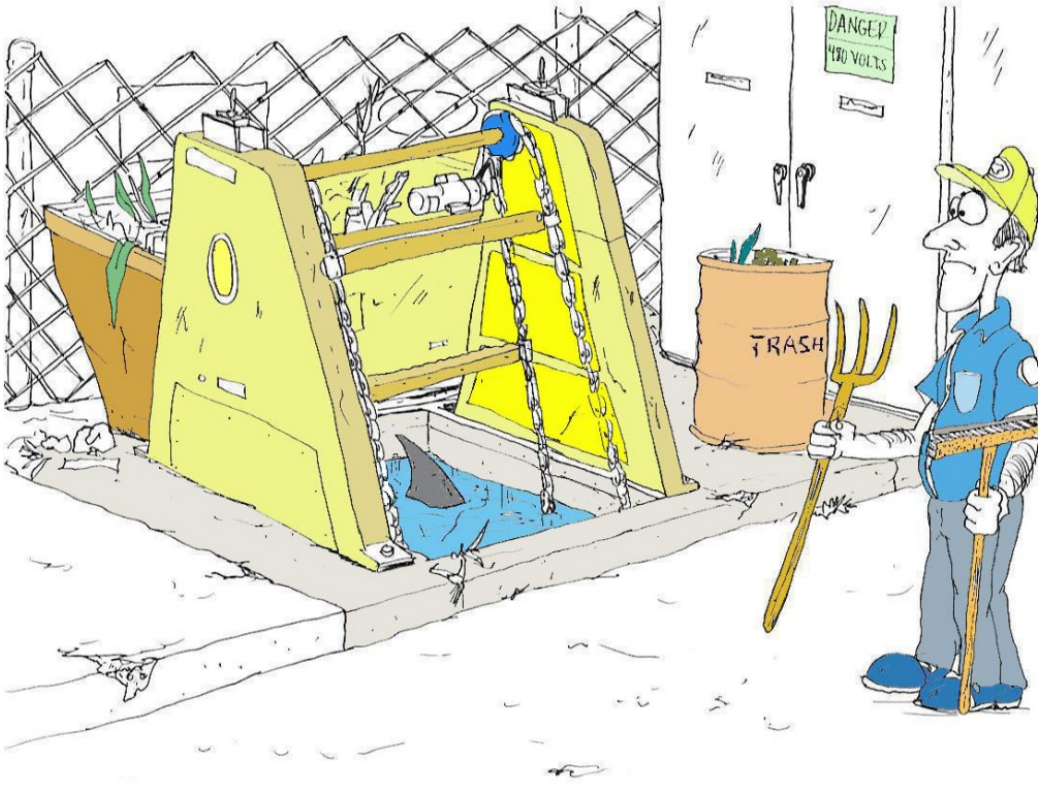
Nature of turbidity: The turbidity in natural surface waters is composed of a large number of sizes of particles. The sizes of particles can be changing constantly, depending on precipitation and manmade factors. When heavy rains occur, runoff into streams, rivers, and reservoirs occurs, causing turbidity levels to increase. In most cases, the particle sizes are relatively large and settle relatively quickly in both the water treatment plant and the source of supply. However, in some instances, fine, colloidal material may be present in the supply, which may cause some difficulty in the coagulation process.

Generally, higher turbidity levels require higher coagulant dosages. However, seldom is the relationship between turbidity level and coagulant dosage linear. Usually, the additional coagulant required is relatively small when turbidities are much higher than normal due to higher collision probabilities of the colloids during high turbidities. Conversely, low turbidity waters can be very difficult to coagulate due to the difficulty in inducing collision between the colloids. In this instance, floc formation is poor, and much of the turbidity is carried directly to the filters. Organic colloids may be present in a water supply due to pollution, and these colloids can be difficult to remove in the coagulation process. In this situation, higher coagulant dosages are generally required.

Water temperature: Cold water temperatures can cause two factors which add to the difficulty of the coagulation process. As water temperatures approach freezing, almost all chemical reactions occur more slowly. It can be more difficult therefore to evenly disperse the coagulants into the water. As a result, the coagulant process becomes less efficient, and higher coagulant dosages are generally used to compensate for these effects. In addition, floc settling characteristics become poor due to the higher density of the water during near freezing temperatures.

Mixing Effects: Poor or inadequate mixing results in an uneven dispersion of the coagulant. Unfortunately, many older plants were designed with mixing facilities which generally do not accomplish mixing in the most efficient manner. As a result, it becomes necessary to use higher than necessary dosages of coagulant to achieve an optimum level of efficiency in the process. The effects of low turbidity and cold water temperatures can tend to aggravate the lack of adequate mixing facilities in some plants.

Effect of the coagulant: The choice of the proper coagulant for the given conditions is of critical importance in maintaining an efficient coagulation scheme under widely varying conditions. The chemicals most commonly used in the coagulation process are Aluminum Sulfate, Ferric Chloride, Ferric Sulfate, and Cationic Polymers.



Coagulants

Aluminum Sulfate (Alum): Aluminum Sulfate is also known as alum, filter alum, and alumina sulfate. Alum is the most widely used coagulant. Alum is available in dry form as a powder or in lump form. It can also be purchased and fed as a liquid. Alum has no exact formula due to the varying water molecules of hydration which may be attached to the aluminum sulfate molecule. Once in water, alum can react with hydroxides, carbonates, bicarbonates, and other anions as discussed previously to form large, positively charged molecules. Carbon dioxide and sulfate are generally byproducts of these reactions. During the reactions, alum acts as an acid to reduce the pH and alkalinity of the water supply. It is important that sufficient alkalinity be present in the water supply for the various reactions to occur.

On a theoretical basis, 1.0 mg/l of dry alum will react with:
0.50 mg/l of natural alkalinity as calcium carbonate
0.33 mg/l of 85% quicklime as calcium oxide
0.39 mg/l of 95% hydrated lime as calcium hydroxide
0.54 mg/l of soda ash as sodium carbonate

Alum can be effective in the pH range of 5.5 to 7.8, but seems to work best in most water supplies in a pH range of 6.8 to 7.5. Below a pH range of 5.5, alkalinity in the water supply is generally insufficient. The aluminum ions become soluble rather than insoluble and do not participate in the hydration and olation reactions necessary to make the alum effective as a coagulant. In these instances the plant may experience higher than normal filtered water turbidities, and much of the aluminum will pass through the filters.

When the pH level of the water is above 7.8 after the addition of the alum, the aluminum ions again become soluble, and the efficiency of coagulation is decreased. Under these conditions, aluminum ions again penetrate the filters, and post filtration alum coagulation can occur in the clear well and in the distribution system in some cases.

Ferric Chloride (Ferric): Traditionally, ferric chloride has not been used widely as a coagulant, but this trend is not continuing. Ferric chloride is becoming more extensively used as a coagulant due partially to the fact that the material can be purchased as a liquid.

Ferric chloride may also be purchased as an anhydrous solid. Liquid ferric chloride is highly corrosive, and must be isolated from all corrodible metals. Like ferric sulfate, ferric chloride exhibits a wide pH range for coagulation, and the ferric ion does not easily become soluble. As a result, many plants are replacing alum with ferric chloride to eliminate the penetration of aluminum ions through the plant filters. Ferric chloride also reacts as an acid in water to reduce alkalinity.

Other inorganic coagulants are available, such as potash alum, ammonia alum, ferrous sulfate (copperas), and chlorinated copperas. None of these materials are widely used. Typical dosages of the inorganic coagulants range from 50 pounds per million gallons of water treated under ideal conditions to as high as 800 to 1000 pounds per million gallons of water treated under worst case conditions.

H_2S Control – Traditional Wet Scrubbing using Chemicals

The most common method of control of H_2S gas is to pass the smelly gas through a vertical, packed bed wet scrubber. The air passes up the tower as the scrubbing liquid containing caustic (NaOH) and oxidizing agent (most often bleach or NaOCl, sodium hypochlorite) flows down the tower in the counter-current fashion. The high pH provided by the caustic drives the mass transfer from gas to liquid phase by solubolizing H_2S as HS^- bisulfide and S^{-2} sulfide ions. Once in solution, the reaction between hydrogen sulfide and oxidizing agent is almost instantaneous (assuming sufficient oxidizing agent is present). This reaction converts the sulfide to sulfate (SO_4^{-2}) ion. The overall chemical reaction is described by the following equation:

$H_2S + 4NaOCl + 2NaOH \rightarrow Na_2SO_4 + 4NaCl + 2H_2O$

Therefore, theoretically, for each molecule of H_2S destroyed, four molecules of bleach and two molecules of caustic are consumed. However, the chemistry is not quite so simple, as partial oxidation of H_2S also takes place which forms elemental sulfur:

$H_2S + NaOCl \rightarrow NaCl + H_2O + S \downarrow$

This reaction represents about 1% of the chemistry present in a wet scrubber. The presence of excess bleach helps to minimize the formation of elemental sulfur. But bleach is an expensive chemical. The use of two stage scrubbing is often employed both to minimize chemical consumption as well as to control sulfur deposits when scrubbing H_2S. The first stage operates at 80% efficiency and uses a caustic only scrub at high pH (12.5). The air then passes to the second stage, where the remaining H_2S is scrubbed with caustic / bleach solution at pH 9.5. The H_2S present is destroyed at 99%+ efficiency. The blowdown from the 2^{nd} stage, which will contain some amount of unsued NaOCl, is sent to the sump of the 1^{st} stage. In this way additional H_2S is destroyed and maximum consumption of expensive oxidizing agent is assured.

Never the less, there are losses of chemicals which cannot be prevented, which of course raise the cost of odor scrubbing. These losses are due to the facts that bleach, NaOCl, slowly decomposes in storage as well as the fact that some amount of caustic is constantly lost to CO_2 absorption in both scrubbing stages.

Emissions
Volatile organic compounds (VOCs) are the primary air pollutants emitted from rendering operations. The major constituents that have been qualitatively identified as potential emissions include organic sulfides, disulfides, C-4 to C-7 aldehydes, trimethylamine, C-4 amines, quinoline, dimethyl pyrazine, other pyrazines, and C-3 to C-6 organic acids. In addition, lesser amounts of C-4 to C-7 alcohols, ketones, aliphatic hydrocarbons, and aromatic compounds are potentially emitted. No quantitative emission data were presented. Historically, the VOCs are considered an odor nuisance in residential areas in close proximity to rendering plants, and emission controls are directed toward odor elimination. The odor detection threshold for many of these compounds is low; some as low as 1 part per billion (ppb). Of the specific constituents listed, only quinoline is classified as a hazardous air pollutant (HAP). In addition to emissions from rendering operations, VOCs may be emitted from the boilers used to generate steam for the operation.

Hard Water Section

Water contains various amounts of dissolved minerals, some of which impart a quality known as hardness. Consumers frequently complain about problems attributed to hard water, such as the formation of scale on cooking utensils and hot water heaters. In this document we will examine the occurrence, and effects, of hard water and the hard water treatment or softening process that removes the hardness-causing minerals. The precipitation process most frequently used is generally known as the lime process or lime soda process. Because of the special facilities required and the complexity of the process, it is generally applicable only to medium- or large-size water systems where all treatment can be accomplished at a central location. This process will provide softened water at the lowest cost. Lime softening can be used for treatment of either groundwater or surface water sources.



The other commonly used method of softening involves the ion exchange process. This process has the advantages of a considerably lower initial cost and ease of use by small systems or by large systems at multiple locations. The principal disadvantage is that operating costs are considerably higher. Ion exchange processes can typically be used for direct treatment of ground-water, so long as turbidity and iron levels are not excessive. For treatment of surface water, the process normally must be preceded by conventional treatment. Softening can also be accomplished using membrane technology, electrodialysis, distillation, and freezing. Of these, membrane methods seem to have the greatest potential.

Distillers

Various sizes of distillers are available for home use. They all work on the principle of vaporizing water and then condensing the vapor. In the process, dissolved solids such as salt, metals, minerals, asbestos fibers, and other particles are removed. Some organic chemicals are also removed, but those that are more volatile are often vaporized and condensed with the product water. Distillers are effective in killing all microorganisms.



The principal problem with a distiller is that a small unit can produce only 2-3 gal (7.5 -11 Lt) a day, and that the power cost for operation will be substantially higher than the operating cost of other types of treatment devices.

Water Distillers have a high energy cost (approximately 20-30 cents per gallon). They must be carbon filtered before and/or after to remove volatile chemicals. It is considered "***dead***" water because the process removes all extra oxygen and energy. It has no taste. It is still second only to reverse osmosis water for health. Diet should be rich in electrolytes, as the aggressive nature of distilled water can "**leach**" electrolytes from the body.

Occurrence of Hard Water

Hard water is caused by soluble, divalent, metallic cations, (positive ions having valence of 2). The principal chemicals that cause water hardness are calcium (**Ca**) and magnesium (**Mg**). Strontium, aluminum, barium, and iron are usually present in large enough concentrations to contribute significantly to the total hardness.

Water hardness varies considerably in different geographic areas of the contiguous 48 states. This is due to different geologic formations, and is also a function of the contact time between water and limestone deposits. Magnesium is dissolved as water passes over and through dolomite and other magnesium-bearing minerals. Because groundwater is in contact with these formations for a longer period of time than surface water, groundwater is normally harder than surface water.

Expressing Water Hardness Concentration

Water hardness is generally expressed as a concentration of calcium carbonate, in terms of milligrams per liter as $CaCO_3$. The degree of hardness that consumers consider objectionable will vary, depending on other qualities of the water and on the hardness to which they have become accustomed. We will show two different classifications of the relative hardness of water:

Comparative classifications of water for softness and hardness

Classification	mg/L as $CaCO_3$ *	mg/L as $CaCO_3$ +
Soft	0 – 75	0 – 60
Moderately hard	75 – 150	61 – 120
Hard	150 – 300	121 – 180
Very hard	Over 300	Over 180

Source: Adapted from sawyer 1960 and Briggs and Ficke 1977.

* Per Sawyer (1960)
\+ Per Briggs and Ficke (1977)

Types of Water Hardness

Hardness can be categorized by either of two methods: calcium versus magnesium hardness and carbonate versus non-carbonate hardness. The calcium-magnesium distinction is based on the minerals involved. Hardness caused by calcium is called calcium hardness, regardless of the salts associated with it, which include calcium sulfate (**$CaSO_4$**), calcium chloride (**$CaCl_2$**), and others. Likewise, hardness caused by magnesium is called magnesium hardness. Calcium and magnesium are normally the only significant minerals that cause harness, so it is generally assumed that

Total harness = calcium hardness + magnesium hardness

The carbonate-noncarbonate distinction, however, is based on hardness from either the bicarbonate salts of calcium or the normal salts of calcium and magnesium involved in causing water hardness. Carbonate hardness is caused primarily by the bicarbonate salts of calcium and magnesium, which are calcium bicarbonate, $Ca(HCO_3)_2$, and magnesium bicarbonate $Mg(HCO_3)_2$. Calcium and magnesium combined with carbonate (CO_3) also contribute to carbonate hardness.

Noncarbonate hardness is a measure of calcium and magnesium salts other than carbonate and bicarbonate salts. These salts are calcium sulfate, calcium chloride, magnesium sulfate ($MgSO_4$), and magnesium chloride ($MgCl_2$). Calcium and magnesium combined with nitrate may also contribute to noncarbonate hardness, although it is a very rare condition. For carbonate and noncarbonate hardness,

Total hardness = carbonate hardness + noncarbonate hardness

When hard water is boiled, carbon dioxide (CO_2) is driven off, and Bicarbonate salts of calcium and magnesium then settle out of the water to form calcium and magnesium carbonate precipitates. These precipitates form the familiar chalky deposits on teapots. Because it can be removed by heating, carbonate hardness is sometimes called ***"Temporary hardness."*** Because noncarbonated hardness cannot be removed or precipitated by prolonged boiling, it is sometimes called ***"permanent hardness."***

Objections to Hard Water

Scale Formation

Hard water forms scale, usually calcium carbonate, which causes a variety of problems. Left to dry on the surface of glassware and plumbing fixtures, including showers doors, faucets, and sink tops; hard water leaves unsightly white scale known as water spots. Scale that forms on the inside of water pipes will eventually reduce the flow capacity or possibly block it entirely. Scale that forms within appliances and water meters causes wear on moving parts.



When hard water is heated, scale forms much faster. In particular, when the magnesium hardness is more than about 40 mg/l (**as $CaCO_3$**), magnesium hydroxide scale will deposit in hot water heaters that are operated at normal temperatures of 140-150^{o}F (60-66^{o}C). A coating of only 0.04 in. (1 mm) of scale on the heating surfaces of a hot water heater creates an insulation effect that will increase heating costs by about 10 percent.

Effect on Soap

The historical objection to hardness has been its effect on soap. Hardness ions form precipitates with soap, causing unsightly "**curd**," such as the familiar bathtub ring, as well as reduced efficiency in washing and laundering. To counteract these problems, synthetic detergents have been developed and are now used almost exclusively for washing clothes and dishes.

These detergents have additives known as sequestering agents that "**tie up**" the hardness ions so that they cannot form the troublesome precipitates. Although modern detergents counteract many of the problems of hard water, many customers prefer softer water. These customers can install individual softening units or use water from another source, such as a cistern, for washing.

Water Softening

Water softening is a method of removing from water the minerals that make it hard. Hard water does not dissolve soap readily. It forms scale in pipes, boilers, and other equipment in which it is used. The principal methods of softening water are the lime soda process and the ion exchange process.

In the ***lime soda process***, soda ash and lime are added to the water in amounts determined by chemical tests. These chemicals combine with the calcium and magnesium in the water to make insoluble compounds that settle to the bottom of the water tank.

In the ***ion exchange process,*** the water filters through minerals called ***zeolites.*** As the water passes through the filter, the sodium ions in the zeolite are exchanged for the calcium and magnesium ions in the water, and the water is softened. After household softeners become exhausted, a strong solution of ***sodium chloride*** (salt) is passed through the filter to replace the sodium that has been lost. The use of two exchange materials makes it possible to remove both metal and acid ions from water. Some cities and towns, however, prohibit or restrict the use of ion exchange equipment on drinking water, pending the results of studies on how people are affected by the consumption of the added sodium in softened water. The containers hold the resin for the deionization. Calcium and magnesium in water create hard water, and high levels can clog pipes. The best way to soften water is to use a water softener unit connected into the water supply line. You may want to consider installing a separate faucet for unsoften water for drinking and cooking. Water softening units also remove iron.

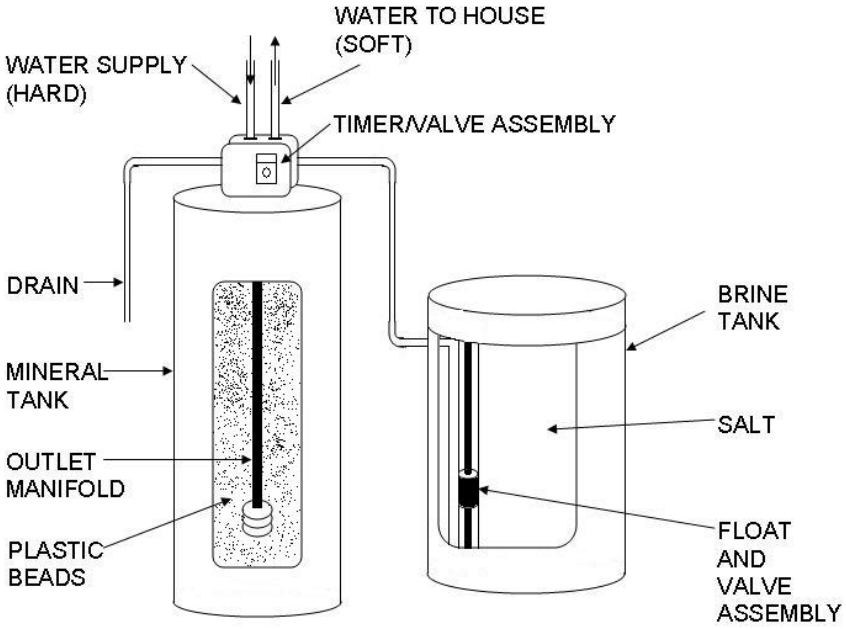


The most common way to soften household water is to use a water softener. Softeners may also be safely used to remove up to about 5 milligrams per liter of dissolved iron if the water softener is rated for that amount of iron removal. Softeners are automatic, semi-automatic, or manual. Each type is available in several sizes and is rated on the amount of hardness it can remove before regeneration is necessary. Using a softener to remove iron in naturally soft water is not advised; a green-sand filter is a better method. When the resin is filled to capacity, it must be recharged. Fully automatic softeners regenerate on a preset schedule and return to service automatically. Regeneration is usually started by a preset time clock; some units are started by water use meters or hardness detectors.

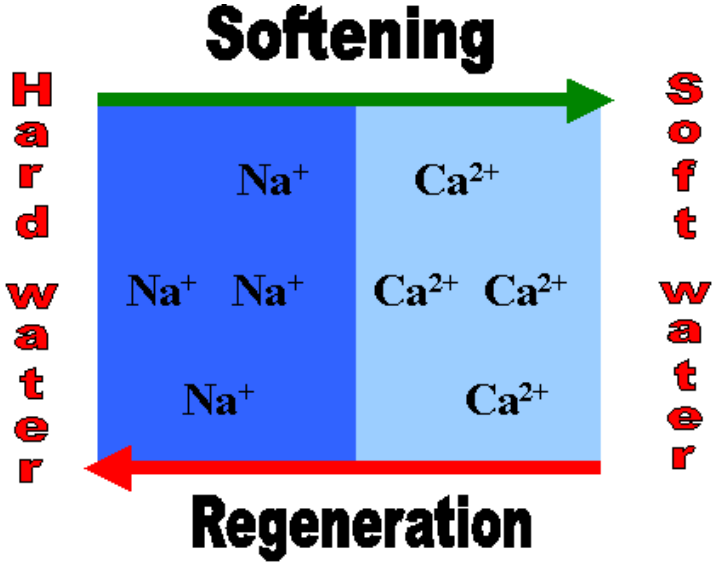
Semi-automatic softeners have automatic controls for everything except for the start of regeneration. Manual units require manual operation of one or more valves to control back washing, brining and rinsing. In many areas, there are companies that provide a water softening service. For a monthly fee the company installs a softener unit and replaces it periodically with a freshly charged unit.

The principle behind water softening is really just simple chemistry. A water softener contains resin beads which hold electrically charged ions. When hard water passes through the softener, calcium and magnesium ions are attracted to the charged resin beads. It's the resulting removal of calcium and magnesium ions that produces "***soft water***."

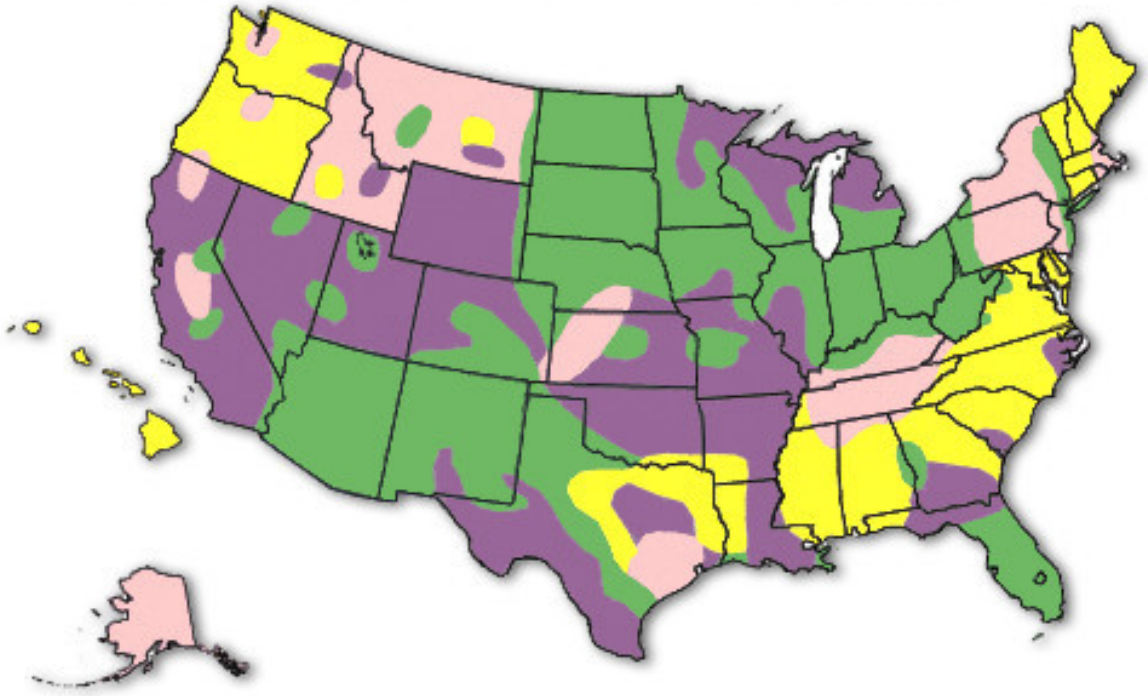
The diagram shows the exchange that takes place during the water softening process. When the resin beads in your softener become saturated with calcium and magnesium ions, they need to be recharged. Sodium ions from the water softening salt reactivate the resin beads so they can continue to do their job. Without sufficient softening salt, your water softener is less efficient. As a rule, you should check your water softener once a week to be sure the salt level is always at least one quarter full.



Conventional Household Water Softener



HARD WATER LEVELS THROUGHOUT THE U.S.

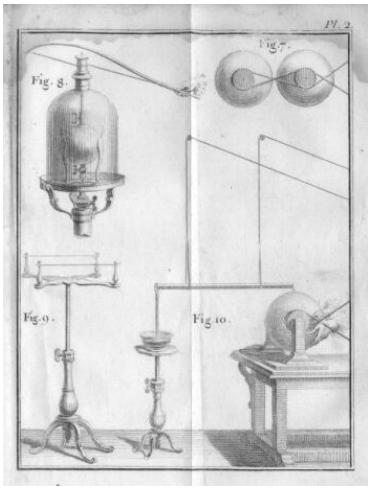


LEGEND

- 0 - 3.5 grains per gallon – Soft
- 3.5 - 7.0 grains per gallon – Moderately Hard
- 7.0 - 10.5 grains per gallon – Hard
- over 10.5 grains per gallon – Very Hard

Due to the nature of the water bed sub-soil structure, water hardness may vary from one source to another within a general area.





French physicist Nollet and his first RO unit.

Membrane Filtration Processes

In 1748, the French physicist Nollet first noted that water would diffuse through a pig bladder membrane into alcohol. This was the discovery of osmosis, a process in which water from a dilute solution will naturally pass through a porous membrane into a concentrate solution. Over the years, scientists have attempted to develop a membrane that would be useful in industrial processes, but it wasn't until the late 1950s that membranes were produced that could be used for what is known as reverse osmosis. In reverse osmosis, water is forced to move through a membrane from a concentrate solution to a dilute solution.

Since that time, continual improvements and new developments have been made in membrane technology, resulting in ever-increasing uses in many industries. In potable water treatment, membranes have been used for desalinization, removal of dissolved inorganic and organic chemicals, water softening, and removal of the fine solids.

In particular, membrane technology enables some water systems having contaminated water sources to meet new, more stringent regulations. In some cases, it can also allow secondary sources, such as brackish groundwater, to be used. There is great potential for the continuing wide use of membrane filtration processes in potable water treatment, especially as technology is improved and costs are reduced.

Description of Membrane Filtration Processes

In the simplest membrane processes, water is forced through a porous membrane under pressure, while suspended solids, large molecules, or ions are held back or rejected.

Types of Membrane Filtration Processes

The two general classes of membrane processes, based on the driving force used to make the process work, are:

- Pressure-driven processes
- Electric-driven processes



Pressure-Driven Processes

The four general membrane processes that operate by applying pressure to the raw water are:

- Microfiltration
- Ultrafiltration
- Nanofiltration
- Reverse Osmosis

Microfiltration
Microfiltration (**MF**) is a process in which water is forced under pressure through a porous membrane. Membranes with a pore size of 0.45 □m are normally used; this size is relatively large compared with the other membrane filtration processes. This process has not been generally applicable to drinking water treatment because it either does not remove substances that require removal from potable water, or the problem substances can be removed more economically using other processes.

The current primary use of MF is by industries to remove very fine particles from process water, such as in electronic manufacturing. In addition, the process has also been used as a pretreatment for other membrane processes. In particular, Reverse Osmosis (**RO**) membranes are susceptible to clogging or binding unless the water being processed is already quite clean.

However, in recent years, microfiltration has been proposed as a filtering method for particles resulting from the direct filtration process. Traditionally, this direct filtration process has used the injection of coagulants such as alum or polymers into the raw water stream to remove turbidity such as clay or silts. The formed particles were then removed by rapid sand filters. Their suggested use is to improve filtering efficiency, especially for small particles that could contain bacterial and protozoan life.

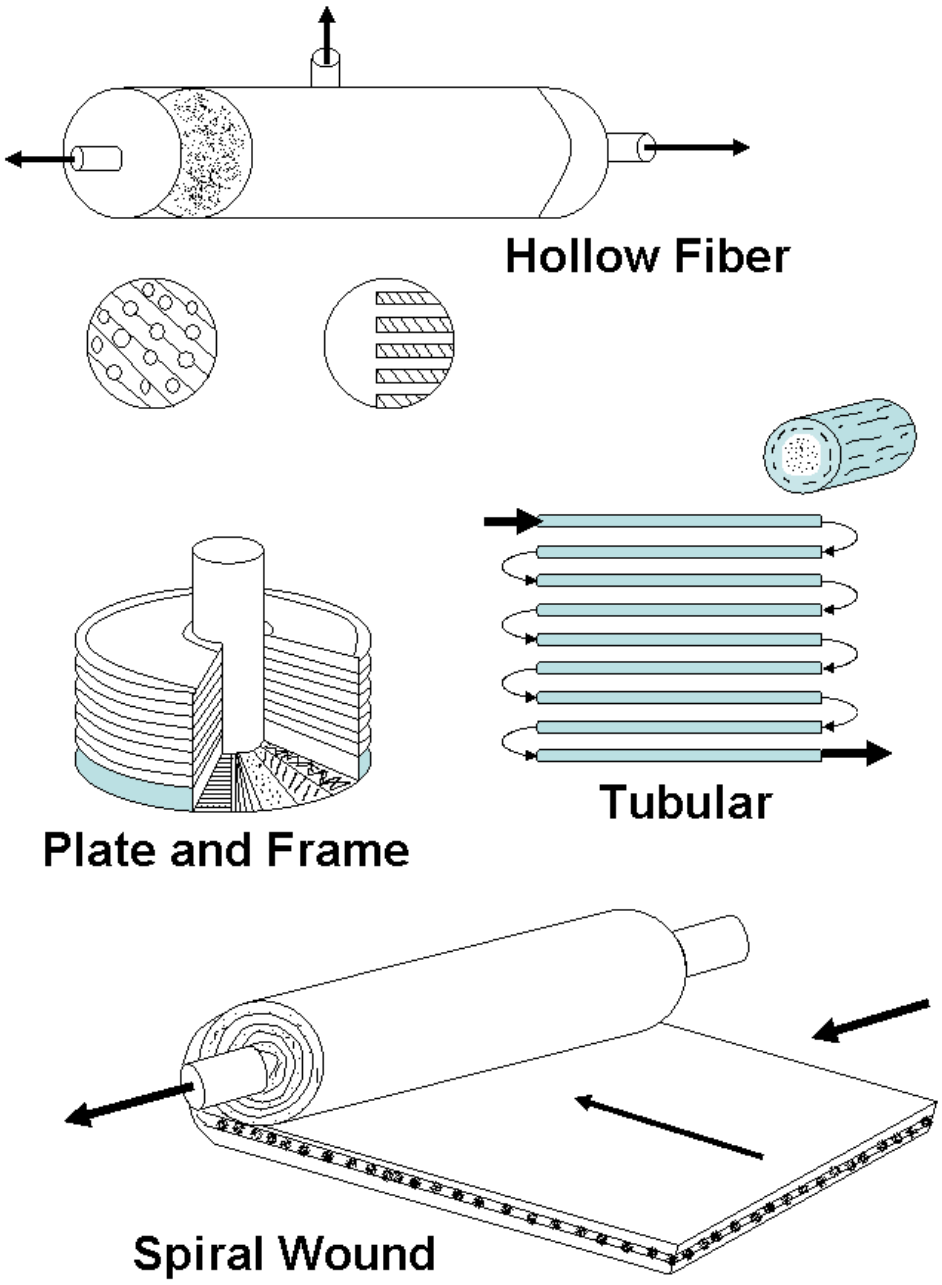
Ultrafiltration
Ultrafiltration (**UF**) is a process that uses a membrane with a pore size generally below 0.1 □m. The smaller pore size is designed to remove colloids and substances that have larger molecules, which are called high-molecular-weight materials. UF membranes can be designed to pass material that weigh less than or equal to a certain molecular weight. This weight is called the molecular weight cutoff (**MWC**) of the membrane. Although UF does not generally work well for removal of salt or dissolved solids, it can be used effectively for removal or most organic chemicals.

Nanofiltration
Nanofiltration (**NF**) is a process using membrane that will reject even smaller molecules than UF. The process has been used primarily for water softening and reduction of total dissolved solids (**TDS**). NF operates with less pressure than reverse osmosis and is still able to remove a significant proportion of inorganic and organic molecules. This capability will undoubtedly increase the use of NF for potable water treatment.

Reverse Osmosis
Reverse Osmosis (**RO**) is a membrane process that has the highest rejection capability of all the membrane processes. These RO membranes have very low pore size that can reject ions at very high rates, including chloride and sodium. Water from this process is very pure due to the high reject rates. The process has been used primarily in the water industry for desalinization of seawater because the capital and operating costs are competitive with other processes for this service.

The RO also works for most organic chemicals, radionuclides and microorganisms. For industrial water uses such as semiconductor manufacturing, is also an important RO process. RO is discussed in more detail later.

Membrane Configurations



Electric-Driven Processes

There are two membrane processes that purify a water stream by using an electric current to move ions across a membrane.

These processes are

- **Electrodialysis**
- **Electrodialysis Reversal**

Electrodialysis

Electrodialysis (**ED**) is a process in which ions are transferred through a membrane as a result of direct electric current applied to the solution. The current carries the ions through a membrane from the less concentrated solution to the more concentrated one.

Electrodialysis Reversal
Electrodialysis Reversal (**EDR**) is a process similar to ED, except that the polarity of the direct current is periodically reversed. The reversal in polarity reverses the flow of ions between demineralizing compartments, which provides automatic flushing of scale-forming materials from the membrane surface.

As a result, EDR can often be used with little or no pretreatment of feedwater to prevent fouling. So far, ED and EDR have been used at only a few locations for drinking water treatment.



GAC inside Carbon vessels like these are often used for taste and odor control.

Reverse Osmosis

Osmosis is a natural phenomenon in which a liquid - water in this case - passes through a semi-permeable membrane from a relatively dilute solution toward a more concentrated solution. This flow produces a measurable pressure, called osmotic pressure.

If pressure is applied to the more concentrated solution, and if that pressure exceeds the osmotic pressure, water flows through the membrane from the more concentrated solution toward the dilute solution. This process, called reverse osmosis, or RO, removes up to 98% of dissolved minerals, and virtually 100% of colloidal and suspended matter. RO produces high quality water at low cost compared to other purification processes.

The membrane must be physically strong to stand up to high osmotic pressure - in the case of sea water, 2500 kg/m. Most membranes are made of cellulose acetate or polyamide composites cast into a thin film, either as a sheet or fine hollow fibers.

The membrane is constructed into a cartridge called a reverse osmosis module.

RO Skid



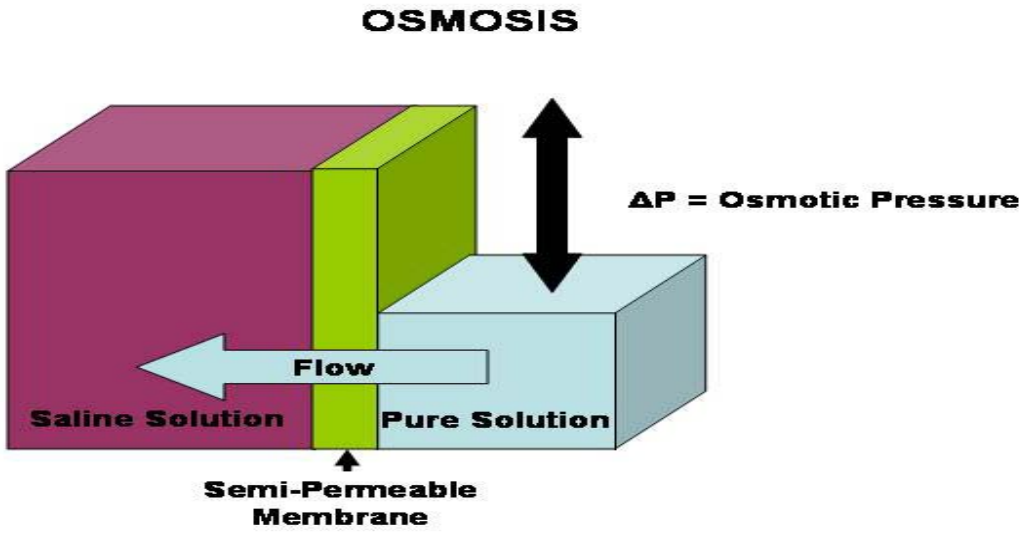
After filtration to remove suspended particles, incoming water is pressurized with a pump to 200 - 400 psi (1380 - 2760 kPa) depending on the RO system model.

This exceeds the water's osmotic pressure. A portion of the water (**permeate**) diffuses through the membrane, leaving dissolved salts and other contaminants behind with the remaining water where they are sent to drain as waste (**concentrate**).

RO

Pretreatment is important because it influences permeate quality and quantity. It also affects the module's life because many water-borne contaminants can deposit on the membrane and foul it. Generally, the need for pretreatment increases as systems become larger and operate at higher pressures, and as permeate quality requirements become more demanding. Because reverse osmosis is the principal membrane filtration process used in water treatment, it is described here in greater detail.

To understand Reverse Osmosis, one must begin by understanding the process of osmosis, which occurs in nature. In living things, osmosis is frequently seen. The component parts include a pure or relatively pure water solution and a saline or contaminated water solution, separated by a semi-permeable membrane, and a container or transport mechanism of some type.



The semi-permeable membrane is so designated because it permits certain elements to pass through, while blocking others. The elements that pass through include water, usually smaller molecules of dissolved solids, and most gases. The dissolved solids are usually further restricted based on their respective electrical charge. In osmosis, naturally occurring in living things, the pure solution passes through the membrane until the osmotic pressure becomes equalized, at which point osmosis ceases. The osmotic pressure is defined as the pressure differential required to stop osmosis from occurring. This pressure differential is determined by the total dissolved solids content of the saline solution, or contaminated solution on one side of the membrane. The higher the content of dissolved solids, the higher the osmotic pressure. Each element that may be dissolved in the solution contributes to the osmotic pressure, in that the molecular weight of the element affects the osmotic pressure.

Generally, higher molecular weights result in higher osmotic pressures. Hence, the formula for calculating osmotic pressure is very complex. However, approximate osmotic pressures are usually sufficient to design a system. Common tap water, as found in most areas, may have an osmotic pressure of about 10 PSI (Pounds per Square Inch), or about 1.68 Bar. Seawater at 36,000 PPM typically has an osmotic pressure of about 376 PSI (26.75 Bar). Thus, to reach the point at which osmosis stops for tap water, a pressure of 10 PSI would have to be applied to the saline solution. To stop osmosis in seawater, a pressure of 376 PSI would have to be applied to the seawater side of the membrane. Several decades ago, U.S. Government scientists had the idea that the principles of osmosis could be harnessed to purify water from various sources, including brackish water and seawater. In order to transform this process into one that purifies water, osmosis would have to be reversed, and suitable synthetic membrane materials would have to be developed. Additionally, ways of configuring the membranes would have to be engineered to handle a continuous flow of raw and processed water without clogging or scaling the membrane material.

These ideas were crystallized and, fueled by U.S. Government funding, usable membrane materials and designs resulted. One of the membrane designs was the spiral wound membrane element. This design enabled the engineers to construct a membrane element that could contain a generous amount of membrane area in a small package, and to permit the flow of raw water to pass along the length of the membrane.

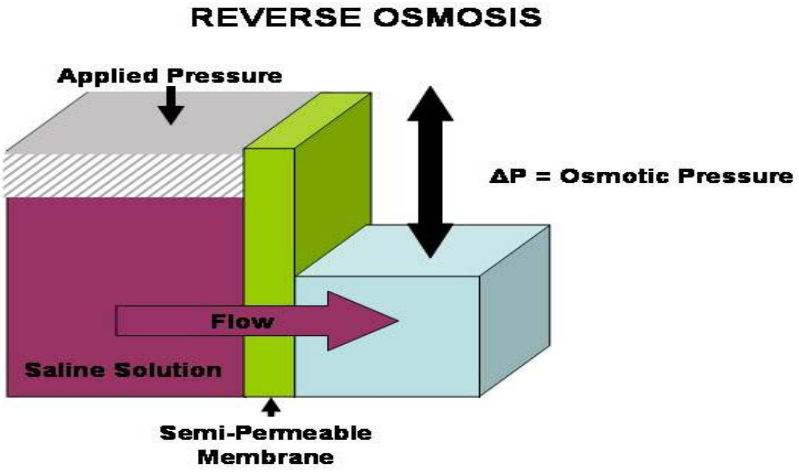
This permits flows and pressures to be developed to the point that ample processed or purified water is produced, while keeping the membrane surface relatively free from particulate, colloidal, bacteriological or mineralogical fouling.

The design features a perforated tube in the center of the element, called the product or permeate tube. Wound around this tube are one or more "***envelopes***" of membrane material, opening at the permeate tube. Each envelope is sealed at the incoming and exiting edge. Thus, when water penetrates or permeates though the membrane, it travels, aided by a fine mesh called the permeate channel, around the spiral and collects in the permeate tube. The permeate or product water is collected from the end of each membrane element, and becomes the product or result of the purification process.

Meanwhile, as the raw water flows along the "***brine channel***" or coarse medium provided to facilitate good flow characteristics, it gets more and more concentrated. This concentrated raw water is called the reject stream or concentrate stream. It may also be called brine if it is coming from a salt water source. The concentrate, when sufficient flows are maintained, serves to carry away the impurities removed by the membrane, thus keeping the membrane surface clean and functional. This is important, as buildup on the membrane surface, called fouling, impedes or even prevents the purification process.

The membrane material itself is a special thin film composite (**TFC**) polyamide material, cast in a microscopically thin layer on another, thicker cast layer of Polysulfone, called the microporous support layer. The microporous support layer is cast on sheets of paper-like material that are made from synthetic fibers such as polyester, and manufactured to the required tolerances.

Each sheet of membrane material is inspected at special light tables to ensure the quality of the membrane coating, before being assembled into the spiral wound element design. To achieve Reverse Osmosis, the osmotic pressure must be exceeded, and to produce a reasonable amount of purified water, the osmotic pressure is generally doubled. Thus with seawater osmotic pressure of 376 PSI, a typical system operating pressure is about 800 PSI.



Factors that affect the pressure required include raw water temperature, raw water TDS (**Total Dissolved Solids**), membrane age, and membrane fouling.

The effect of temperature is that with higher temperatures, the salt passage increases, flux (permeate flow) increases, and operating pressure required is lower. With lower temperatures, the inverse occurs, in that salt passage decreases (reducing the TDS in the permeate or product water), while operating pressures increase. Or, if operating pressures do not increase, then the amount of permeate or product water is reduced. In general, Reverse Osmosis (**R/O**) systems are designed for raw water temperatures of 25° C (77° F). Higher temperatures or lower temperatures can be accommodated with appropriate adjustments in the system design.

Membranes are available in "**standard rejection**" or "**high rejection**" models for seawater and brackish water. The rejection rate is the percentage of dissolved solids rejected, or prevented from passing through the membrane. For example, a membrane with a rejection rate of 99% (usually based on Na (**Sodium**)) will allow only 1% of the concentration of dissolved solids to pass through into the permeate. Hence, product water from a source containing 10,000 PPM would have 100 PPM remaining. Of course, as the raw water is processed, the concentrations of TDS increase as it passes along the membrane's length, and usually multiple membranes are employed, with each membrane in the series seeing progressively higher dissolved solids levels.

Typically, starting with seawater of 36,000 PPM, standard rejection membranes produce permeate below 500 PPM, while high rejection membranes under the same conditions produce drinking water TDS of below 300 PPM. There are many considerations when designing R/O systems that competent engineers are aware of. These include optimum flows and pressures, optimum recovery rates (the percentage of permeate from a given stream of raw water), prefiltration and other pretreatment considerations, and so forth. Membrane systems in general cannot handle the typical load of particulate contaminants without prefiltration. Often, well designed systems employ multiple stages of prefiltration, tailored to the application, including multi-media filtration and one or more stages of cartridge filtration. Usually the last stage would be 5m or smaller, to provide sufficient protection for the membranes.

R/O systems typically have the following components:
A supply pump or pressurized raw water supply; prefiltration in one or more stages; chemical injection of one or more pretreatment agents may be added; a pressure pump suited to the application, sized and driven appropriately for the flow and pressure required; a membrane array including one or more membranes installed in one or more pressure tubes (also called pressure vessels, R/O pressure vessels, or similar); various gauges and flow meters; a pressure regulating valve, relief valve(s) and/or safety pressure switches; and possibly some form of post treatment. Post treatment should usually include a form of sterilization such as Chlorine, Bromine, Ultra-Violet (**U-V**), or Ozone. Other types of post treatment may include carbon filters, pH adjustment, or mineral injection for some applications.



Right side-Packaged treatment skid instrumentation, UV, and softening.

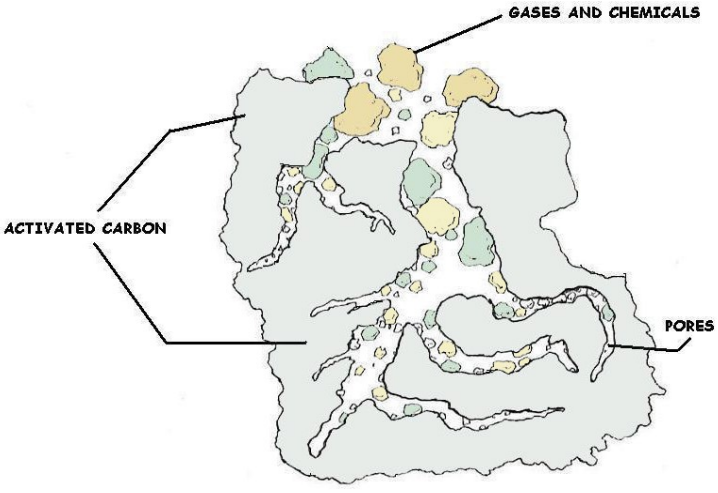
Granular Activated Carbon / Powdered Activated Carbon

Along with aeration, granular activated carbon (**GAC**) and powdered activated carbon (**PAC**) are suitable treatments for removal of organic contaminants such as VOCs, solvents, PCBs, herbicides and pesticides. Activated carbon is carbon that has been exposed to a very high temperature, creating a vast network of pores with a very large internal surface area; one gram of activated carbon has a surface area equivalent to that of a football field. It removes contaminants through adsorption, a process in which dissolved contaminants adhere to the surface of the carbon particles.

GAC can be used as a replacement for existing media (such as sand) in a conventional filter or it can be used in a separate contactor such as a vertical steel pressure vessel used to hold the activated carbon bed. After a period of a few months or years, depending on the concentration of the contaminants, the surface of the pores in the GAC can no longer adsorb contaminants and the carbon must be replaced. Several operational and maintenance factors affect the performance of granular activated carbon. Contaminants in the water can occupy adsorption sites, whether or not they are targeted for removal. Also, adsorbed contaminants can be replaced by other contaminants with which GAC has a greater affinity, so their presence might interfere with removal of contaminants of concern.

A significant drop in the contaminant level in influent water can cause a GAC filter to desorb, or slough off adsorbed contaminants, because GAC is essentially an equilibrium process. As a result, raw water with frequently changing contaminant levels can result in treated water of unpredictable quality. Bacterial growth on the carbon is another potential problem. Excessive bacterial growth may cause clogging and higher bacterial counts in the treated water. The disinfection process must be carefully monitored in order to avoid this problem.

Powdered activated carbon consists of finely ground particles and exhibits the same adsorptive properties as the granular form. PAC is normally applied to the water in a slurry and then filtered out. The addition of PAC can improve the organic removal effectiveness of conventional treatment processes and also remove tastes and odors. The advantages of PAC are that it can be used on a short-term or emergency basis with conventional treatment, it creates no headloss, it does not encourage microbial growth, and it has relatively small capital costs. The main disadvantage is that some contaminants require large doses of PAC for removal. It is also somewhat ineffective in removing natural organic matter due to the competition from other contaminants for surface adsorption and the limited contact time between the water and the carbon.



ACTIVATED CARBON ABSORBS GASES AND CHEMICALS

Clean-In-Place

Some very low cost R/O systems may dispense with most of the controls and instruments. However, systems installed in critical applications should be equipped with a permeate or product flow meter, a reject, concentrate or brine flow meter; multiple pressure gauges to indicate the pressure before and after each filtration device, and the system operation pressure in the membrane loop; preferably both before and after the membrane array. Another feature found in better systems is a provision to clean the membranes in place, commonly known as a "**Clean In Place**" (**CIP**) system. Such a system may be built right into the R/O system or may be provided as an attachment for use as required.

Reverse Osmosis has proven to be the most reliable and cost effective method of desalinating water, and hence its use has become more and more widespread. Energy consumption is usually some 70% less than for comparable evaporation technologies. Advancements have been made in membrane technology, resulting in stable, long-lived membrane elements. Component parts have been improved as well, reducing maintenance and down time. Additional advancements in pretreatment have been made in recent years, further extending membrane life and improving performance.

Reverse Osmosis delivers product water or permeate having essentially the same temperature as the raw water source (an increase of 1° C or 1.8° F may occur due to pumping and friction in the piping). This is more desirable than the hot water produced by evaporation technologies. R/O Systems can be designed to deliver virtually any required product water quality. For these and other reasons, R/O is usually the preferred method of desalination today.

Reverse osmosis, also known as hyperfiltration, is the finest filtration known. This process will allow the removal of particles as small as ions from a solution. Reverse osmosis is used to purify water and remove salts and other impurities in order to improve the color, taste, or properties of the fluid. It can be used to purify fluids such as ethanol and glycol, which will pass through the reverse osmosis membrane, while rejecting other ions and contaminants from passing. The most common use for reverse osmosis is in purifying water. It is used to produce water that meets the most demanding specifications that are currently in place.

Reverse osmosis uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. Most reverse osmosis technology uses a process known as cross-flow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane. The process of reverse osmosis requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases.

Reverse osmosis is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 Daltons. The separation of ions with reverse osmosis is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

Reverse Osmosis, when properly configured with sediment, carbon and/or carbon block technology, produces pure water that is clearly the body's choice for optimal health. It is the best tasting because it is oxygen-rich.

A Reverse Osmosis System removes virtually all of the following: bad taste, odor, turbidity, organic compounds, herbicides, insecticides, pesticides, chlorine and THM's, bacteria, virus, cysts, parasites, arsenic, heavy metals, lead, cadmium, aluminum, dissolved solids, sodium, calcium, magnesium, inorganic dead dirt minerals, fluoride, sulfates, nitrates, phosphates, detergents, radioactivity and asbestos.

Ozone

Ozone ($\mathbf{O_3}$) is probably the strongest oxidizing agent available for water treatment. Although it is widely used throughout the world, is has not found much application in the United States. Ozone is obtained by passing a flow of air or oxygen between two electrodes that are subjected to an alternating current in the order of 10,000 to 20,000 volts.

$$\mathbf{3O_2 + electrical\ discharge \rightarrow 2O_3}$$

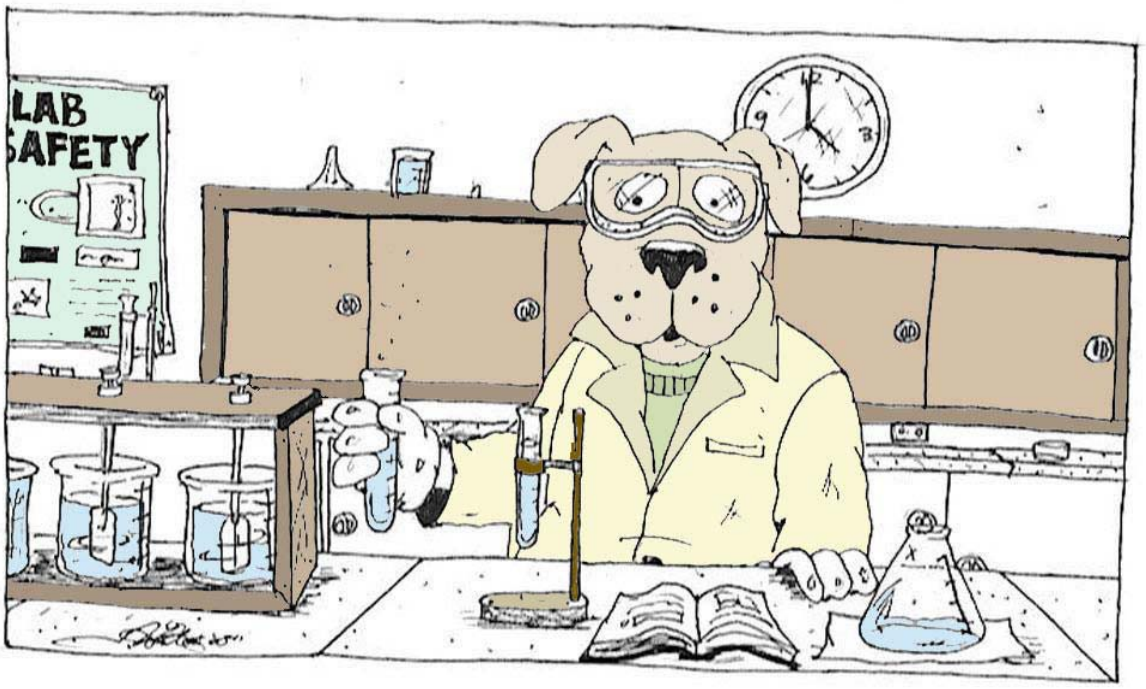
Liquid ozone is very unstable and can readily explode. As a result, it is not shipped and must be manufactured on-site. Ozone is a light blue gas at room temperature. It has a self-policing pungent odor similar to that sometimes noticed during and after heavy electrical storms. In use, ozone breaks down into oxygen and nascent oxygen.

$$\mathbf{O_3 = O_2 + O}$$

It is the nascent oxygen that produces the high oxidation, disinfections, and even sterilization. Each water has its own ozone demand, in the order of 0.5 ppm to 5.0 ppm. Contact time, temperature, and pH of the water are factors in determining Ozone demand. Ozone acts as a complete disinfectant. It is an excellent aid to the flocculation and coagulation process, and will remove practically all color, taste, odor, iron, and manganese. It does not form chloramines or THMs, and while it may destroy some THMs, it may produce other byproducts when followed by chlorination. Ozone is not practical for complete removal of chlorine or chloramines, or of THM and other inorganics. Further, because of the possibility of formation of other carcinogens (such as aldehydes or phthalates) it falls into the same category as other disinfectants, because it can produce DBPs.



Ozone Generator.



Turbidity

One physical characteristic of water. A measure of the cloudiness of water caused by suspended particles. The cloudy appearance of water caused by the presence of tiny particles. High levels of turbidity may interfere with proper water treatment and monitoring. If high quality raw water is low in turbidity, there will be a reduction in water treatment costs. Turbidity is undesirable because it causes health hazards. An MCL for turbidity established by the EPA because turbidity interferes with disinfection. This characteristic of water changes the most rapidly after a heavy rainfall. The following conditions may cause an inaccurate measure of turbidity; the temperature variation of a sample, a scratched or unclean sample tube in the nephelometer and selecting an incorrect wavelength of a light path.

Ultraviolet Radiation

The enormous temperatures on the sun create ultraviolet (**UV**) rays in great amounts, and this radiation is so powerful that all life on earth would be destroyed if these rays were not scattered by the atmosphere and filtered out by the layers of ozone gas that float some 20 miles above the earth.



This radiation can be artificially produced by sending strong electric currents thorough various substances. A sun lamp, for example, sends out UV rays that, when properly controlled, result in a suntan. Of course, too much will cause sunburn.

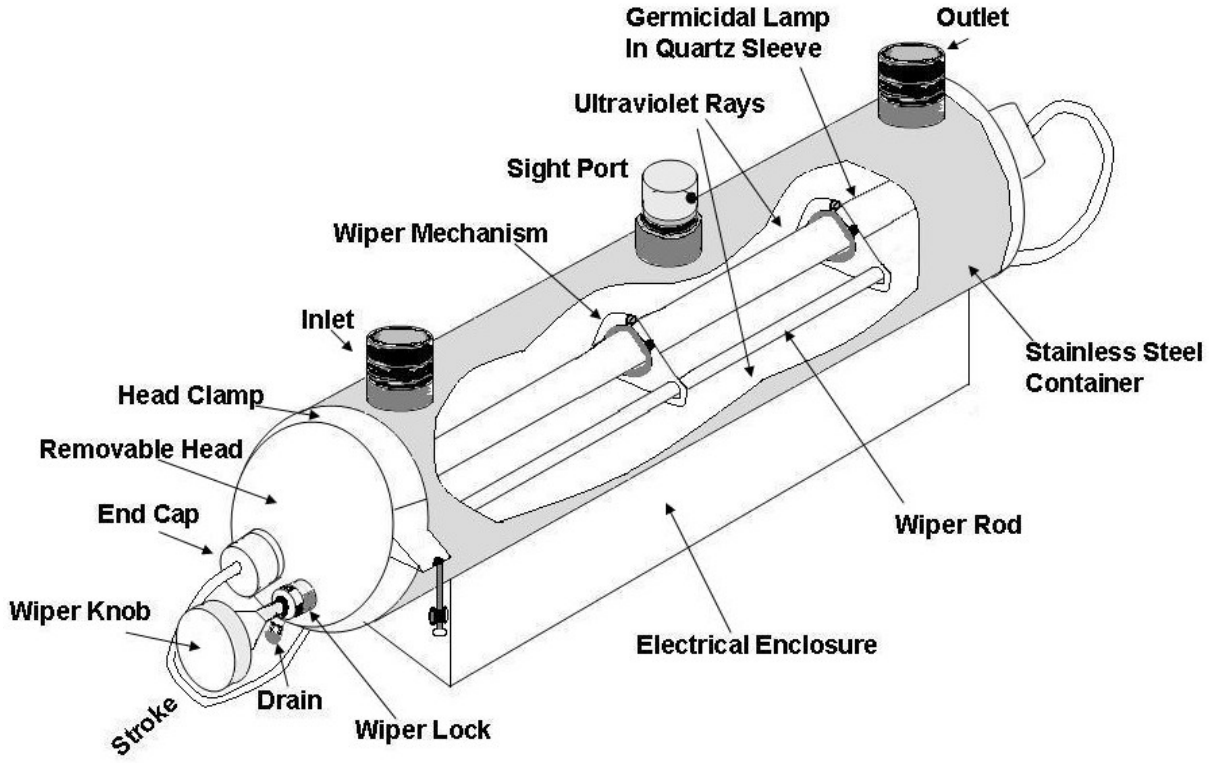
The UV lamp that can be used for the disinfection of water depends upon the low-pressure mercury vapor lamp to produce the ultraviolet energy. A mercury vapor lamp is one in which an electric arc is passed through an inert gas. This, in turn, will vaporize the mercury contained in the lamp resulting in the production of UV rays.



The lamp itself does not come into direct contact with the water, The lamp is placed inside a quartz tube, and the water is in contact with the outside of the quartz tube. Quartz is used in this case since practically none of the UV rays are absorbed by the quartz, allowing all of the rays to reach the water. Ordinary glass cannot be used since it will absorb the UV rays, leaving little for disinfection. The water flows around the quartz tube. The UV sterilizer will consist of a various number of lamps and tubes, depending upon the amount of water to be treated. As water enters the sterilizer, it is given a tangential flow pattern so that the water spins over and around the quartz sleeves. In this way, the microorganisms spend maximum time in contact with the outside of the quartz tube and the source of the UV rays. The basic design flow of water of certain UV units is in the order of 2.0 gpm for each inch of the lamp. Further, the units are designed, so the contact or retention time of the water in the unit is not less than 15 seconds.

Most manufacturers claim UV lamps have a life of about 7,500 hours, which is about 1 year's time. The lamp must be replaced when it loses about 40% to 50% of its UV output; in any installation this is determined by means of a photoelectric cell and a meter that shows the output of the lamp. Each lamp is outfitted with its own photoelectric cell, and an alarm that will be activated when the penetration drops to a preset level.

Ultraviolet radiation is an excellent disinfectant that is highly effective against viruses, molds, and yeasts; and it is safe to use. It adds no chemicals to the water, it leaves no residual, and it does not form THMs. It is used to remove traces of ozone and chloramines from the finished water. Alone, UV radiation will not remove precursors, but in combination with ozone, it is said to be effective in the removal of THM precursors and THMs.



The germicidal effect of UV is thought to be associated with its absorption by various organic components essential to the cell's function. For effective use of ultraviolet, the water to be disinfected must be clean and free of any suspended solids. The water must also be colorless and free of any colloids, iron, manganese, taste, and odor. These are conditions that must be met. Also, although water may appear to be clear, such substances as excesses of chlorides, bicarbonates, and sulfates affect absorption of the ultraviolet rays. These parameters will probably require at least filtration of one type or another. The UV manufacturer will, of course, stipulate which pretreatment may be necessary.

Removal of Disinfection By-Products

Disinfectant	*Disinfectant By-product*	*Disinfectant By-product Removal*
Chlorine (HOCl)	Trialomethane (THM) Chloramine Chlorophenol	Granular Activated Carbon (**GAC**), resins, controlled coagulation, aeration. GAC-UV GAC
Chloramine (NH_xCl_y)	Probably no THM Others?	GAC UV?
Chlorine dioxide (ClO_2)	Chlorites Chlorates	Use of Fe2+ in coagulation, RO, ion-exchange
Permanganate ($KMnO_4$)	No THMs	
Ozone (O_3)	Aldehydes, Carboxylics, Phthalates	GAC
Ultraviolet (UV)	None known	GAC

The table indicates that most of the disinfectants will leave a by-product that is or would possibly be inimical to health. This may aid with a decision as to whether or not precursors should be removed before these disinfectants are added to water.

If it is decided that removal of precursors is needed, research to date indicates that this removal can be attained through the application of controlled chlorination plus coagulation and filtration, aeration, reverse osmosis, nanofiltration, GAC or combinations of other processes.



Modern Water Treatment Disinfectants

Many water suppliers add a disinfectant to drinking water to kill germs such as Giardia and e coli. Especially after heavy rainstorms, your water system may add more disinfectant to guarantee that these germs are killed.

Chlorine. Some people who use drinking water containing chlorine well in excess of EPA standards could experience irritating effects to their eyes and nose. Some people who drink water containing chlorine well in excess of EPA standards could experience stomach discomfort.

Chloramine. Some people who use drinking water containing chloramines well in excess of EPA standards could experience irritating effects to their eyes and nose. Some people who drink water containing chloramines well in excess of EPA standards could experience stomach discomfort or anemia.

Chlorine Dioxide. Some infants and young children who drink water containing chlorine dioxide in excess of EPA standards could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorine dioxide in excess of EPA standards. Some people may experience anemia.

Disinfectant alternatives will include Ozone and Ultraviolet light. You will see an increase of these technologies in the near future.

Disinfection Byproducts (DBPS)
Disinfection byproducts form when disinfectants added to drinking water to kill germs react with naturally-occurring organic matter in water.



Total Trihalomethanes. Some people who drink water containing trihalomethanes in excess of EPA standards over many years may experience problems with their liver, kidneys, or central nervous systems, and may have an increased risk of getting cancer.

Haloacetic Acids. Some people who drink water containing haloacetic acids in excess of EPA standards over many years may have an increased risk of getting cancer.

Bromate. Some people who drink water containing bromate in excess of EPA standards over many years may have an increased risk of getting cancer.

Chlorite. Some infants and young children who drink water containing chlorite in excess of EPA standards could experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of EPA standards. Some people may experience anemia.

Corrosion Control

Corrosion is the deterioration of a substance by chemical action. Lead, cadmium, zinc, copper and iron might be found in water when metals in water distribution systems corrode. Drinking water contaminated with certain metals (such as lead and cadmium) can harm human health.

Corrosion also reduces the useful life of water distribution systems and can promote the growth of microorganisms, resulting in disagreeable tastes, odors, slimes and further corrosion. Because it is widespread and highly toxic, lead is the corrosion product of greatest concern. The EPA has banned the use of lead solders, fluxes and pipes in the installation or repair of any public water system. In the past, solder used in plumbing has been 50% tin and 50% lead. Using lead-free solders, such as silver-tin and antimony-tin is a key factor in lead corrosion control.

The highest level of lead in consumers' tap water will be found in water that has been standing in the pipes after periods of nonuse (overnight or longer). This is because standing water tends to leach lead or copper out of the metals in the distribution system more readily than does moving water. Therefore, the simplest short-term or immediate measure that can be taken to reduce exposure to lead in drinking water is to let the water run for two to three minutes before each use. Also, drinking water should not be taken from the hot water tap, as hot water tends to leach lead more readily than cold.

Long-term measures for addressing lead and other corrosion by-products include pH and alkalinity adjustment; corrosion inhibitors; coatings and linings; and Cathodic protection, all discussed below.

Cathodic Protection
Cathodic protection protects steel from corrosion which is the natural electrochemical process that results in the deterioration of a material because of its reaction with its environment.

Metallic structures, components, and equipment exposed to aqueous environments, soil, or seawater can be subject to corrosive attack and accelerated deterioration. Therefore, it is often necessary to utilize either impressed current or sacrificial anode Cathodic protection (**CP**) in combination with coatings as a means of suppressing the natural degradation phenomenon to provide a long and useful service life. However, if proper considerations are not given, problems can arise which can produce unexpected, premature failure.

There are two types of Cathodic protection:
Ø Sacrificial Anodes (Galvanic Systems)
Ù Impressed (Induced) Current Systems

How Does Cathodic Protection Work?
Sacrificial anodes are pieces of metal more electrically active than the steel piping system.

Because these anodes are more active, the corrosive current will exit from them rather than the piping system. Thus, the system is protected while the attached anode is "***sacrificed***."

Sacrificial anodes can be attached to the existing piping system or coated steel for a pre-engineered cathodic protection system. An asphalt coating is not considered a suitable dielectric coating. Depleted anodes must be replaced for continued Cathodic protection of the system.

Impressed or Induced Current Systems
An impressed current cathodic protection system consists of anodes, cathodes, a rectifier and the soil. The rectifier converts the alternating current to direct current. The direct current is then sent through an insulated copper wire to anodes that are buried in the soil near the piping system. Typical anode materials are ceramic, high silicon cast iron, or graphite.

Ceramic anodes are not consumed, whereas high silicon cast iron and graphite anodes partially dissolve each year and must be replaced over time. The direct current then flows from the anode through the soil to the piping system, which acts as the cathode, and back to the rectifier through another insulated copper wire.

As a result of the electrochemical properties of the impressed current cathodic protection system, corrosion takes place only at the anodes and not at the piping system. Depleted anodes must be replaced for continued cathodic protection of the piping system.

Sacrificial Anode System
In this system, a metal or alloy reacting more vigorously than the corroding specimen acts as an anode and the corroding structure as a whole is rendered Cathodic. These anodes are made of materials such as magnesium, aluminum or zinc, which are anodic with respect to the protected structure. The sacrificial anodes are connected directly to the structure.

Advantages
1. Needs no external power source.
2. Does not involve maintenance work
3. If carefully designed, it can render protection for anticipated period.
4. Installation is simple.
5. Does not involve expensive accessories like rectifier unit, etc.,
6. Economical for small structures

Disadvantages
1. The driving voltage is small and therefore the anodes have to be fitted close to the structure or on the structure, thereby increasing the weight or load on the structure.
2. The anodes have to be distributed all over the structure (as throwing power is lower) and therefore have design limitations in certain applications.
3. Once designed and installed, protection current cannot be altered or increased as may be needed in case of cathode area extension (unprotected) or foreign structure interference (physical contact).

Impressed Current System
The impressed current anode system, on the other hand, has several advantages over the sacrificial anode systems. In this system the protection current is "***Forced***" through the environment to the structure (cathode) by means of an external D.C. source. Obviously we need some material to function as anodes. It can be high silicon chromium cast iron anodes, graphite anodes, or lead-silver alloy anodes.

Advantages
1. Since the driving voltage is large, this system offers freedom of installation design and location
2. Fewer anodes can protect a large structure
3. Variations in protection current requirements can be adjusted to some extent (to be incorporated at design stage)

Disadvantages
1. Shut down of D.C. supply for a long time allows structure to corrode again.
2. Reversal of anode cathode connection at D.C. source will be harmful as structure will dissolve anodic
3. Needs trained staff for maintenance of units and for monitoring
4. Initial investments are higher and can pay off only in long run and economic only for large structures
5. Power cost must be incorporated in all economic consideration.
6. Possibility of overprotection should be avoided as it will affect the life of the paint.
7. Any foreign structure coming within this field will cause an interference problem.



Raw Water Intake

Alkalinity and pH Adjustment

Adjusting pH and alkalinity is the most common corrosion control method because it is simple and inexpensive. pH is a measure of the concentration of hydrogen ions present in water; alkalinity is a measure of water's ability to neutralize acids.

Generally, water pH less than 6.5 is associated with uniform corrosion, while pH between 6.5 and 8.0 can be associated with pitting corrosion. Some studies have suggested that systems using only pH to control corrosion should maintain a pH of at least 9.0 to reduce the availability of hydrogen ions as electron receptors. However, pH is not the only factor in the corrosion equation; carbonate and alkalinity levels affect corrosion as well.

Generally, an increase in pH and alkalinity can decrease corrosion rates and help form a protective layer of scale on corrodible pipe material. Chemicals commonly used for pH and alkalinity adjustment are hydrated lime ($CaOH_2$ or calcium hydroxide), caustic soda (NaOH or sodium hydroxide), soda ash (Na_2CO_3 or sodium carbonate), and sodium bicarbonate ($NaHCO_3$, essentially baking soda).



Care must be taken, however, to maintain pH at a level that will control corrosion but not conflict with optimum pH levels for disinfection and control of disinfection by-products.

Corrosion Inhibitors

Inhibitors reduce corrosion by forming protective coatings on pipes. The most common corrosion inhibitors are inorganic phosphates, sodium silicates and mixtures of phosphates and silicates. These chemicals have proven successful in reducing corrosion in many water systems.

The phosphates used as corrosion inhibitors include polyphosphates, orthophosphates, glassy phosphates and bimetallic phosphates. In some cases, zinc is added in conjunction with orthophosphates or polyphosphates.

Glassy phosphates, such as sodium hexametaphosphate, effectively reduce iron corrosion at dosages of 20 to 40 mg/l. Glassy phosphate has an appearance of broken glass and can cut the operator. Sodium silicates have been used for over 50 years to inhibit corrosion. The effectiveness depends on the water pH and carbonate concentration.

Sodium silicates are particularly effective for systems with high water velocities, low hardness, low alkalinity and a pH of less than 8.4. Typical coating maintenance doses range from 2 to 12 mg/1. They offer advantages in hot water systems because of their chemical stability. For this reason, they are often used in the boilers of steam heating systems.



Common water sample bottles for distribution systems.

Radiochems, VOCs, (Volatile Organic Compounds), TTHMs, Total Trihalomethanes), Nitrate, Nitrite.

Most of these sample bottles will come with the preservative already inside the bottle.

Some bottles will come with a separate preservative (acid) for the field preservation.

Slowly add the acid or other preservative to the water sample; not water to the acid or preservative.

Surface Water

Some of the water will be immediately impounded in lakes and reservoirs, and some will collect as runoff to form streams and rivers that will then flow into the ocean. Water is known as the universal solvent because most substances that come in contact with it will dissolve. What's the difference between lakes and reservoirs? Reservoirs are lakes with man-made dams. Surface water is usually contaminated and unsafe to drink. Depending on the region, some lakes and rivers receive discharge from sewer facilities or defective septic tanks. Runoff could produce mud, leaves, decayed vegetation, and human and animal refuse. The discharge from industry could increase volatile organic compounds. Some lakes and reservoirs may experience seasonal turnover. Changes in the dissolved oxygen, algae, temperature, suspended solids, turbidity, and carbon dioxide will change because of biological activities.

Quality of Water

If you classified water by its characteristics and could see how water changes as it passes on the surface and below the ground it would be in these four categories:



Physical characteristics such as taste, odor, temperature, and turbidity; this is how the consumer judges how well the provider is treating the water.

Chemical characteristics are the elements found that are considered alkali, metals, and non-metals such as fluoride, sulfides or acids. The consumer relates it to scaling of faucets or staining.

Biological characteristics are the presence of living or dead organisms. This will also interact with the chemical composition of the water. The consumer will become sick or complain about hydrogen sulfide odors--the rotten egg smell.

Radiological characteristics are the result of water coming in contact with radioactive materials. This could be associated with atomic energy.

Managing Water Quality at the Source

Depending on the region, source water may have several restrictions of use as part of a Water Shed Management Plan. In some areas, it may be restricted from recreational use, discharge or runoff from agriculture, or industrial and wastewater discharge. Another aspect of quality control is aquatic plants. The ecological balance in lakes and reservoirs plays a natural part in purifying and sustaining the life of the lake. For example, algae and rooted aquatic plants are essential in the food chain of fish and birds. Algae growth is the result of photosynthesis. Algae growth is supplied by the energy of the sun. As algae absorbs this energy, it converts carbon dioxide to oxygen.

This creates **aerobic** conditions that supply fish with oxygen. Without sun light, the algae would consume oxygen and release carbon dioxide. The lack of dissolved oxygen in water is known as **anaerobic** conditions. Certain vegetation removes the excess nutrients that would promote the growth of algae. Too much algae will imbalance the lake and kill fish.

Most treatment plant upsets such as taste and odor, color, and filter clogging is due to algae. The type of algae determines the problem it will cause, for instance slime, corrosion, color, and toxicity. Algae have been controlled by using chemicals such as copper sulfate. Depending on federal regulations and the amount of copper found natural in water, operators have used potassium permanganate, powdered activated carbon and chlorine. The pH and alkalinity of the water will determine how these chemicals will react. Most systems no longer use Chlorine because it reacts with the organics in the water to form Trihalomethanes.



Examples of different types of chemical storage tanks found in water treatment facilities.



Review Statements

Surface Water
As with Surface water, it is important to remember that activities many miles away from you may affect the quality of ground water. Your annual drinking report or CCR will tell you where your water supplier gets your water. Your water will normally contain chlorine and varying amounts of dissolved minerals including calcium, magnesium, sodium, chlorides, sulfates and bicarbonates, depending on its source. It is also not uncommon to find traces of iron, manganese, copper, aluminum, nitrates, insecticides and herbicides. Although the maximum amounts of all these substances as mentioned above, are strictly limited by the regulations. These are usually referred to as contaminants

Surface water is usually contaminated and unsafe to drink. Depending on the region, some lakes and rivers receive discharge from sewer facilities or defective septic tanks.

Runoff could produce mud, leaves, decayed vegetation, and human and animal refuse. The discharge from industry could increase volatile organic compounds.

Some lakes and reservoirs may experience seasonal turnover.

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Most of these substances are of natural origin and are picked up as water passes around the water cycle. Some are present due to the treatment processes which are used make the water suitable for drinking and cooking. The water will also contain a relatively low level of bacteria, which are not generally a risk to health.

Insecticides and herbicides (sometimes referred to as pesticides) are widely used in agriculture, industry, leisure facilities and gardens to control weeds and insect pests and may enter the water cycle in many ways.

Aluminum salts are added during water treatment to remove color and suspended solids.

Lead does not usually occur naturally in water supplies but is derived from lead distribution and domestic pipework and fittings.

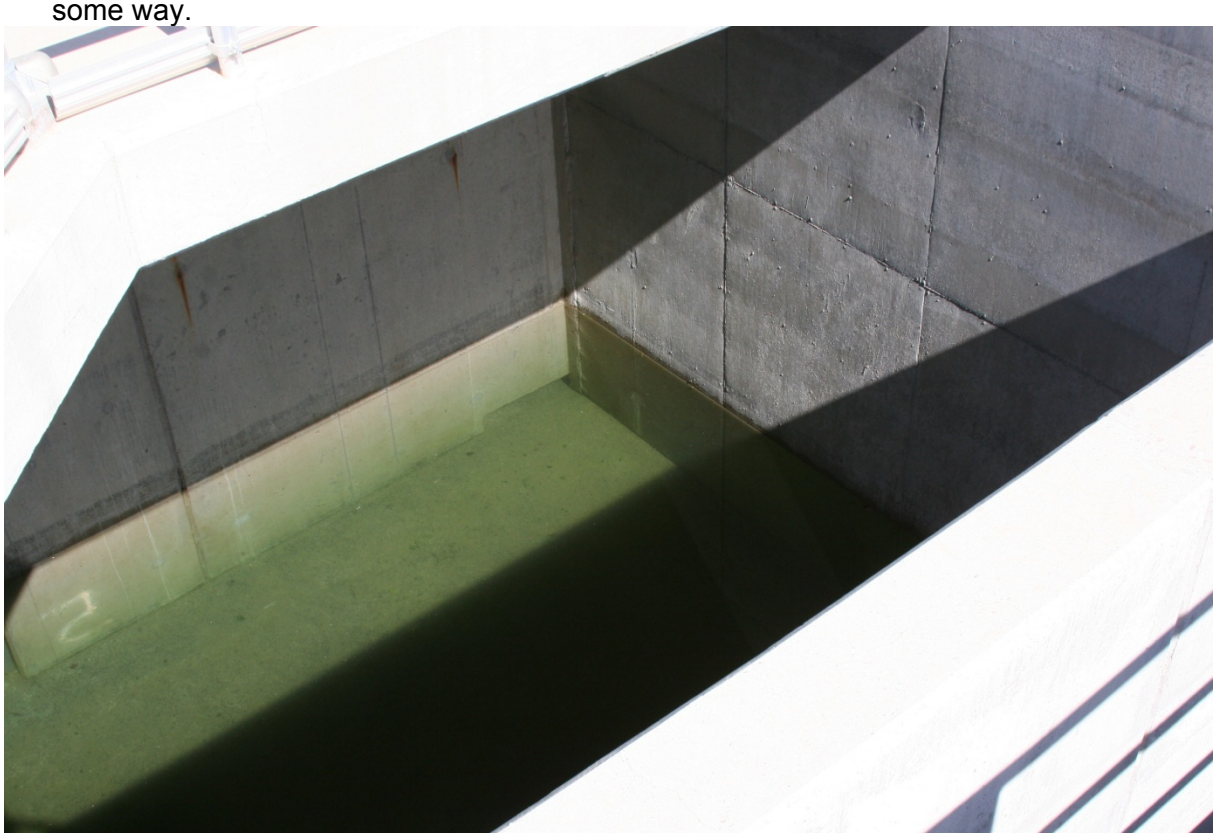
Water suppliers have removed most of the original lead piping from the mains distribution system, many older properties still have lead service pipes and internal lead pipework.

The pipework (including the service pipe) within the boundary of the property is the responsibility of the owner of the property, not the water supplier.

Hardness
There are two types of hardness: temporary and permanent. Temporary hardness comes out of the water when it's heated and is deposited as scale and fur on kettles, coffee makers and taps and appears as a scum or film on tea and coffee. Permanent hardness is unaffected by heating.

Cysts
Cysts are associated with the reproductive stages of parasitic micro-organisms (protozoans) which can cause acute diarrhea type illnesses; they come from farm animals, wild animals and people. Cysts are very resistant to normal disinfection processes but can be removed by advanced filtration processes installed in water treatment works. Cysts are rarely present in the public water supply.

Particles and rust come from the gradual breakdown of the lining of concrete or iron mains water pipes or from sediment which has accumulated over the years and is disturbed in some way.



Water Production Section

Groundwater and Wells

A well can be easily contaminated if it is not properly constructed or if toxic materials are released into the well. Toxic material spilled or dumped near a well can leach into the aquifer and contaminate the groundwater drawn from that well. Contaminated wells used for drinking water are especially dangerous. Wells can be tested to see what chemicals may be in the well and if they are present in dangerous quantities.

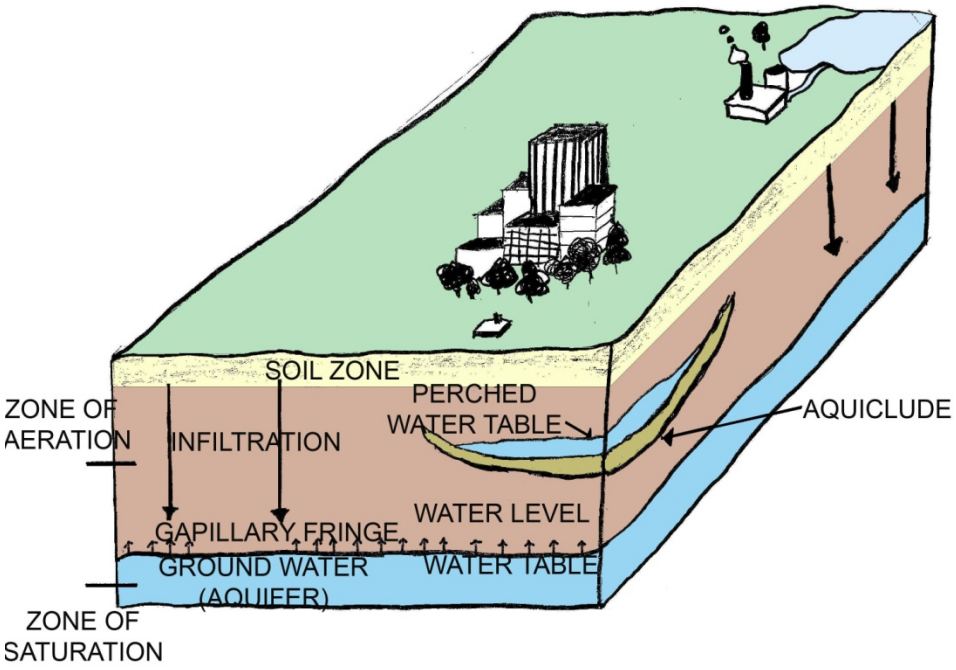
Groundwater is withdrawn from wells to provide water for everything from drinking water for the home and business to water for irrigating crops. When water is pumped from the ground, the dynamics of groundwater flow change in response to this withdrawal. Groundwater flows slowly through water-bearing formations (aquifers) at different rates. In some places, where groundwater has dissolved limestone to form caverns and large openings, its rate of flow can be relatively fast, but this is exceptional.



Groundwater production well with a mineral oil sealed vertical turbine pump. Sometimes, this mineral oil will get into the distribution system.

Groundwater Resource
Many terms are used to describe the nature and extent of the groundwater resource. The level below which all the spaces are filled with water is called the ***water table***. Above the water table lies the ***unsaturated zone.*** Here the spaces in the rock and soil contain both air and water. Water in this zone is called ***soil moisture.*** The entire region below the water table is called the ***saturated zone*** and water in this saturated zone is called ***groundwater.***

Fractured aquifers are rocks in which the groundwater moves through cracks, joints or fractures in otherwise solid rock. Examples of fractured aquifers include granite and basalt. Limestones are often fractured aquifers, but here the cracks and fractures may be enlarged by solution, forming large channels or even caverns. Limestone terrain where solution has been very active is termed ***karst***. Porous media such as sandstone may become so highly cemented or recrystalized that all of the original space is filled. In this case, the rock is no longer a porous medium. However, if it contains cracks it can still act as a fractured aquifer. Most of the aquifers of importance to us are unconsolidated porous media such as sand and gravel. Some very porous materials are not permeable. Clay, for instance, has many spaces between its grains, but the spaces are not large enough to permit free movement of water.

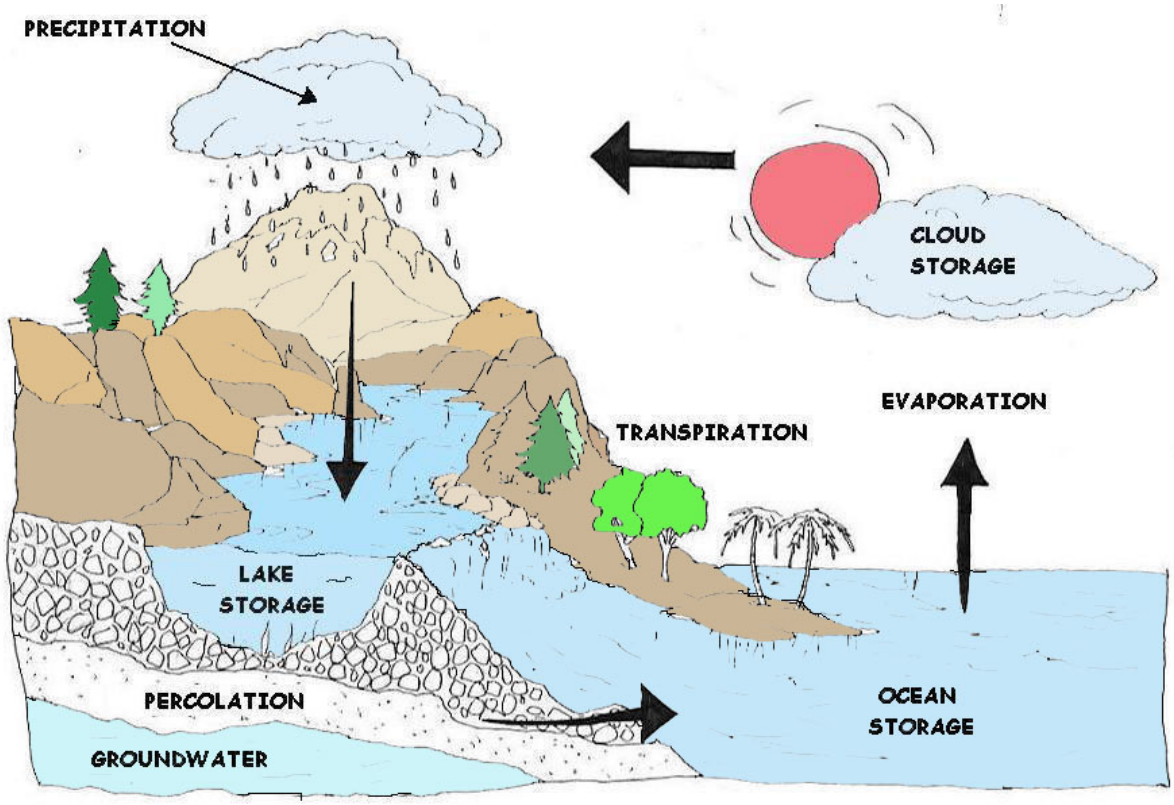


Groundwater usually flows downhill with the slope of the water table. Like surface water, groundwater flows toward, and eventually drains into, streams, rivers, lakes and the oceans. Groundwater flow in the aquifers underlying surface drainage basins, however, does not always mirror the flow of water on the surface. Therefore, groundwater may move in different directions below the ground than the water flowing on the surface.

Unconfined aquifers are those that are bounded by the water table. Some aquifers, however, lie beneath layers of impermeable materials. These are called ***confined aquifers*****,** or sometimes ***artesian aquifers***. A well in such an aquifer is called an ***artesian well***. The water in these wells rises higher than the top of the aquifer because of confining pressure. If the water level rises above the ground surface, a ***flowing artesian well*** occurs. The ***piezometric surface*** is the level to which the water in an artesian aquifer will rise.

Water Sources

Before we discuss the types of treatment it is easier to first understand how the source of water arrives.



Water Cycle Terms - Good information for your Assignment.

- **Precipitation:** The process by which atmospheric moisture falls onto the land or water surface as rain, snow, hail, or other forms of moisture.
- **Infiltration:** The gradual flow or movement of water into and through the pores of the soil.
- **Evaporation:** The process by which the water or other liquids become a gas.
- **Condensation:** The collection of the evaporated water in the atmosphere.
- **Runoff:** Water that drains from a saturated or impermeable surface into stream channels or other surface water areas. Most lakes and rivers are formed this way.
- **Transpiration**: Moisture that will come from plants as a byproduct of photosynthesis.

Once the precipitation begins, water is no longer in its purest form. Water will be collected as surface supplies or circulate to form in the ground. As it becomes rain or snow it may be polluted with organisms, organic compounds, and inorganic compounds. Because of this, we must treat the water for human consumption.

Source Water Quality

Groundwater

Groundwater contributes most of all of the water that is derived from wells or springs. It occurs in the natural open spaces (i.e., fractures or pore spaces between grains) in sediments and rocks below the surface. Groundwater is distributed fairly evenly throughout the crust of the earth, but it is not readily accessible or extractable everywhere. More than 90 percent of the world's total supply of drinkable water is groundwater.

Groundwater originates as precipitation that sinks into the ground. Some of this water percolates down to the water table (shallowest surface of the groundwater) and recharges the aquifer. For shallow wells (i.e., less than 50-75 feet) the recharge area is often the immediate vicinity around the well or ***"wellhead."*** Some wells are recharged in areas that may be a great distance from the well itself. If the downward percolating precipitation encounters any source of contamination, at the surface or below it, the water may dissolve some of that contaminant and carry it to the aquifer. Groundwater moves from areas where the water table is high to where the water table is low. Consequently, a contaminant may enter the aquifer some distance upgradient from you and still move towards your well. When a well is pumping, it lowers the water table in the immediate vicinity of the well, increasing the tendency for water to move towards the well. Contaminants can be lumped into three categories: microorganisms (bacteria, viruses, Giardia, etc.), inorganic chemicals (nitrate, arsenic, metals, etc.) and organic chemicals (solvents, fuels, pesticides, etc.).

Although it is common practice to associate contamination with highly visible features such as landfills, gas stations, industry or agriculture, potential contaminants are widespread and often come from common everyday activities as well, such as septic systems, lawn and garden chemicals, pesticides applied to highway right-of-ways, stormwater runoff, auto repair shops, beauty shops, dry cleaners, medical institutions, photo processing labs, etc. Importantly, it takes only a very small amount of some chemicals in drinking water to raise health concerns. For example, one gallon of pure trichloroethylene, a common solvent, will contaminate approximately 292 million gallons of water.

Wellhead Protection

Wellhead protection refers to programs designed to maintain the quality of groundwater used as public drinking water sources by managing the land uses around the wellfield. The theory is that management of land use around the well, and over water moving (underground) toward the well, will help to minimize damage to subsurface water supplies by spills or improper use of chemicals. The concept usually includes several stages.

Wellhead Protection Sequence

A) Build a community-wide planning team.
B) Delineate geologically the protection zone.
C) Perform a contaminant use inventory.
D) Create a management plan for the protection zone.
E) Plan for the future.

Water Rights

Appropriative: Acquired water rights for exclusive use.
Prescriptive: Rights based upon legal prescription or long use or custom.
Riparian: Water rights because property is adjacent to a river or surface water.

Contaminated Wells

Contaminated wells used for drinking water are especially dangerous. Wells can be tested to see what chemicals may be in the well and if they are present in dangerous quantities.

Groundwater is withdrawn from wells to provide water for everything from drinking water for the home and business to water to irrigate crops to industrial processing water. When water is pumped from the ground, the dynamics of groundwater flow change in response to this withdrawal. Groundwater flows slowly through water-bearing formations (aquifers) at different rates. In some places, where groundwater has dissolved limestone to form caverns and large openings, its rate of flow can be relatively fast but this is exceptional.



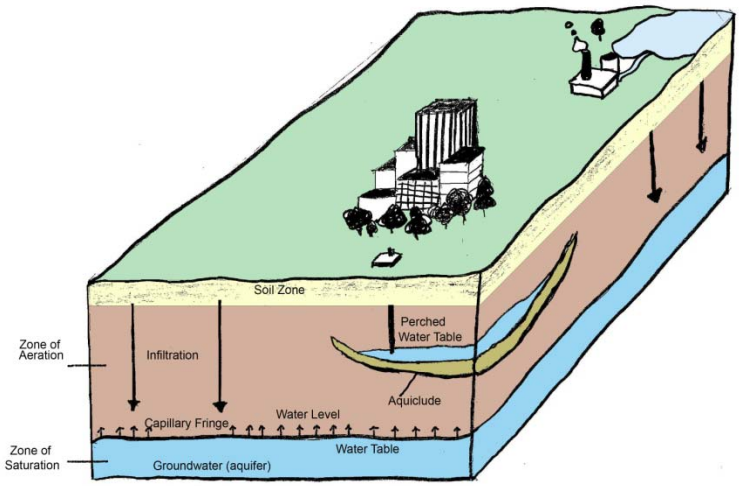
Well with a mineral oil sealed vertical turbine pump.

Aquifer

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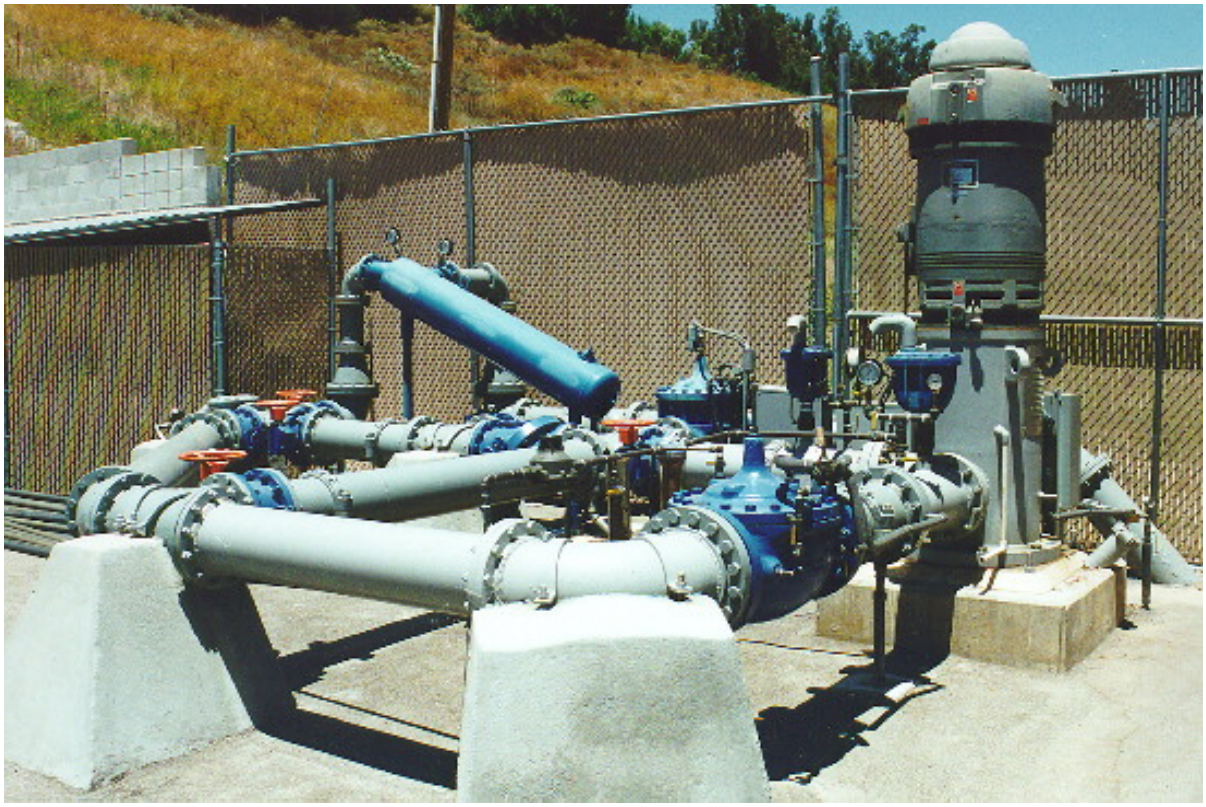
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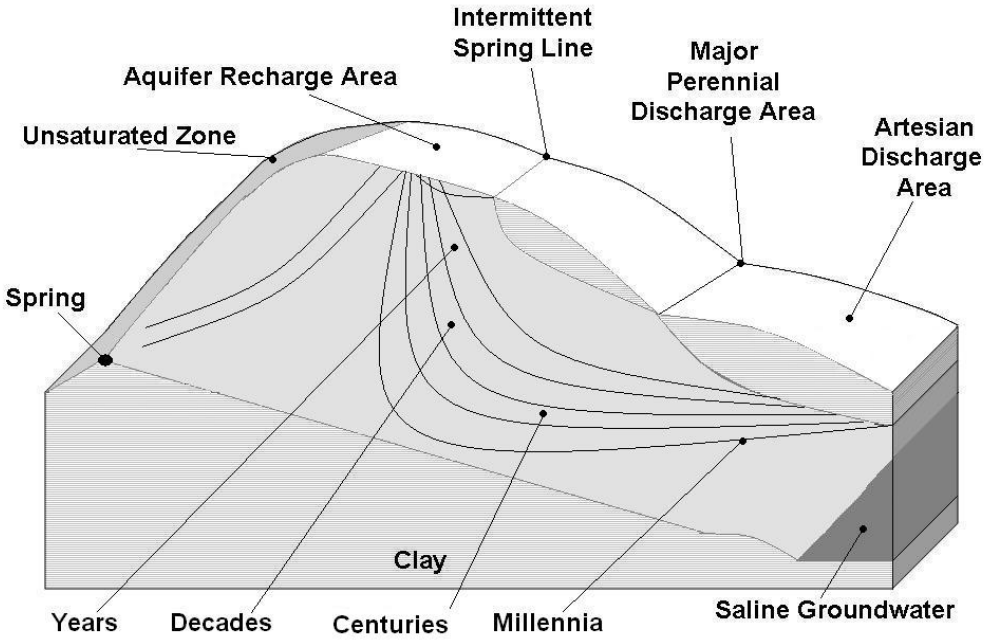
Vertical Turbine Well

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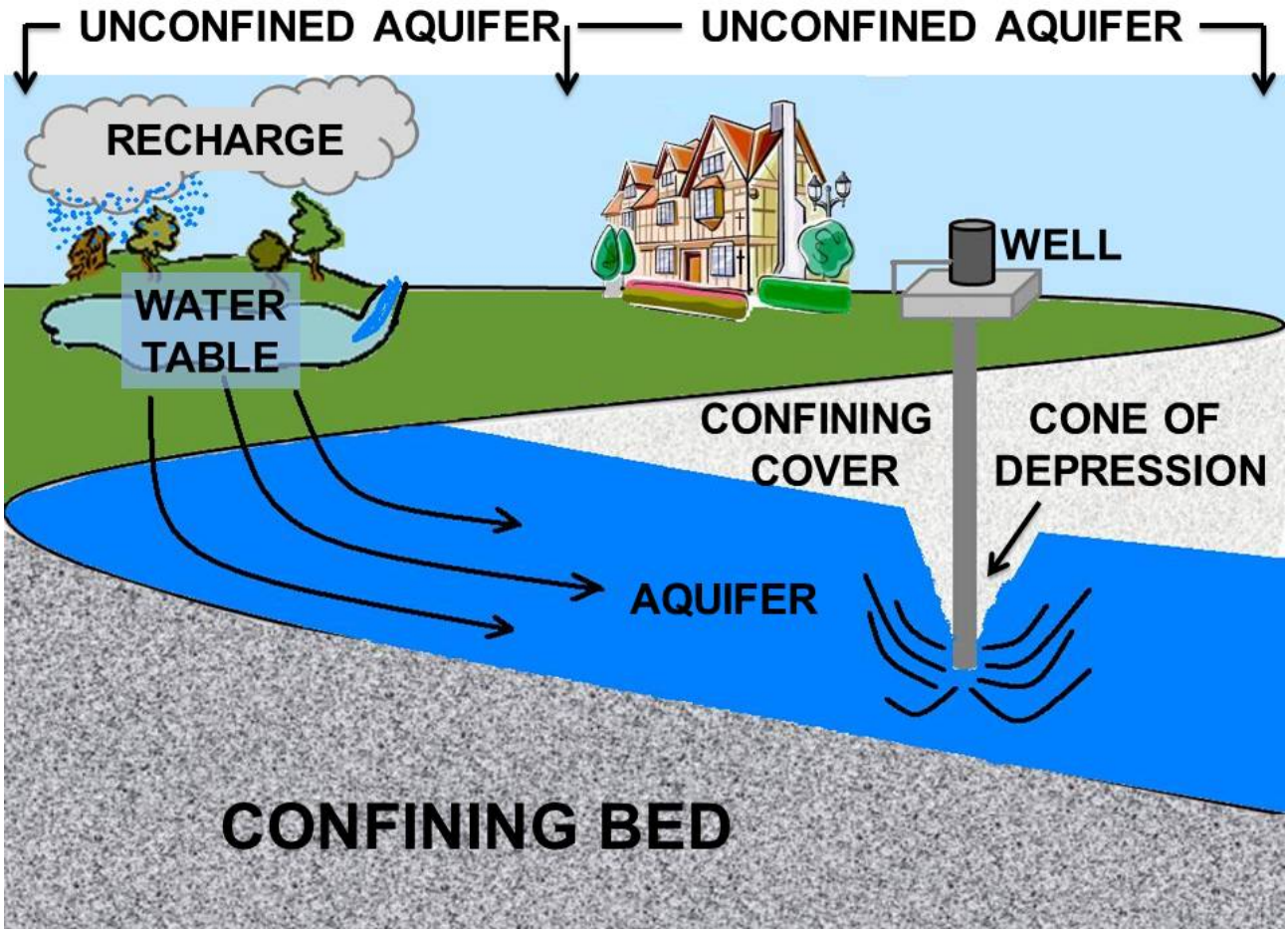
The *piezometric surface* is the level to which the water in an artesian aquifer will rise.

Cone of Depression
When pumping begins, water begins to flow towards the well in contrast to the natural direction of groundwater movement. The water level in the well falls below the water table in the surrounding aquifer.

As a result, water begins to move from the aquifer into the well. As pumping continues, the water level in the well continues to increase until the rate of flow into the well equals the rate of withdrawal from pumping. The movement of water from an aquifer into a well results in the formation of a cone of depression. The cone of depression describes a three-dimensional inverted cone surrounding the well that represents the volume of water removed as a result of pumping. Drawdown is the vertical drop in the height between the water level in the well prior to pumping and the water level in the well during pumping.



When a well is installed in an unconfined aquifer, water moves from the aquifer into the well through small holes or slits in the well casing or, in some types of wells, through the open bottom of the well. The level of the water in the well is the same as the water level in the aquifer. Groundwater continues to flow through and around the well in one direction in response to gravity.



Aquifer Description

Groundwater Section

Half of all Americans and more than 95 percent of rural Americans get their household water supplies from underground sources of water, or ground water. Ground water also is used for about half of the nation's agricultural irrigation and nearly one-third of the industrial water needs. This makes ground water a vitally important national resource.

Over the last 10 years, however, public attention has been drawn to incidents of ground-water contamination. This has led to the development of ground-water protection programs at federal, state, and local levels. Because ground-water supplies and conditions vary from one area to another, the responsibility for protecting a community's ground-water supplies rests substantially with the local community.

If your community relies on ground water to supply any portion of its fresh water needs, you, the citizen, will be directly affected by the success or failure of a ground-water protection program. Equally important, you, the citizen, can directly affect the success or failure of your community's ground-water protection efforts.

This guide is intended to help you take an active and positive role in protecting your community's ground-water supplies. It will introduce you to the natural cycle that supplies the earth with ground water, briefly explain how ground water can become contaminated, examine ways to protect our vulnerable ground-water supplies, and, most important of all, describe the roles you and your community can play in protecting valuable ground-water supplies.



Groundwater Transducer (pH, Temp. chemical detection and D.O.) depth probe. These tools are used to find the depth and pH of well water.

Groundwater Explained

Many people have never heard of ground water. That's not really so surprising since it isn't readily visible -- ground water can be considered one of our "***hidden***" resources.

What Is Groundwater and Where Does It Come From?
Actually ground water occurs as part of what can be called the oldest recycling program - the hydrologic cycle. The hydrologic cycle involves the continual movement of water between the earth and the atmosphere through evaporation and precipitation. As rain and snow fall to the earth, some of the water runs off the surface into lakes, rivers, streams, and the oceans; some evaporates; and some is absorbed by plant roots. The rest of the water soaks through the ground's surface and moves downward through the unsaturated zone, where the open spaces in rocks and soil are filled with a mixture of air and water, until it reaches the water table. The water table is the top of the saturated zone, or the area in which all interconnected spaces in rocks and soil are filled with water. The water in the saturated zone is called ground water. In areas where the water table occurs at the ground's surface, the ground water discharges into marshes, lakes, springs, or streams and evaporates into the atmosphere to form clouds, eventually falling back to earth again as rain or snow - thus beginning the cycle all over again.

Where Is Ground Water Stored?
Ground water is stored under many types of geologic conditions. Areas where ground water exists in sufficient quantities to supply wells or springs are called aquifers, a term that literally means "water bearer." Aquifers store water in the spaces between particles of sand, gravel, soil, and rock as well as cracks, pores, and channels in relatively solid rocks. An aquifer's storage capacity is controlled largely by its porosity, or the relative amount of open space present to hold water. Its ability to transmit water, or permeability, is based in part on the size of these spaces and the extent to which they are connected. Basically, there are two kinds of aquifers: confined and unconfined. If the aquifer is sandwiched between layers of relatively impermeable materials (e.g., clay), it is called a confined aquifer. Confined aquifers are frequently found at greater depths than unconfined aquifers. In contrast, unconfined aquifers are not sandwiched between these layers of relatively impermeable materials, and their upper boundaries are generally closer to the surface of the land.

Does Ground Water Move?
Ground water can move sideways as well as up or down. This movement is in response to gravity, differences in elevation, and differences in pressure. The movement is usually quite slow, frequently as little as a few feet per year, although it can move as much as several feet per day in more permeable zones. Ground water can move even more rapidly in karst aquifers, which are areas in water soluble limestone and similar rocks where fractures or cracks have been widened by the action of the ground water to form sinkholes, tunnels, or even caves.

How Is Ground Water Used?
According to the U.S. Geological Survey, ground-water use increased from about 35 billion gallons a day in 1950 to about 87 billion gallons a day in 1980. Approximately one-half of all fresh water used in the nation comes from ground water. Whether it arrives via a public water supply system or directly from a private well, ground water ultimately provides approximately 35 percent of the drinking water supply for urban areas and 95 percent of the supply for rural areas, quenching the thirst and meeting other household needs of more than 117 million people in this nation.

Overall, more than one-third of the water used for agricultural purposes is drawn from ground water; Arkansas, Nebraska, Colorado, and Kansas use more than 90 percent of their ground-water withdrawals for agricultural activities. In addition, approximately 30 percent of all ground water is used for industrial purposes. Groundwater use varies among the states, with some states, such as Hawaii, Mississippi, Florida, Idaho, and New Mexico, relying on ground water to supply considerably more than three-fourths of their household water needs and other states, such as Colorado and Rhode Island, supplying less than one-quarter of their water needs with ground water.

Ground-Water Quality
Until the 1970s, ground water was believed to be naturally protected from contamination. The layers of soil and particles of sand, gravel, crushed rocks, and larger rocks were thought to act as filters, trapping contaminants before they could reach the ground water. Since then, however, every state in the nation has reported cases of contaminated ground water, with some instances receiving widespread publicity. We now know that some contaminants can pass through all of these filtering layers into the saturated zone to contaminate ground water.

Between 1971 and 1985, 245 ground-water related disease outbreaks, with 52,181 associated illnesses, were reported. Most of these diseases were short-term digestive disorders. About 10 percent of all ground-water public water supply systems are in violation of drinking water standards for biological contamination. In addition, approximately 74 pesticides, a number of which are known carcinogens, have been detected in the ground water of 38 states. Although various estimates have been made about the extent of ground-water contamination, these estimates are difficult to verify given the nature of the resource and the difficulty of monitoring its quality.

How Does Ground Water Become Contaminated?
Ground-water contamination can originate on the surface of the ground, in the ground above the water table, or in the ground below the water table. Table I shows the types of activities that can cause ground-water contamination at each level. Where a contaminant originates is a factor that can affect its actual impact on ground-water quality. For example, if a contaminant is spilled on the surface of the ground or injected into the ground above the water table, it may have to move through numerous layers of soil and other underlying materials before it reaches the ground water. As the contaminant moves through these layers, a number of processes are in operation (e.g., filtration, dilution, oxidation, biological decay) that can lessen the eventual impact of the substance once it finally reaches the ground water. The effectiveness of these processes also is affected by both the distance between the ground water and where the contaminant is introduced and the amount of time it takes the substance to reach the ground water. If the contaminant is introduced directly into the area below the water table, the primary process that can affect the impact of the contaminant is dilution by the surrounding ground water.

GROUND SURFACE	Infiltration of polluted surface water Land disposal of wastes Stockpiles Dumps Sewage sludge disposal	De-icing salt use & storage Animal feedlots Fertilizers & pesticides Accidental spills Airborne source particulates
ABOVE WATER TABLE	Septic tanks, cesspools, & privies Holding ponds & lagoons Sanitary landfills Waste disposal in excavations Underground storage tank leaks	Underground pipeline leaks Artificial recharge Sumps and dry wells Graveyards
BELOW WATER TABLE	Waste disposal in wells Drainage wells and canals Underground storage Mines	Exploratory wells Abandoned wells Water-supply wells Ground-water withdrawal

TABLE 1. Activities That Can Cause Ground-Water Contamination
In comparison with rivers or streams, ground water tends to move very slowly and with very little turbulence. Therefore, once the contaminant reaches the ground water, little dilution or dispersion normally occurs. Instead, the contaminant forms a concentrated plume that can flow along the same path as the ground water. Among the factors that determine the size, form, and rate of movement of the contaminant plume are the amount and type of contaminant and the speed of ground-water movement. Because ground water is hidden from view, contamination can go undetected for years until the supply is tapped for use.

What Kinds of Substances Can Contaminate Groundwater, and Where Do They Come From?
Substances that can contaminate ground water can be divided into two basic categories: substances that occur naturally and substances produced or introduced by man's activities. Substances that occur naturally include minerals such as iron, calcium, and selenium. Substances resulting from man's activities include synthetic organic chemicals and hydrocarbons (e.g., solvents, pesticides, petroleum products); landfill leachates (liquids that have dripped through the landfill and carry dissolved substances from the waste materials), containing such substances as heavy metals and organic decomposition products; salt; bacteria; and viruses. A significant number of today's ground-water contamination problems stem from man's activities and can be introduced into ground water from a variety of sources.

Septic Tanks, Cesspools, and Privies
A major cause of ground-water contamination in many areas of the United States is effluent, or outflow, from septic tanks, cesspools, and privies. Approximately one fourth of all homes in the United States rely on septic systems to dispose of their human wastes. If these systems are improperly sited, designed, constructed, or maintained, they can allow contamination of the ground water by bacteria, nitrates, viruses, synthetic detergents, household chemicals, and chlorides. Although each system can make an insignificant contribution to ground-water contamination, the sheer number of such systems and their widespread use in every area that does not have a public sewage treatment system makes them serious contamination sources.

Surface Impoundments
Another potentially significant source of ground-water contamination is the more than 180,000 surface impoundments (e.g., ponds, lagoons) used by municipalities, industries, and businesses to store, treat, and dispose of a variety of liquid wastes and wastewater. Although these impoundments are supposed to be sealed with compacted clay soils or plastic liners, leaks can and do develop.

Agricultural Activities
Agricultural activities also can make significant contributions to ground-water contamination with the millions of tons of fertilizers and pesticides spread on the ground and from the storage and disposal of livestock wastes. Homeowners, too, can contribute to this type of ground-water pollution with the chemicals they apply to their lawns, rosebushes, tomato plants, and other garden plants.

Landfills
There are approximately 500 hazardous waste land disposal facilities and more than 16,000 municipal and other landfills nationwide. To protect ground water, these facilities are now required to be constructed with clay or synthetic liners and leachate collection systems. Unfortunately, these requirements are comparatively recent, and thousands of landfills were built, operated, and abandoned in the past without such safeguards. A number of these sites have caused serious ground-water contamination problems and are now being cleaned up by their owners, operators, or users; state governments; or the federal government under the Superfund program (see p. 8). In addition, a lack of information about the location of many of these sites makes it difficult, if not impossible, to determine how many others may now be contaminating ground water.

Underground Storage Tanks
Between five and six million underground storage tanks are used to store a variety of materials, including gasoline, fuel oil, and numerous chemicals. The average life span of these tanks is 18 years, and over time, exposure to the elements causes them to corrode. Now, hundreds of thousands of these tanks are estimated to be leaking, and many are contaminating ground water. Replacement costs for these tanks are estimated at $1 per gallon of storage capacity; a cleanup operation can cost considerably more.

Abandoned Wells
Wells can be another source of ground-water contamination. In the years before there were community water supply systems, most people relied on wells to provide their drinking water. In rural areas this can still be the case. If a well is abandoned without being properly sealed, however, it can act as a direct channel for contaminants to reach ground water.

Accidents and Illegal Dumping
Accidents also can result in ground-water contamination. A large volume of toxic materials is transported throughout the country by truck, train, and airplane.

Every day accidental chemical or petroleum product spills occur that, if not handled properly, can result in ground-water contamination. Frequently, the automatic reaction of the first people at the scene of an accident involving a spill will be to flush the area with water to dilute the chemical. This just washes the chemical into the soil around the accident site, allowing it to work its way down to the ground water. In addition, there are numerous instances of ground-water contamination caused by the illegal dumping of hazardous or other potentially harmful wastes.

Highway De-icing
A similar flushing mechanism also applies to the salt that is used to de-ice roads and highways throughout the country every winter. More than 11 million tons of salt are applied to roads in the United States annually. As ice and snow melt or rain subsequently falls, the salt is washed into the surrounding soil where it can work its way down to the ground water. Salt also can find its way into ground water from improperly protected storage stockpiles.

What Can Be Done After Contamination Has Occurred?
Unlike rivers, lakes, and streams that are readily visible and whose contamination frequently can be seen with the naked eye, ground water itself is hidden from view. Its contamination occurs gradually and generally is not detected until the problem has already become extensive. This makes cleaning up contamination a complicated, costly, and sometimes impossible process.

In general, a community whose ground-water supply has been contaminated has five options:
* Contain the contaminants to prevent their migration from their source.
* Withdraw the pollutants from the aquifer.
* Treat the ground water where it is withdrawn or at its point of use.
* Rehabilitate the aquifer by either immobilizing or detoxifying the contaminants while they are still in the aquifer.
* Abandon the use of the aquifer and find alternative sources of water

Which option is chosen by the community is determined by a number of factors, including the nature and extensiveness of the contamination, whether specific actions are required by statute, the geologic conditions, and the funds available for the purpose. All of these options are costly. For example, a community in Massachusetts chose a treatment option when the wells supplying its public water system were contaminated by more than 2,000 gallons of gasoline that had leaked into the ground from an underground storage tank less than 600 feet from one of the wells.

The town temporarily provided alternative water supplies for its residents and then began a cleanup process that included pumping out and treating the contaminated water and then recharging the aquifer with the treated water. The cleanup effort alone cost more than $3 million. Because of the high costs and technical difficulties involved in the various containment and treatment methods, many communities will choose to abandon the use of the aquifer when facing contamination of their ground-water supplies. This requires the community to either find other water supplies, drill new wells farther away from the contaminated area of the aquifer, deepen existing wells, or drill new wells in another aquifer if one is located nearby. As Atlantic City, New Jersey, found, these options also can be very costly for a community. The wells supplying that city's public water system were contaminated by leachate from a landfill. The city estimated that development of a new wellfield would cost approximately $2 million.

Government Ground-Water Protection Activities
Given the importance of ground water as a source of drinking water for so many communities and individuals and the cost and difficulty of cleaning it up, common sense tells us that the best way to guarantee continued supplies of clean ground water is to prevent contamination.

Are There Federal Laws or Programs to Protect Ground Water?
The U.S. Environmental Protection Agency (**EPA**) is responsible for federal activities relating to the quality of ground water. EPA's ground-water protection activities are authorized by a number of laws, including:

* The Safe Drinking Water Act, which authorizes EPA to set standards for maximum levels of contaminants in drinking water, regulate the underground disposal of wastes in deep wells, designate areas that rely on a single aquifer for their water supply, and establish a nationwide program to encourage the states to develop programs to protect public water supply wells (i.e., wellhead protection programs).

* The Resource Conservation and Recovery Act, which regulates the storage, transportation, treatment, and disposal of solid and hazardous wastes to prevent contaminants from leaching into ground water from municipal landfills, underground storage tanks, surface impoundments, and hazardous waste disposal facilities.

* The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), which authorizes the government to clean up contamination caused by chemical spills or hazardous waste sites that could (or already do) pose threats to the environment, and whose 1986 amendments include provisions authorizing citizens to sue violators of the law and establishing "community right-to-know" programs (Title III).

* The Federal Insecticide, Fungicide, and Rodenticide Act, which authorizes EPA to control the availability of pesticides that have the ability to leach into ground water.

* The Toxic Substances Control Act which authorizes EPA to control the manufacture, use, storage, distribution, or disposal of toxic chemicals that have the potential to leach into ground water.

* The Clean Water Act, which authorizes EPA to make grants to the states for the development of ground-water protection strategies and authorizes a number of programs to prevent water pollution from a variety of potential sources.

The federal laws tend to focus on controlling potential sources of ground-water contamination on a national basis. Where federal laws have provided for general ground-water protection activities such as wellhead protection programs or development of state ground-water protection strategies, the actual implementation of these programs must be by the states in cooperation with local governments.
A major reason for this emphasis on local action is that protection of ground water generally involves making very specific decisions about how land is used. Local governments frequently exercise a variety of land-use controls under state laws.

Do the States Have Laws or Programs to Protect Ground Water?
According to a study conducted for EPA in 1988, most of the states have passed some type of ground-water protection legislation and developed some kind of ground-water policies. State ground-water legislation can be divided into the following subject categories:

* Statewide strategies - Requiring the development of a comprehensive plan to protect the state's ground-water resources from contamination.

* Ground-water classification - Identifying and categorizing ground-water sources by how they are used to determine how much protection is needed to continue that type of use.

* Standard setting - Identifying levels at which an aquifer is considered to be contaminated.

* Land-use management - Developing planning and regulatory mechanisms to control activities on the land that could contaminate an aquifer.

* Ground-water funds - Establishing specific financial accounts for use in the protection of ground-water quality and the provision of compensation for damages to underground drinking water supplies (e.g., reimbursement for ground-water cleanup, provision of alternative drinking water supplies).

* Agricultural chemicals - Regulating the use, sale, labeling, and disposal of pesticides, herbicides, and fertilizers.

* Underground storage tanks - Establishing criteria for the registration, construction, installation, monitoring, repair, closure, and financial responsibility associated with tanks used to store hazardous wastes or materials.

* Water-use management - Including ground-water quality protection in the criteria used to justify more stringent water allocation measures where excessive ground-water withdrawal could cause ground-water contamination.

Appendix 1 presents a matrix showing the types of ground-water protection legislation enacted by the states. In addition to ground-water protection programs states may have developed under their own laws, one state ground-water protection program is required by federal law. The 1986 amendments to the Safe Drinking Water Act established the wellhead protection program and require each state to develop comprehensive programs to protect public water supply wells from contaminants that could be harmful to human health. Wellhead protection is simply protection of all or part of the area surrounding a well from which the well's ground water is drawn. This is called a wellhead protection area (WHPA). The size of the WHPA will vary from site to site depending on a number of factors, including the goals of the state's program and the geologic features of the area.

The law specifies certain minimum components for the wellhead protection programs:

* The roles and duties of state and local governments and public water suppliers in the management of wellhead protection programs must be established.

* The WHPA for each wellhead must be delineated (i.e., outlined or defined).

* Contamination sources within each WHPA must be identified.

* Approaches for protecting the water supply within the WHPAs from the contamination sources (e.g., use of source controls, education, training) must be developed.

* Contingency plans must be developed for use if public water supplies become contaminated.

* Provisions must be established for proper sitting of new wells to produce maximum water yield and reduce the potential for contamination as much as possible.

* Provisions must be included to ensure public participation in the process.

For a program to be successful, all levels of government must participate in the wellhead protection program. The federal government is responsible for approving state wellhead protection programs and for providing technical support to state and local governments. State governments must develop and implement wellhead protection programs that meet the requirements of the Safe Drinking Water Act. Although the responsibilities of local governments depend on the specific requirements of their state's program, these governments often are in the best position (and have the greatest incentive) to ensure proper protection of wellhead areas. They have the most to lose if their ground-water becomes contaminated.





Well Development Section

Once well construction is complete, the well is *developed*. The purpose of well development is to *purge* the well and bore of all drilling mud and or fluid, fine grained sediment, and loose aquifer matter.

The well development process also helps to settle the gravel or filter pack and/or rearrange particles within the well and nearby aquifer to allow for the most efficient operation of the well. Not surprisingly, the drilling procedure often damages the aquifer around the well.

Well development can significantly improve a well's performance by essentially repairing as much of this damage as possible by improving the transition from the aquifer to the well. The screened and productive portions of the well can be subjected to various development techniques.

All methods of well development essentially involve the flushing of water back and forth between the well and aquifer.

If you think of the aquifer as one great big *natural media filter*, the development process to a well is much the same as the backwashing process for a water treatment system. So what about hard rock wells? Wells constructed in hard rock aquifers are not composed of unconsolidated sediments. Still, they can and should be developed because fine cuttings, drilling mud, and clay within the *fractures* and *pore spaces* near the well can obstruct flow from otherwise productive zones.

Well development procedures can remove such sediments from hard rock wells also. Several common methods of well development include, surge-block, jetting, airlift, and pump surging.

Well Surging or Backwashing

Pump surging (sometimes called ***Rawhiding)*** involves the repeated pumping and resting of the well for well development purposes. A column of water that is withdrawn through a pump is allowed to surge back into the well by turning the pump on and off repeatedly. However, sufficient time for the pump motor to stop reverse rotation must be allowed, such that pump damage can be avoided. Occasionally, water is pumped to waste until it is clear of sediment before again shutting the pump off. This is done to permanently remove the sediments that are being developed by the backwashing action. The process continues until sufficient quantities of water produced are consistently clean.

Surge-blocks, ***swabs, or plungers*** are disc shaped devices made to fit tightly within the well. Their edges are usually fitted with rubber or leather rings to make a tight seal against the well casing. Pipe sections are then attached to the surge-block to lower it into the well, above the well screen, and about 15 feet below the water level. The assembly is then repeatedly lifted up and down. The up and down action of the surge-block creates suction, and compression strokes that force water in and out of the well through the screened interval, gravel pack, and aquifer. It works like a plunger in the way that it removes small obstructions and sediments from the well. The surge-block is slowly lowered each time resistance begins to decrease.

Once the top of the screen is reached, the assembly may be removed and accumulated sediment either bailed or airlifted out of the well. Surging within known problem areas of the screened interval may be conducted also. The cycle of swabbing and removing sediment should be continued until resistance to the action of the swab or block is significantly lower than at the start of development. The development is complete when the amount of sediment removed is both significantly and consistently less than when surging began.

Airlifting (or **Air surging)** involves the introduction of large short blasts of air within the well that lifts the column of water to the surface and then drop it back down again. Continuous airlifting or **air pumping** from the bottom of the well is then used occasionally to lift sediments out of the well. Airlift development is most often used following initial pump surging, and is employed to confirm that the well is productive, since the injection of air into a plugged well may result in casing or screen failure.

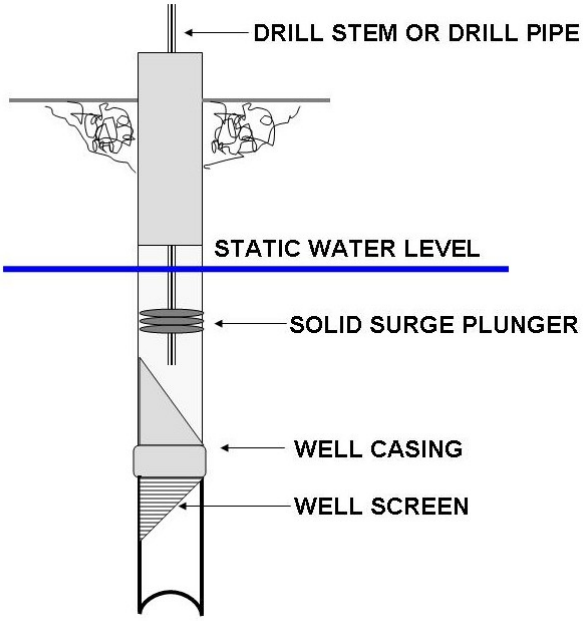
Air lifting development is most often done with a rotary drilling rig through the drill string. Sometimes special air diffusers or jets are used to direct the bursts of air into preferred directions (see jetting). Piping is inserted into the well and intermittent blasts of air are introduced as the piping is slowly lowered into the well. Sometimes surfactant or drill foam is added to aid in the efficiency of sediment removal and cleaning of the well. Air surging development is much the same as drilling the well with air rotary; only the well has already been constructed. Specialized air development units are available independent of a drilling rig, which may be used as well. The great thing about air rotary drilled wells is that they are essentially developed while drilling, particularly in hard rock formations, when greater than 100 gallons per minute is being lifted to the surface. The development of a filter pack (if used) in such wells is still recommended.

Jetting is a type of well development technique in which water and/or air is *jetted* or sprayed horizontally into the well screen. This method is especially suited for application in *stratified* and *unconsolidated* formations. The water or air is forced through *nozzles* in a specially designed *jetting tool* (or simply drilled pipe and fittings) at high velocities. Normally, air lifting or pumping is used in conjunction with jetting methods in order to minimize potential damage to the well bore. Jetting with water alone can be so powerful that the sediment, which is supposed to be removed, can be forced into the formation causing clogging problems.

This is why pumping or airlifting while jetting with water is so important. Jetting is normally conducted from the bottom of the well screen upwards.

Rotary Rig

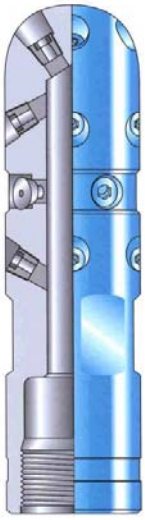
A rotary rig is often used to provide the fluid or air with sustained pressure while the tool is slowly raised up through the screen. As jetting proceeds, sediment is occasionally removed from the bottom of the well bore thru the use of a bailer or airlifting. Several passes should be made over the length of screen until sediment generation drops off. Air is normally used for jetting in shallow aquifers (less than 300 feet of submergence) due to limited supply pressures. Jetting in PVC constructed wells is not recommended since the high velocities of fluid and sediment can erode and possibly cut through the plastic well screen. In addition, wells constructed with louvered or slotted screen limit the effectiveness of jetting. In these types of wells, surging may be more effective.





Surge of air developing a Well.

Jetting Nozzle that can be → attached to drill pipe.



In the best of situations a combination of methods can be used to ensure the efficient development and operation of a well.

Selecting an Optimum Pumping Rate

Before a well can be completed with the necessary pumping equipment, it should be tested for capacity and proper operation. When the well was drilled, the driller and geologist kept close watch of the amount of water production that had been obtained. The development techniques used can also be useful in estimating a wells production rate. However, the driller will normally know what to expect based on his experience, and the geologist or *hydrologist* will also obtain information on other nearby wells to bracket the expected production rate. If the well was drilled with air rotary, the *airlift* at the time of drilling also can serve as a baseline to estimate the well's production rate. Either way, the well is normally pump tested following well development.

A *pumping test* is normally conducted for at least eight hours in order to estimate a well's maximum production rate. Ideally, a twenty-four hour step test is conducted. A step test is a *variable rate* pumping test, typically conducted for 24 hours at up to six different pumping rates. Typically, the well will be pumped at the lower estimated maximum pumping rate for the first four hours.

The pumping rate is then adjusted upwards in equal amounts every four hours until 24 hours of pumping have been completed. The personnel conducting the test keep track of the water levels in the well to ensure that the steps are not too large and not too small.

In the end, the optimum pumping rate is selected following a careful review and comparison of the water level data for each rate. The well's *specific capacity (Sc)* is then determined. Specific capacity is the gallons per minute the well can produce per foot of drawdown. Specific capacities for each of the pumping steps are compared. The highest Sc observed is normally associated with the optimum pumping rate. That rate should also have resulted in *stabilized* pumping levels or *drawdown*.



Well pumping test being conducted in photograph above. (Notice the portable electric generator for powering the pump. The Hydrogeologist is using a depth probe to measure the drop in the static water level.)

Selection of Pumping Equipment

The proper selection of pumping equipment for a well is of great importance. The primary factors that must be considered before selecting the well pump are: flow rate, line pressure, pumping lift (total dynamic head), power requirements (and limitations), and size of piping. Each of these components must be considered together when selecting well pumps.

Pumping Lift and Total Dynamic or Discharge Head
The most important components in selecting the correct pump for your application are: *total pumping lift* and *total dynamic or discharge head*. Total dynamic head refers to the total equivalent feet of lift that the pump must overcome in order to deliver water to its destination, including frictional losses in the delivery system.

Basic Pump Operating Characteristics
"Head" is a term commonly used with pumps. Head refers to the height of a vertical column of water. Pressure and head are interchangeable concepts in irrigation, because a column of water 2.31 feet high is equivalent to 1 pound per square inch (PSI) of pressure. The total head of a pump is composed of several types of head that help define the pump's operating characteristics.

Total Dynamic Head
The total dynamic head of a pump is the sum of the total static head, the pressure head, the friction head, and the velocity head.

The Total Dynamic Head (TDH) is the sum of the total static head, the total friction head and the pressure head.

Total Static Head
The total static head is the total vertical distance the pump must lift the water. When pumping from a well, it would be the distance from the pumping water level in the well to the ground surface plus the vertical distance the water is lifted from the ground surface to the discharge point. When pumping from an open water surface, it would be the total vertical distance from the water surface to the discharge point.

Pressure Head
The pressure head at any point where a pressure gauge is located can be converted from pounds per square inch (PSI) to feet of head by multiplying by 2.31. For example, 20 PSI is equal to 20 times 2.31 or 46.2 feet of head. Most city water systems operate at 50 to 60 PSI, which, as illustrated in Table 1, explains why the centers of most city water towers are about 130 feet above the ground.

Table 1. Pounds per square inch (PSI) and equivalent head in feet of water.

PSI	Head (feet)
0	0
5	11.5
10	23.1
15	34.6
20	46.2
25	57.7

30	69.3
35	80.8
40	92.4
45	104
50	115
55	127
60	138
65	150
70	162
75	173
80	185
85	196
90	208
95	219
100	231

Friction Head
Friction head is the energy loss or pressure decrease due to friction when water flows through pipe networks. The velocity of the water has a significant effect on friction loss. Loss of head due to friction occurs when water flows through straight pipe sections, fittings, valves, around corners, and where pipes increase or decrease in size. Values for these losses can be calculated or obtained from friction loss tables. The friction head for a piping system is the sum of all the friction losses.

Velocity Head
Velocity head is the energy of the water due to its velocity. This is a very small amount of energy and is usually negligible when computing losses in an irrigation system.

Suction Head
A pump operating above a water surface is working with a suction head. The suction head includes not only the vertical suction lift, but also the friction losses through the pipe, elbows, foot valves, and other fittings on the suction side of the pump. There is an allowable limit to the suction head on a pump and the net positive suction head (NPSH) of a pump sets that limit.

The theoretical maximum height that water can be lifted using suction is 33 feet. Through controlled laboratory tests, manufacturers determine the NPSH curve for their pumps. The NPSH curve will increase with increasing flow rate through the pump. At a certain flow rate, the NPSH is subtracted from 33 feet to determine the maximum suction head at which that pump will operate. For example, if a pump requires a minimum NPSH of 20 feet the pump would have a maximum suction head of 13 feet. Due to suction pipeline friction losses, a pump rated for a maximum suction head of 13 feet may effectively lift water only 10 feet. To minimize the suction pipeline friction losses, the suction pipe should have a larger diameter than the discharge pipe.

Operating a pump with suction lift greater than it was designed for, or under conditions with excessive vacuum at some point in the impeller, may cause cavitation. Cavitation is the implosion of bubbles of air and water vapor and makes a very distinct noise like gravel in the pump. The implosion of numerous bubbles will eat away at an impeller and it eventually will be filled with holes.

Pump Power Requirements
The power added to water as it moves through a pump can be calculated with the following formula:

$$WHP = \frac{Q \times TDH}{3960} \quad (1)$$

where:

WHP = Water Horse Power
Q = Flow rate in gallons per minute (GPM)
TDH = Total Dynamic Head (feet)

However, the actual power required to run a pump will be higher than this because pumps and drives are not 100 percent efficient. The horsepower required at the pump shaft to pump a specified flow rate against a specified TDH is the **Brake Horsepower** (BHP) which is calculated with the following formula:

$$BHP = \frac{WHP}{\text{Pump Eff.} \times \text{Drive Eff.}} \quad (2)$$

BHP -- Brake Horsepower (continuous horsepower rating of the power unit).

Pump Eff. -- Efficiency of the pump usually read from a pump curve and having a value between 0 and 1.

Drive Eff. -- Efficiency of the drive unit between the power source and the pump. For direct connection this value is 1, for right angle drives the value is 0.95 and for belt drives it can vary from 0.7 to 0.85.

Effect of Speed Change on Pump Performance
The performance of a pump varies with the speed at which the impeller rotates. **Theoretically**, varying the pump speed will result in changes in flow rate, TDH and BHP according to the following formulas:

$$\left(\frac{RPM_2}{RPM_1}\right) \times GPM_1 = GPM_2 \quad (3)$$

$$\left(\frac{RPM_2}{RPM_1}\right)^2 \times TDH_1 = TDH_2 \quad (4)$$

$$\left(\frac{RPM_2}{RPM_1}\right)^3 \times BPH_1 = BPH_2 \quad (5)$$

where:
RPM_1 = Initial revolutions per minute setting
RPM_2 = New revolutions per minute setting
GPM = Gallons per Minute
(subscripts same as for RPM)
TDH = Total Dynamic Head
(subscripts same as for RPM)
BHP = Brake Horsepower
(subscripts same as for RPM)

As an example, if the RPM are increased by 50 percent, the flow rate will increase by 50 percent, the TDH will increase 2.25 times, and the required BHP will increase 3.38 times that required at the lower speed. It is easy to see that with a speed increase the BHP requirements of a pump will increase at a **faster rate** than the head and flow rate changes.

Pump Efficiency
Manufacturers determine by tests the operating characteristics of their pumps and publish the results in pump performance charts commonly called "**pump curves**."

A typical pump curve for a horizontal centrifugal pump. NPSH is the Net Positive Suction Head required by the pump and TDSL is the Total Dynamic Suction Lift available (both at sea level).

All pump curves are plotted with the flow rate on the horizontal axis and the TDH on the vertical axis. The curves in a pump curve are for a centrifugal pump tested at different RPM. Each curve indicates the GPM versus TDH relationship at the tested RPM. In addition, pump efficiency lines have been added and wherever the efficiency line crosses the pump curve lines **that** number is what the efficiency is at that point. Brake horsepower (BHP) curves have also been added; they slant down from left to right. The BHP curves are calculated using the values from the efficiency lines. At the top of the chart is an NPSH curve with its scale on the right side of the chart.

Reading a Pump Curve
When the desired flow rate and TDH are known, these curves are used to select a pump. The pump curve shows that a pump will operate over a wide range of conditions. However, it will operate at peak efficiency only in a narrow range of flow rate and TDH. As an example of how a pump characteristic curve is used, let's use the pump curve to determine the horsepower and efficiency of this pump at a discharge of 900 gallons per minute (**GPM**) and 120 feet of TDH.

Solution: Follow the dashed vertical line from 900 GPM until it crosses the dashed horizontal line from the 120 feet of TDH. At this point the pump is running at a peak efficiency just below 72 percent, at a speed of 1600 RPM. If you look at the BHP curves, this pump requires just less than 40 BHP on the input shaft. A more accurate estimate of BHP can be calculated with equations 1 and 2. Using equation 1, the WHP would be [900 x 120] / 3960 or 27.3, and from equation 2 the BHP would be 27.3 / 0.72 or 37.9, assuming the drive efficiency is 100 percent. The NPSH curve was used to calculate the Total Dynamic Suction Lift (TDSL) markers at the bottom of the chart. Notice that the TDSL at 1400 GPM is 10 feet, but at 900 GPM the TDSL is over 25 feet.

Changing Pump Speed
In addition, suppose this pump is connected to a diesel engine. By varying the RPM of the engine we can vary the flow rate, the TDH and the BHP requirements of this pump. As an example, let's change the speed of the engine from 1600 RPM to 1700 RPM. What effect does this have on the GPM, TDH and BHP of the pump?

Solution: We will use equations 3, 4 and 5 to calculate the change. Using equation 3, the change in GPM would be (1700/1600) x 900, which equals 956 GPM. Using equation 4, the change in TDH would be $(1700/1600)^2$ x 120, which equals 135.5 feet of TDH. Using equation 5, the change in BHP would be $(1700/1600)^3$ x 37.9, which equals 45.5 BHP. This point is plotted on Figure 2 as the circle with the dot in the middle. Note that the new operating point is up and to the right of the old point and that the efficiency of the pump has remained the same.
When a pump has been selected for installation, a copy of the pump curve should be provided by the installer. In addition, if the impeller(s) was trimmed, this information should also be provided. This information will be valuable in the future, especially if repairs have to be made.

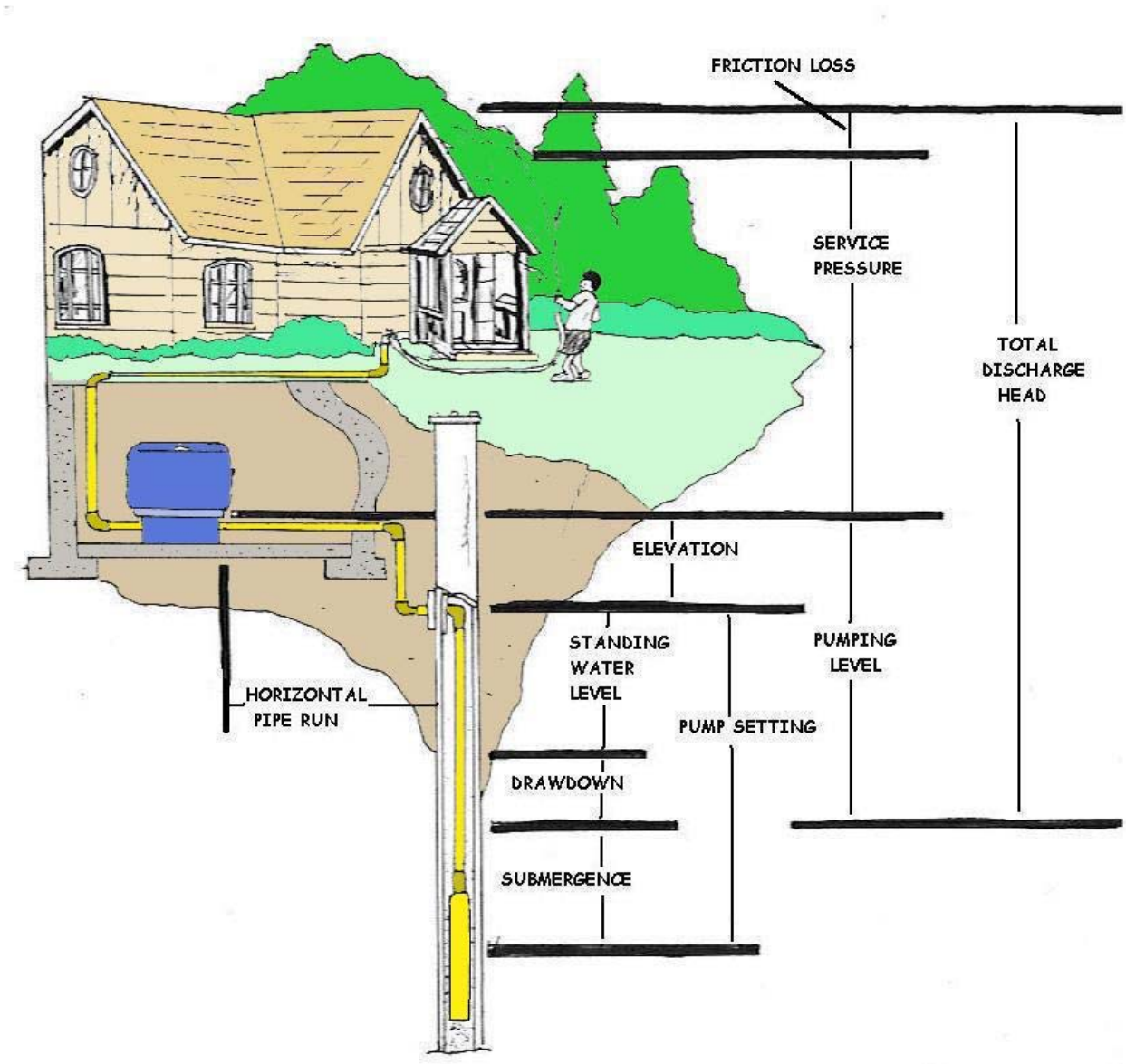
Determining Friction Losses
A well system installer and/or engineer can help in determining the friction losses in the distribution system. There are numerous friction loss tables with values of equivalent feet of head for given flow rates and types and diameters of pipe available. However, unless great distances or small diameter pipes are used, friction loss is almost negligible. The lift requirements for the pump primarily include the height to which the pump must deliver the water from the wellhead, plus the distance from the pumping level to the land surface.

For example: A municipal supply well has been tested and determined to yield 500gpm. The well was constructed with 10 inch casing that has been perforated from 200 to 500 feet below the ground surface within an unconfined aquifer. The static water level has been measured at 100 feet while the drawdown at 500gpm has been estimated at 80 feet. The full level of the storage tank for the well exerts about 87psi at the wellhead and is connected to the well via a 12-inch distribution main. Three-phase power is available and 4-inch column pipe is to be used down the hole. The pump intake is to be set at 180 feet.

Before we can select an appropriate pump, we first need to determine what the total dynamic head is. After referring to a friction loss table for flow in 4 inch and 12-inch pipe; we determine that the friction losses in the 4 inch pipe will be about 24 feet per 100 foot, while losses in the 12 inch main are negligible.

This leads us to determine that there will be about 43 feet of friction loss through the 4-inch pipe. We also know that the total lift is equal to the drawdown, plus the distance to the land surface from the static water level, plus the vertical distance to the full level of the storage tank. We know from physics that for every foot of water there is .433psi of pressure or 2.31ft of head for every 1 psi. The line pressure at the well head is equal to the height of the column of water above the well head, which gives us a line pressure at the well head of 87psi or 200 feet of water. The total lift from the pump to the wellhead 180 feet and equivalent to 78psi. So the total dynamic head is equivalent to a lift of 380 feet or an equivalent pressure of about 165psi at the pump, plus about 43 feet of friction loss. Therefore, in order to pump 500gpm under these circumstances, the pump that is selected should have its most efficient operating range in the neighborhood of 423 feet total lift. We then look at *performance curves* from the various pump manufacturers to determine the best pump and power combination for the application.

Because this is a municipal supply well that is pumping directly into the distribution system, we will choose a submersible turbine for the job rather than a line shaft turbine, which must be lubricated. Upon looking at the *curves* for this application, one will find that a 75HP, 8in, 5 stage, submersible pump will do the job most efficiently without risking the over-pumping of the well.



Elements of Total Dynamic Head for the proper selection of pumping equipment.



A new 8 inch submersible pump and motor with 6 inch column pipe about to be installed in a high capacity municipal supply well.

The Well Head Assembly

An approved well cap or seal is to be installed at the *wellhead* to prevent any contamination from entering the well through the top once construction is complete. When the well is completed with pumping equipment a well vent is also required.

The well *vent pipe* should be at least ½ inch in diameter, 8 inches above the finished grade, and be turned down, with the opening screened with a minimum 24-mesh durable screen to prevent entry of insects. Only approved well casing material meeting the requirements of the Code may be utilized.

In addition, frost protection should be provided by use of insulation or pump house. Turbine and submersible pumps are normally used. Any pressure, vent, and electric lines to and from the pump should enter the casing only through a watertight seal.

Pumps and pressure tanks may be located in basements and enclosures. However, wells should not be located within vaults or pits, except with a *variance permit*.

If the pump discharge line passes through the well casing underground, an approved *pitless adapter* should be installed. The *well manifold* should include an air relief valve, flow meter, sample port, isolation valve, and a check valve. If the well should need rehabilitation, additional construction, or repair, it must be done in compliance with the State or Local Water Well Construction Codes.

Water Storage Section

Water storage facilities and tanks vary in size, shape, and application. There are different types that are used in the water distribution systems, such as standpipes, elevated tanks and reservoirs, hydropneumatic tanks and surge tanks.

These tanks serve multiple purposes in the distribution system. Just the name alone can give you an idea of its purpose.

- **SURGE tanks**
- **RESERVOIRS**
- **ELEVATED tanks** *Water towers and Standpipes*

Surge Tanks
What really causes water main breaks - **ENERGY** - when released in a confined space, such as a water distribution system. Shock waves are created when hydrants, valves, or pumps are opened and closed quickly, trapping the kinetic energy of moving water within the confined space of a piping system.



These shock waves can create a turbulence that travels at the speed of sound, seeking a point of release. The release the surge usually finds is an elevated tank, but the surge doesn't always find this release quickly enough. Something has to give, often times, it's your pipe fittings.

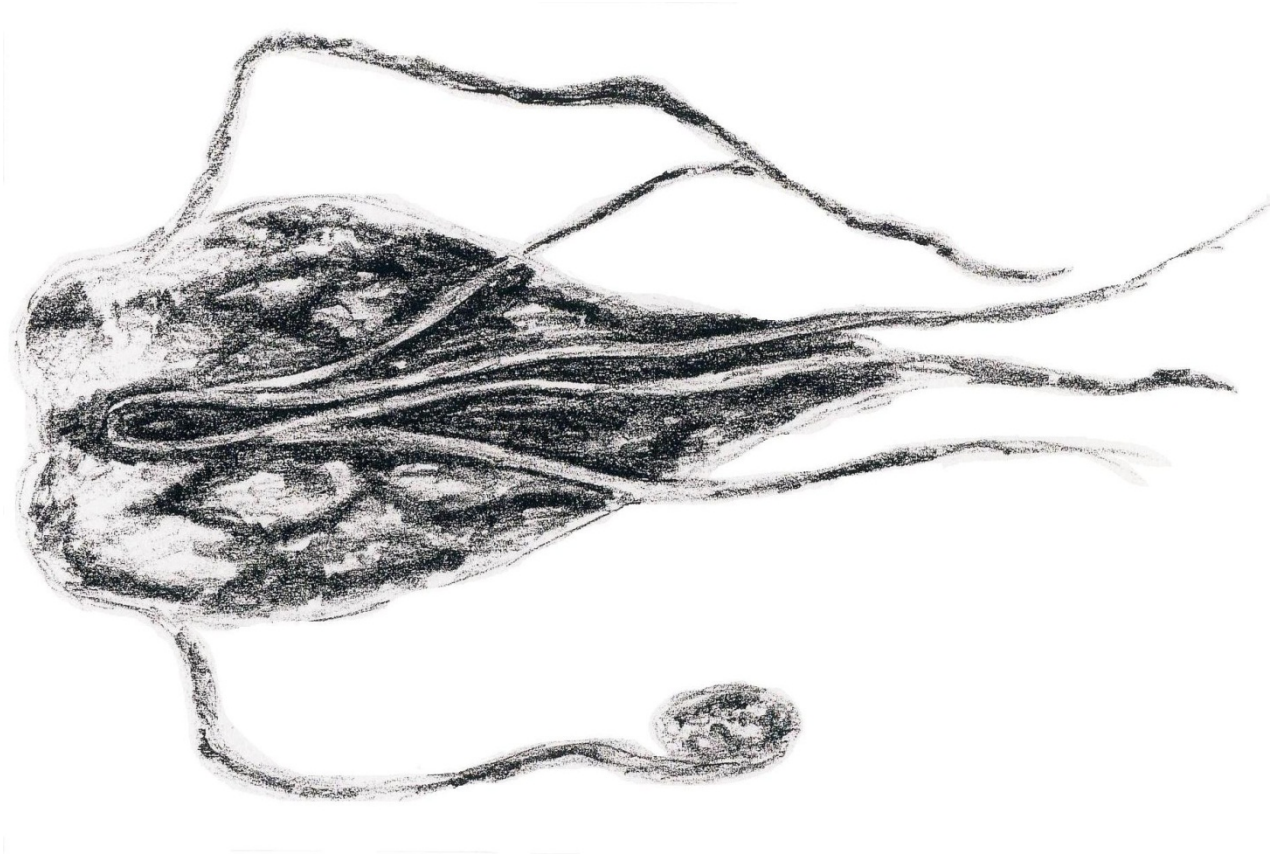
Distribution operators are aware of this phenomenon! It's called **WATER HAMMER**.

This banging can be heard as water hammer. Try it at home - turn on your tap, then turn it off very quickly. You should hear a bang, and maybe even several. If you turn the tap off more slowly, it should stay quiet, as the liquid in the pipes slows down more gradually.

A Surge tank should not be used for water storage.



The goal of the water tower or standpipe is to store water high in the air, where it has lots of gravitational potential energy. This stored energy can be converted to pressure potential energy or kinetic energy for delivery to homes. Since height is everything, building a cylindrical water tower is inefficient. Most of the water is then near the ground. By making the tower wider near the top, it puts most of its water high up.



Giardia



Cryptosporidium

Chlorine Section



1-ton chlorine containers, rear side of container.



Professor Durbin in front of a Chlorine rotometer.

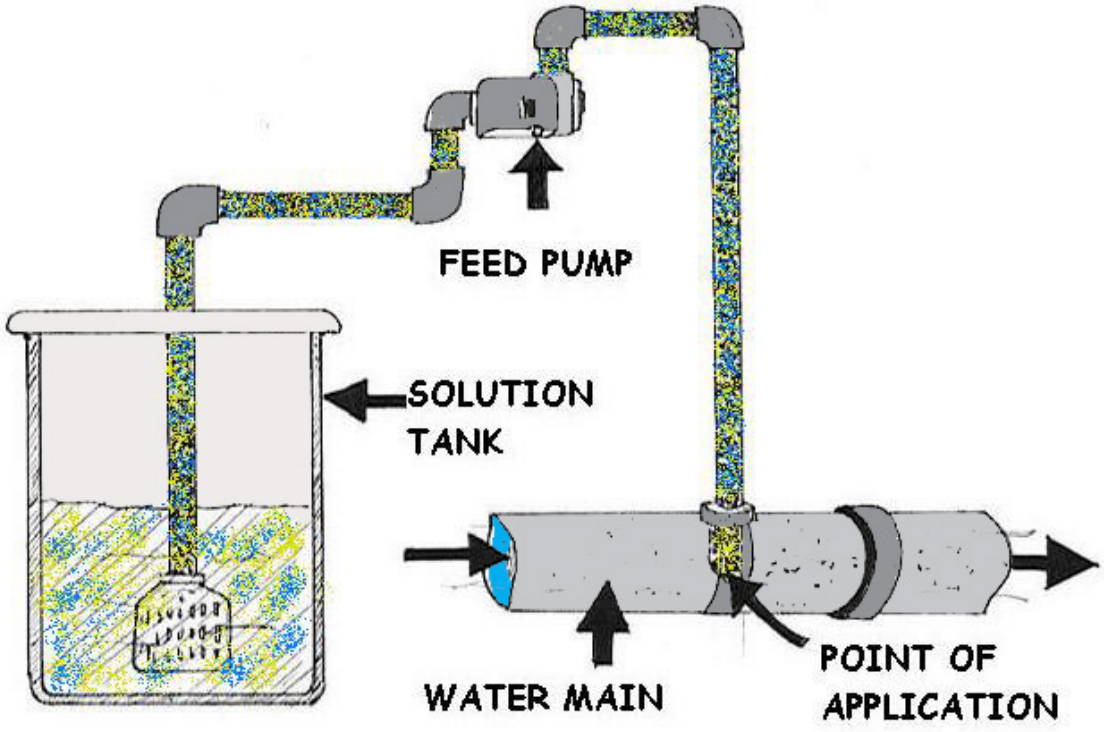


Hard to tell, but these are 1- ton chlorine gas containers. Notice the five gallon bucket of motor oil in the bottom photograph. Also notice that this photograph is the only eye wash station that we found during our inspection of 10 different facilities. Do you have an eye wash and emergency shower?



Chlorine Gas

Background
Chlorine gas is a pulmonary irritant with intermediate water solubility that causes acute damage in the upper and lower respiratory tract. Chlorine gas was first used as a chemical weapon at Ypres, France in 1915. Of the 70,552 American soldiers poisoned with various gasses in World War I, 1843 were exposed to chlorine gas. Approximately 10.5 million tons and over 1 million containers of chlorine are shipped in the U.S. each year.



Chlorine is a yellowish-green gas at standard temperature and pressure. It is extremely reactive with most elements. Because its density is greater than that of air, the gas settles low to the ground. It is a respiratory irritant, and it burns the skin. Just a few breaths of it are fatal. Cl2 gas does not occur naturally, although Chlorine can be found in a number of compounds.

Atomic Number: 17
Standard State: Gas at 298K
Melting Point: 171.6K (-101.5 C)
Boiling Point: 239.11K (-34.04 C)
Density: N/A
Molar Volume: 17.39 cm^3
Electronegativity: 3.16 Pauling Units
Crystal Structure: The Diatomic Chlorine molecules arrange themselves in an orthorhombic structure.

Pathophysiology
Chlorine is a greenish-yellow, noncombustible gas at room temperature and atmospheric pressure. The intermediate water solubility of chlorine accounts for its effect on the upper airway and the lower respiratory tract. Exposure to chlorine gas may be prolonged because its moderate water solubility may not cause upper airway symptoms for several minutes. In addition, the density of the gas is greater than that of air, causing it to remain near ground level and increasing exposure time.

The odor threshold for chlorine is approximately 0.3-0.5 parts per million (**ppm**); however, distinguishing toxic air levels from permissible air levels may be difficult until irritative symptoms are present.

Mechanism of Activity
The mechanisms of the above biological activity are poorly understood and the predominant anatomic site of injury may vary, depending on the chemical species produced. Cellular injury is believed to result from the oxidation of functional groups in cell components, from reactions with tissue water to form hypochlorous and hydrochloric acid, and from the generation of free oxygen radicals. Although the idea that chlorine causes direct tissue damage by generating free oxygen radicals was once accepted, this idea is now controversial.

The cylinders on the right contain chlorine gas. The gas comes out of the cylinder through a gas regulator. The cylinders are on a scale that operators use to measure the amount used each day. The chains are used to prevent the tanks from falling over.



Chlorine gas is stored in vented rooms that have panic bar equipped doors. Operators have the equipment necessary to reduce the impact of a gas leak, but rely on trained emergency response teams to contain leaks.

Solubility Effects
Hydrochloric acid is highly soluble in water. The predominant targets of the acid are the epithelia of the ocular conjunctivae and upper respiratory mucus membranes.

Hypochlorous acid is also highly water soluble with an injury pattern similar to hydrochloric acid.

Hypochlorous acid may account for the toxicity of elemental chlorine and hydrochloric acid to the human body.

Early Response to Chlorine Gas
Chlorine gas, when mixed with ammonia, reacts to form chloramine gas. In the presence of water, chloramines decompose to ammonia and hypochlorous acid or hydrochloric acid.

The early response to chlorine exposure depends on the (1) concentration of chlorine gas, (2) duration of exposure, (3) water content of the tissues exposed, and (4) individual susceptibility.

Immediate Effects
The immediate effects of chlorine gas toxicity include acute inflammation of the conjunctivae, nose, pharynx, larynx, trachea, and bronchi. Irritation of the airway mucosa leads to local edema secondary to active arterial and capillary hyperemia.

Plasma exudation results in filling the alveoli with edema fluid, resulting in pulmonary congestion.

Pathological Findings
Pathologic findings are nonspecific. They include severe pulmonary edema, pneumonia, hyaline membrane formation, multiple pulmonary thromboses, and ulcerative tracheo-bronchitis.

The hallmark of pulmonary injury associated with chlorine toxicity is pulmonary edema, manifested as hypoxia. Non-cardiogenic pulmonary edema is thought to occur when there is a loss of pulmonary capillary integrity.



1-ton chlorine gas containers.

Unbelievably, this facility uses between 20 and 30 containers per day. 3 shifts are required to handle the chlorine change outs each day. Normally this is a slow boring job if everything is working properly. This crew is also responsible for any and all chlorine leaks. Even when the fire crews show up for a Cl_2 leak, the fire crews are too scared to touch a leaking cylinder and will ask the water treatment personnel to fix the leak.

Chemical Equations, Oxidation States, and Balancing of Equations

Before we breakdown chlorine and other chemicals, let's start with this review of basic chemical equations.

Beginning
The common chemical equation could be A + B --> C + D. This is chemical A + chemical B, the two reacting chemicals will go to products C + D, etc.

Oxidation
The term "oxidation" originally meant a reaction in which oxygen combines chemically with another substance, but its usage has long been broadened to include any reaction in which electrons are transferred.

Oxidation and reduction always occur simultaneously (redox reactions), and the substance which gains electrons is termed the oxidizing agent. For example, cupric ion is the oxidizing agent in the reaction: Fe (metal) + Cu++ --> Fe++ + Cu (metal); here, two electrons (negative charges) are transferred from the iron atom to the copper atom; thus the iron becomes positively charged (is oxidized) by loss of two electrons, while the copper receives the two electrons and becomes neutral (is reduced).

Electrons may also be displaced within the molecule without being completely transferred away from it. Such partial loss of electrons likewise constitutes oxidation in its broader sense and leads to the application of the term to a large number of processes, which at first sight might not be considered to be oxidation. Reaction of a hydrocarbon with a halogen, for example, CH_4 + 2 Cl --> CH_3Cl + HCl, involves partial oxidation of the methane; halogen addition to a double bond is regarded as an oxidation.

Dehydrogenation is also a form of oxidation; when two hydrogen atoms, each having one electron, are removed from a hydrogen-containing organic compound by a catalytic reaction with air or oxygen, as in oxidation of alcohol to aldehyde.

Oxidation Number
The number of electrons that must be added to or subtracted from an atom in a combined state to convert it to the elemental form; i.e., in barium chloride ($BaCl_2$) the oxidation number of barium is +2 and of chlorine is -1. Many elements can exist in more than one oxidation state.

Now, let us look at some common ions. An ion is the reactive state of the chemical, and is dependent on its place within the periodic table.

Have a look at the "periodic table of the elements". It is arranged in columns of elements, there are 18 columns. You can see column one, H, Li, Na, K, etc. These all become ions as H^+, Li^+, K^+, etc. The next column, column 2, Be, Mg, Ca etc. become ions Be^{2+}, Mg^{2+}, Ca^{2+}, etc. Column 18, He, Ne, Ar, Kr are inert gases. Column 17, F, Cl, Br, I, ionize to a negative F^-, Cl^-, Br^-, I^-, etc.

What you now need to do is memorize the table of common ions, both positive ions and negative ions.

Table of Common Ions
Positive Ions

Valency 1		Valency 2		Valency 3	
lithium	Li^+	magnesium	Mg^{2+}	aluminum	Al^{3+}
sodium	Na^+	calcium	Ca^{2+}	iron III	Fe^{3+}
potassium	K^+	strontium	Sr^{2+}	chromium	Cr^{3+}
silver	Ag^+	barium	Ba^{2+}		
hydronium	H_3O^+	copper II	Cu^{2+}		
(or hydrogen)	H^+	lead II	Pb^{2+}		
ammonium	NH_4^+	zinc	Zn^{2+}		
copper I	Cu^+	manganese II	Mn^{2+}		
mercury I	Hg^+	iron II	Fe^{2+}		
		tin II	Sn^{2+}		

Negative Ions

Valency 1		Valency 2		Valency 3	
fluoride	F^-	oxide	O^{2-}	phosphate	PO_4^{3-}
chloride	Cl^-	sulfide	S^{2-}		
bromide	Br^-	carbonate	CO_3^{2-}		
iodide	I^-	sulfate	SO_4^{2-}		
hydroxide	OH^-	sulfite	SO_3^{2-}		
nitrate	NO_3^-	dichromate	$Cr_2O_7^-$		
bicarbonate	HCO_3^-	chromate	CrO_4^{2-}		
bisulphate	HSO_4^-	oxalate	$C_2O_4^{2-}$		
nitrite	NO_2^-	thiosulfate	$S_2O_3^{2-}$		
chlorate	ClO_3^-	tetrathionate	$S_4O_6^{2-}$		
permanganate	MnO_4^-	monohydrogen phosphate	HPO_4^{2-}		
hypochlorite	OCl^-				
dihydrogen phosphate	$H_2PO_4^-$				

Positive ions will react with negative ions, and vice versa. This is the start of our chemical reactions. For example:
$Na^+ + OH^- \rightarrow NaOH$ (sodium hydroxide)
$Na^+ + Cl^- \rightarrow NaCl$ (salt)
$3H^+ + PO_4^{3-} \rightarrow H_3PO_4$ (phosphoric acid)
$2Na^+ + S_2O_3^{2-} \rightarrow Na_2S_2O_3$

You will see from these examples, that if an ion of one (+), reacts with an ion of one (-) then the equation is balanced. However, an ion like PO_4^{3-} (phosphate) will require an ion of 3+ or an ion of one (+) (but needs three of these) to neutralize the 3- charge on the phosphate. So, what you are doing is balancing the charges (+) or (-) to make them zero, or cancel each other out.

For example, since aluminum exists in its ionic state as Al^{3+}, it will react with many negatively charged ions; for example: Cl^-, OH^-, SO_4^{2-}, PO_4^{3-}.

Let us do these examples and balance them.
$Al^{3+} + Cl^- \rightarrow AlCl$ **(incorrect)**
$Al^{3+} + 3Cl^- \rightarrow AlCl_3$ **(correct)**

How did we work this out?
Al^{3+} has three positives (3+)
Cl^- has one negative (-)
It will require **3 negative charges** to cancel out the **3 positive charges** on the aluminum (Al^{3+}).

When the **left hand side** of the equation is written, to balance the number of chlorine's (Cl^-) required, the number 3 is placed in front of the ion concerned, in this case Cl^-, becomes $3Cl^-$.

On the **right hand side** of the equation, where the ions have become a compound (a chemical compound), the number is transferred to after the relevant ion, Cl_3.

Another example:
$Al^{3+} + SO_4^{2-} \rightarrow AlSO_4$ (**incorrect**)
$2Al^{3+} + 3SO_4^{2-} \rightarrow Al_2(SO_4)_3$ (**correct**)

Let me give you an easy way of balancing:
Al is 3+
SO_4 is 2-
Simply transpose the number of positives (or negatives) for each ion, to the other ion, by placing this value of one ion, in front of the other ion. That is, Al^{3+} the 3 goes in front of the SO_4^{2-} as $3SO_4^{2-}$, and SO_4^{2-}, the 2 goes in front of the Al^{3+} to become $2Al^{3+}$. Then on the **right hand side** of the equation, this same number (now in front of each ion on the **left side** of the equation), is placed after each "ion" entity.

Let us again look at:
$Al^{3+} + SO_4^{2-} \rightarrow AlSO_4$ **(incorrect)**
$Al^{3+} + SO_4^{2-} \rightarrow Al_2(SO_4)_3$ **(correct)**
Put the three from the Al in front of the SO_4^{2-} and the 2 from the SO_4^{2-} in front of the Al^{3+}.
Equation becomes:
$2Al^{3+} + 3SO_4^{2-} \rightarrow Al_2(SO_4)_3$. You simply place the valency of one ion, as a whole number, in front of the other ion, and vice versa.

Remember to encase the SO_4 in brackets. **Why?** Because we are dealing with the sulfate ion, SO_4^{2-}, and it is this ion that is 2- charged (not just the O_4), so we have to ensure that the "ion" is bracketed. Now to check, the 2 times $3^+ = 6^+$, and 3 times $2^- = 6^-$. We have equal amounts of positive ions, and equal amounts of negative ions.

Another example:
NaOH + HCl --> ?
Na is Na^+, OH is OH^-, so this gave us NaOH. Originally, the one positive canceled the one negative.

HCl is $H^+ + Cl^-$, this gave us HCl.

Reaction is going to be the Na^+ reacting with a negatively charged ion. This will have to be the chlorine, Cl^-, because at the moment the Na^+ is tied to the OH^-. **So:** $Na^+ + Cl^-$ --> NaCl
The H+ from the HCl will react with a negative (-) ion this will be the OH^- from the NaOH.
So: $H^+ + OH^-$ --> H_2O (water).

The complete reaction can be written:
NaOH + HCl --> NaCl + H_2O. We have **equal amounts** of all atoms **each side** of the equation, so the equation is **balanced**.
or
$Na^+OH^- + H^+Cl^-$ --> $Na^+Cl^- + H^+OH^-$

Something More Difficult:
$Mg(OH)_2 + H_3PO_4$ --> ? (equation on left **not** balanced)
Mg^{2+} $2OH^- + 3H^+PO_4^{3-}$ --> ? (equation on left **not** balanced), so let us rewrite the equation in **ionic form**.

The Mg^{2+} **needs to react with a negatively charged ion**, this will be the PO_4^{3-},
so: $3Mg^{2+} + 2PO_4^{3-}$ --> $Mg_3(PO_4)_2$
(**Remember** the **swapping** of the positive or negative charges on the ions in the **left side** of the equation, and placing it in front of each ion, and then placing this number after each ion on the **right side** of the equation)

What is left is the H^+ from the H_3PO_4 and this will react with a negative ion, we only have the OH^- from the $Mg(OH)_2$ left for it to react with.
$6H^+ + 6OH^-$ --> $6H_2O$

Where did I get the 6 from? When I balanced the Mg^{2+} with the PO_4^{3-}, the equation became $3Mg^{2+} + 2PO_4^{3-}$ --> $Mg_3(PO_4)_2$

Therefore, I must have required $3Mg(OH)_2$ to begin with, and $2H_3PO_4$, (because we originally had $(OH)_2$ attached to the Mg, and H_3 attached to the PO_4. I therefore have $2H_3$ reacting with $3(OH)_2$. We have to write this, on the **left side** of the equation, as $6H^+ + 6OH^-$ because we need it in ionic form.
The equation becomes:
$6H^+ + 6OH^-$ --> $6H_2O$

The full equation is now balanced and is:
$3Mg(OH)_2 + 2H_3PO_4$ --> $Mg_3(PO_4)_2 + 6H_2O$
I have purposely split the equation into segments of reactions. This is showing you which ions are reacting with each other. Once you get the idea of equations you will not need this step.

The balancing of equations is simple. You need to learn the valency of the common ions (see tables). The rest is pure mathematics; you are balancing valency charges, positives versus negatives. You have to have the **same number** of **negatives**, or **positives**, each side of the equation, and the **same number** of **ions** or **atoms** each side of the equation.

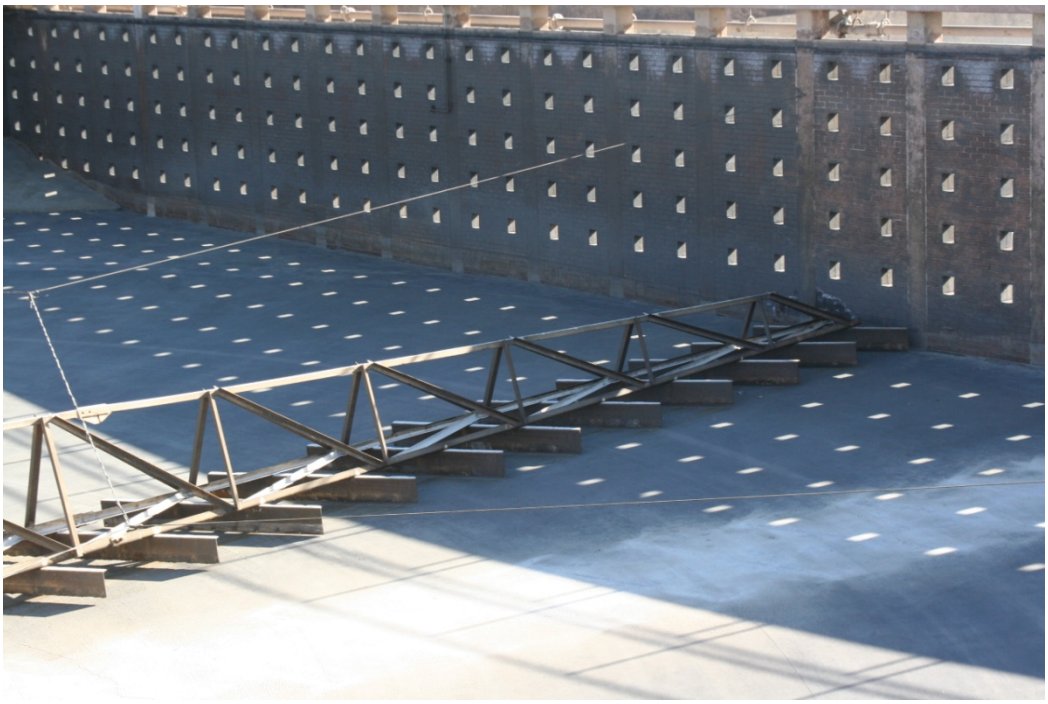
If one ion, example Al^{3+}, (3 positive charges) reacts with another ion, example OH^- (one negative ion) then we require 2 more negatively charged ions (in this case OH^-) to counteract the 3 positive charges the Al^{3+} contains.

Take my earlier hint, place the 3 from the Al^{3+} in front of the OH^-, now reads $3OH^-$, place the 1 from the hydroxyl OH^- in front of the Al^{3+}, now stays the same, Al^{3+} (the 1 is **never** written in chemistry equations).
$Al^{3+} + 3OH^- \rightarrow Al(OH)_3$

The 3 is simply written in front of the OH^-, a recognized ion, there are no brackets placed around the OH^-. On the right hand side of the equation, all numbers in front of each ion on the left hand side of the equation are placed after each same ion on the right side of the equation. Brackets are used in the right side of the equation because the result is a compound. Brackets are also used for compounds (reactants) in the left side of equations, as in $3Mg(OH)_2 + 2H_3PO_4 \rightarrow ?$



The basic routes for a chemical to enter the body in a laboratory setting are: inhalation, skin and eye contact, ingestion, and injection. The prevention of entry by one of these routes can be accomplished by control mechanisms such as engineering controls, personal protective equipment, and administrative controls. Each route can be minimized by a variety of control measures depending on the hazard and operation.



Top- Baffles for slowing water down prior to settling.
Bottom- Rectangular sedimentation basins



Chemistry of Chlorination

Chlorine can be added as sodium hypochlorite, calcium hypochlorite or chlorine gas. When any of these is added to water, chemical reactions occur as these equations show:

Cl 2 + H 2 O → HOCl + HCl
(chlorine gas) (water) (hypochlorous acid) (hydrochloric acid)

CaOCl + H 2 O → 2HOCl + Ca(OH)
(calcium hypochlorite) (water) (hypochlorous acid) (calcium hydroxide)

NaOCl + H 2 O → HOCl + Na(OH)
(sodium hypochlorite) (water) (hypochlorous acid) (sodium hydroxide)

All three forms of chlorine produce hypochlorous acid (HOCl) when added to water. Hypochlorous acid is a weak acid but a strong disinfecting agent. The amount of hypochlorous acid depends on the pH and temperature of the water. Under normal water conditions, hypochlorous acid will also chemically react and break down into a hypochlorite ion.

(OCl -): HOCl H + + OCl – Also expressed HOCl → H + + OCl –
(hypochlorous acid) (hydrogen) (hypochlorite ion)
The hypochlorite ion is a much weaker disinfecting agent than hypochlorous acid, about 100 times less effective.

Let's now look at how pH and temperature affect the ratio of hypochlorous acid to hypochlorite ions. As the temperature is decreased, the ratio of hypochlorous acid increases. Temperature plays a small part in the acid ratio. Although the ratio of hypochlorous acid is greater at lower temperatures, pathogenic organisms are actually harder to kill. All other things being equal, higher water temperatures and a lower pH are more conducive to chlorine disinfection.

Types of Residual

If water were pure, the measured amount of chlorine in the water should be the same as the amount added. But water is not 100% pure. There are always other substances (interfering agents) such as iron, manganese, turbidity, etc., which will combine chemically with the chlorine.

This is called the ***chlorine demand***. Naturally, once chlorine molecules are combined with these interfering agents, they are not capable of disinfection. It is free chlorine that is much more effective as a disinfecting agent.

So let's look now at how free, total, and combined chlorine are related. When a chlorine residual test is taken, either a total or a free chlorine residual can be read.

Total residual is all chlorine that is available for disinfection.

Total chlorine residual = free + combined chlorine residual.

Free chlorine residual is a much stronger disinfecting agent. Therefore, most water regulating agencies will require that your daily chlorine residual readings be of free chlorine residual.

Break-point chlorination is where the chlorine demand has been satisfied; any additional chlorine will be considered ***free chlorine*.**

Residual Concentration/Contact Time (CT) Requirements

Disinfection to eliminate fecal and coliform bacteria may not be sufficient to adequately reduce pathogens such as Giardia or viruses to desired levels. Use of the ***"CT"*** disinfection concept is recommended to demonstrate satisfactory treatment, since monitoring for very low levels of pathogens in treated water is analytically very difficult.

The CT concept, as developed by the United States Environmental Protection Agency (Federal Register, 40 CFR, Parts 141 and 142, June 29, 1989), uses the combination of disinfectant residual concentration (mg/L) and the effective disinfection contact time (in minutes) to measure effective pathogen reduction. The residual is measured at the end of the process, and the contact time used is the T10 of the process unit (time for 10% of the water to pass). CT= Contact time.

CT = Concentration (mg/L) x Time (minutes)



500-pound chlorine gas container and 150-pound Cl_2 gas cylinders. The 1/2 ton is on a scale. Cylinders stand up-right and containers on their sides.

The effective reduction in pathogens can be calculated by reference to standard tables of required CTs (see Appendices A and B).

Required Giardia/Virus Reduction
All surface water treatment systems shall ensure a minimum reduction in pathogen levels: 3-log reduction in Giardia and 4-log reduction in viruses. These requirements are based on unpolluted raw water sources with Giardia levels of = 1 cyst/100 L, and a finished water goal of 1 cyst/100,000 L (equivalent to 1 in 10,000 risk of infection per person per year). Higher raw water contamination levels may require greater removals as shown on Table 4.1.

TABLE 4.1
LEVEL OF GIARDIA REDUCTION
Raw Water Giardia Levels*
Recommended Giardia Log Reduction
< 1 cyst/100 L 3-log
1 cyst/100 L - 10 cysts/100 L 3-log - 4-log
10 cysts/100 L - 100 cysts/100 L 4-log - 5-log
> 100 cysts/100 L > 5-log
*Use geometric means of data to determine raw water Giardia levels for compliance.

Required CT Value
Required CT values are dependent on pH, residual concentration, temperature, and the disinfectant used. The tables attached to Appendices A and B shall be used to determine the required CT.

Calculation and Reporting of CT Data
Disinfection CT values shall be calculated daily, using either the maximum hourly flow and the disinfectant residual at the same time, or by using the lowest CT value if it is calculated more frequently. Actual CT values are then compared to required CT values.

Results shall be reported as a reduction Ratio, along with the appropriate pH, temperature, and disinfectant residual. The reduction Ratio must be greater than 1.0 to be acceptable. Users may also calculate and record actual log reductions. **Reduction Ratio = CT actual ÷ CT required**



Here is an operator checking for leaks with Ammonia. If there is a Cl_2 leak, you will be able to see a white smoke. Even if you cannot smell the chlorine, the ammonia will find it.

Using DPD Method for Chlorine Residuals
N, N – diethyl-p-phenylenediame



Small portable chlorine measuring kit. The redder the mixture the "hotter" or stronger the chlorine in solution.

Measuring Chlorine Residual

Chlorine residual is the amount of chlorine remaining in water that can be used for disinfection. A convenient, simple and inexpensive way to measure chlorine residual is to use a small portable kit with pre-measured packets of chemicals that are added to water. (Make sure you buy a test kit using the ***DPD method***, and not the outdated orthotolodine method.)

Chlorine test kits are very useful in adjusting the chlorine dose you apply. You can measure what chlorine levels are being found in your system (especially at the far ends).

Free chlorine residuals need to be checked and recorded daily. These results should be kept on file for a health or regulatory agency inspection during a regular field visit.

The most accurate method for determining chlorine residuals is to use the laboratory amperometric titration method.

Chlorine (DDBP)

Today, most of our drinking water supplies are free of the micro-organisms — viruses, bacteria, and protozoa — that cause serious and life-threatening diseases, such as cholera and typhoid fever. This is largely due to the introduction of water treatment, particularly chlorination, at the turn of the century.

Living cells react with chlorine and reduce its concentration while they die. Their organic matter and other substances that are present convert to chlorinated derivatives, some of which are effective killing agents. Chlorine present as Cl, HOCl, and OCl^- is called ***free available chlorine*** and that which is bound but still effective is ***combined chlorine***. A particularly important group of compounds with combined chlorine is the chloramines formed by reactions with ammonia.

One especially important feature of disinfection using chlorine is the ease of overdosing to create a "**residual**" concentration. There is a constant danger that safe water leaving the treatment plant may become contaminated later. There may be breaks in water mains, loss of pressure that permits an inward leak, or plumbing errors. This residual concentration of chlorine provides some degree of protection right to the water faucet. With free available chlorine, a typical residual is from 0.1 to 0.5 ppm. Because chlorinated organic compounds are less effective, a typical residual is 2 ppm for combined chlorine.

There will be no chlorine residual unless there is an excess over the amount that reacts with the organic matter present. However, reaction kinetics complicates interpretation of chlorination data. The correct excess is obtained in a method called **"*Break Point Chlorination* ".**

Chlorine By-Products

Chlorination by-products are the chemicals formed when the chlorine used to kill disease-causing micro-organisms reacts with naturally occurring organic matter (i.e., decay products of vegetation) in the water. The most common chlorination by-products found in U.S. drinking water supplies are the trihalomethanes (**THMs**).

The Principal Trihalomethanes are:

Chloroform, bromodichloromethane, chlorodibromomethane, and bromoform. Other less common chlorination by-products includes the haloacetic acids and haloacetonitriles. The amount of THMs formed in drinking water can be influenced by a number of factors, including the season and the source of the water. For example, THM concentrations are generally lower in winter than in summer, because concentrations of natural organic matter are lower and less chlorine is required to disinfect at colder temperatures. THM levels are also low when wells or large lakes are used as the drinking water source, because organic matter concentrations are generally low in these sources. The opposite — high organic matter concentrations and high THM levels — is true when rivers or other surface waters are used as the source of the drinking water.

Health Effects

Laboratory animals exposed to very high levels of THMs have shown increased incidences of cancer. Also, several studies of cancer incidence in human populations have reported associations between long-term exposure to high levels of chlorination by-products and an increased risk of certain types of cancer.

For instance, a recent study conducted in the Great Lakes basin reported an increased risk of bladder and possibly colon cancer in people who drank chlorinated surface water for 35 years or more.

Possible relationships between exposure to high levels of THMs and adverse reproductive effects in humans have also been examined recently. In a California study, pregnant women who consumed large amounts of tap water containing elevated levels of THMs were found to have an increased risk of spontaneous abortion. The available studies on health effects do not provide conclusive proof of a relationship between exposure to THMs and cancer or reproductive effects, but indicate the need for further research to confirm their results and to assess the potential health effects of chlorination by-products other than THMs.



Chlorine storage room, notice the vents at the bottom and top. The bottom vent will allow the gas to ventilate because Cl_2 gas is heavier than air.

Risks and Benefits of Chlorine

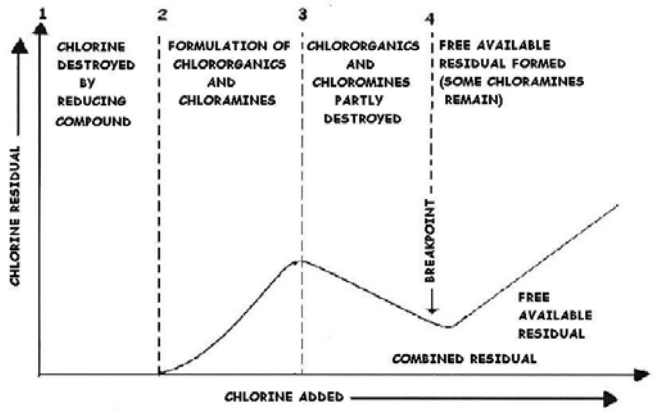
Current evidence indicates that the benefits of chlorinating our drinking water — reduced incidence of water-borne diseases — are much greater than the risks of health effects from THMs.

Although other disinfectants are available, chlorine continues to be the choice of water treatment experts. When used with modern water filtration practices, chlorine is effective against virtually all infective agents — bacteria, viruses, and protozoa. It is easy to apply, and most importantly, small amounts of chlorine remain in the water and continue to disinfect throughout the distribution system. This ensures that the water remains free of microbial contamination on its journey from the treatment plant to the consumer's tap.

A number of cities use ozone to disinfect their source water and to reduce THM formation. Although ozone is a highly effective disinfectant, it breaks down quickly, so that small amounts of chlorine or other disinfectants must be added to the water to ensure continued disinfection as the water is piped to the consumer's tap. Modifying water treatment facilities to use ozone can be expensive, and ozone treatment can create other undesirable by-products that may be harmful to health if they are not controlled (i.e., bromate).

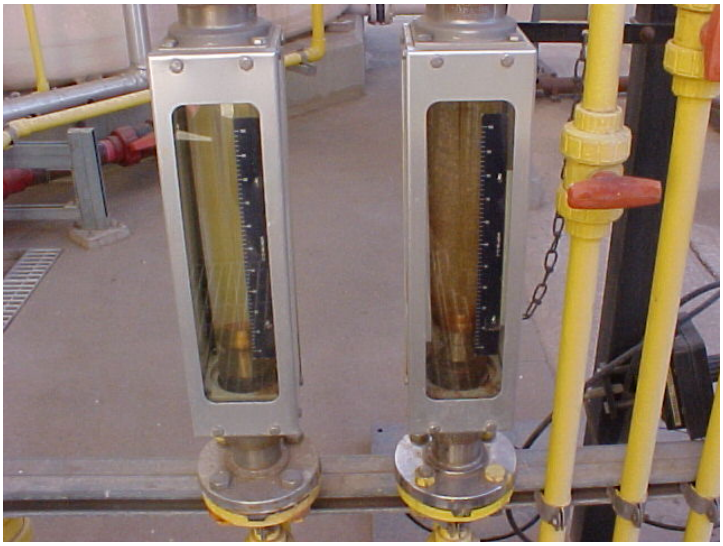
Examples of other disinfectants include chloramines and chlorine dioxide. Chloramines are weaker disinfectants than chlorine, especially against viruses and protozoa; however, they are very persistent and, as such, can be useful for preventing re-growth of microbial pathogens in drinking water distribution systems.

Chlorine dioxide can be an effective disinfectant, but it forms chlorate and chlorite, compounds whose toxicity has not yet been fully determined. Assessments of the health risks from these and other chlorine-based disinfectants and chlorination by-products are currently under way. In general, the preferred method of controlling chlorination by-products is removal of the naturally occurring organic matter from the source water so it cannot react with the chlorine to form by-products. THM levels may also be reduced through the replacement of chlorine with alternative disinfectants. A third option is removal of the by-products by adsorption on activated carbon beds. It is extremely important that water treatment plants ensure the methods used to control chlorination by-products do not compromise the effectiveness of water disinfection.



Chlorinator Parts

- **Ejector**
- **Check Valve Assembly**
- **Rate Valve**
- **Diaphragm Assembly**
- **Interconnection Manifold**
- **Rotameter Tube and Float**
- **Pressure Gauge**
- **Gas Supply**



Chlorine measurement devices or Rotameters.



Safety Information: There is a fusible plug on every chlorine gas cylinder. This metal plug will melt at 158 ^{o} to 165^{o} F. This is to prevent a build-up of excessive pressure and the possibility of cylinder rupture due to fire or high temperatures.

Chlorination Equipment Requirements

For all water treatment facilities, chlorine gas under pressure shall not be permitted outside the chlorine room. The chlorine room is the room where chlorine gas cylinders and/or ton containers are stored. Vacuum regulators shall also be located inside the chlorine room. The chlorinator, which is the mechanical gas proportioning equipment, may or may not be located inside the chlorine room.

For new and upgraded facilities, from the chlorine room, chlorine gas vacuum lines should be run as close to the point of solution application as possible. Injectors should be located to minimize the length of pressurized chlorine solution lines. A gas pressure relief system shall be included in the gas vacuum line between the vacuum regulator(s) and the chlorinator(s) to ensure that pressurized chlorine gas does not enter the gas vacuum lines leaving the chlorine room.

The gas pressure relief system shall vent pressurized gas to the atmosphere at a location that is not hazardous to plant personnel; the vent line should be run in such a manner that moisture collecting traps are avoided. The vacuum regulating valve(s) shall have positive shutdown in the event of a break in the downstream vacuum lines. As an alternative to chlorine gas, it is permissible to use hypochlorite with positive displacement pumping. Anti-siphon valves shall be incorporated in the pump heads or in the discharge piping.

Capacity
The chlorinator shall have the capacity to dose enough chlorine to overcome the demand and maintain the required concentration of the "***free***" or "***combined***" chlorine.

Methods of Control
The chlorine feed system shall be automatic proportional controlled, automatic residual controlled, or compound loop controlled. In the automatic proportional controlled system, the equipment adjusts the chlorine feed rate automatically in accordance with the flow changes to provide a constant pre-established dosage for all rates of flow. In the automatic residual controlled system, the chlorine feeder is used in conjunction with a chlorine residual analyzer which controls the feed rate of the chlorine feeders to maintain a particular residual in the treated water. In the compound loop control system, the feed rate of the chlorinator is controlled by a flow proportional signal and a residual analyzer signal to maintain particular chlorine residual in the water. Manual chlorine feed systems may be installed for groundwater systems with constant flow rate.



Standby Provision
As a safeguard against malfunction and/or shut-down, standby chlorination equipment having the capacity to replace the largest unit shall be provided. For uninterrupted chlorination, gas chlorinators shall be equipped with an automatic changeover system. In addition, spare parts shall be available for all chlorinators.

Weigh Scales
Scales for weighing cylinders shall be provided at all plants using chlorine gas to permit an accurate reading of total daily weight of chlorine used. At large plants, scales of the recording and indicating type are recommended. At a minimum, a platform scale shall be provided. Scales shall be of corrosion-resistant material. Read the scales daily and at the same time.

Securing Cylinders
All chlorine cylinders shall be securely positioned to safeguard against movement. Tag the cylinder "***empty***" and store upright and chained. Ton containers may not be stacked.

Chlorine Leak Detection
Automatic chlorine leak detection and related alarm equipment shall be installed at all water treatment plants using chlorine gas. Leak detection shall be provided for the chlorine rooms. Chlorine leak detection equipment should be connected to a remote audible and visual alarm system and checked on a regular basis to verify proper operation.

Leak detection equipment shall not automatically activate the chlorine room ventilation system in such a manner as to discharge chlorine gas. During an emergency if the chlorine room is unoccupied, the chlorine gas leakage shall be contained within the chlorine room itself in order to facilitate a proper method of clean-up.

Consideration should also be given to the provision of caustic soda solution reaction tanks for absorbing the contents of leaking one-ton cylinders where such cylinders are in use. Chlorine leak detection equipment may not be required for very small chlorine rooms with an exterior door (i.e., floor area less than $3m^2$).You can use a spray solution of Ammonia or a rag soaked with Ammonia to detect a small Cl_2 leak. If there is a leak, the ammonia will create a white colored smoke, Ammonium Chloride.

Safety Equipment
The facility shall be provided with personnel safety equipment to include the following: Respiratory equipment, safety shower, eyewash, gloves, eye protection, protective clothing, cylinder and/or ton repair kits.

Respiratory equipment shall be provided which has been approved under the Occupational Health and Safety Act, General Safety Regulation - Selection of Respiratory Protective Equipment. Equipment shall be in close proximity to the access door(s) of the chlorine room.

Chlorine Room Design Requirements
Where gas chlorination is practiced, the gas cylinders and/or the ton containers up to the vacuum regulators shall be housed in a gas-tight, well illuminated, corrosion resistant and mechanically ventilated enclosure. The chlorinator may or may not be located inside the chlorine room. The chlorine room shall be located at the ground floor level.

Ventilation
Gas chlorine rooms shall have entirely separate exhaust ventilation systems capable of delivering one complete air change per minute during periods of chlorine room occupancy only - there shall be no continuous ventilation. The air outlet from the room shall be 150 mm above the floor and the point of discharge located to preclude contamination of air inlets to buildings or areas used by people. The vents to the outside shall have insect screens. Air inlets should be louvered near the ceiling, the air being of such temperature as to not adversely affect the chlorination equipment.

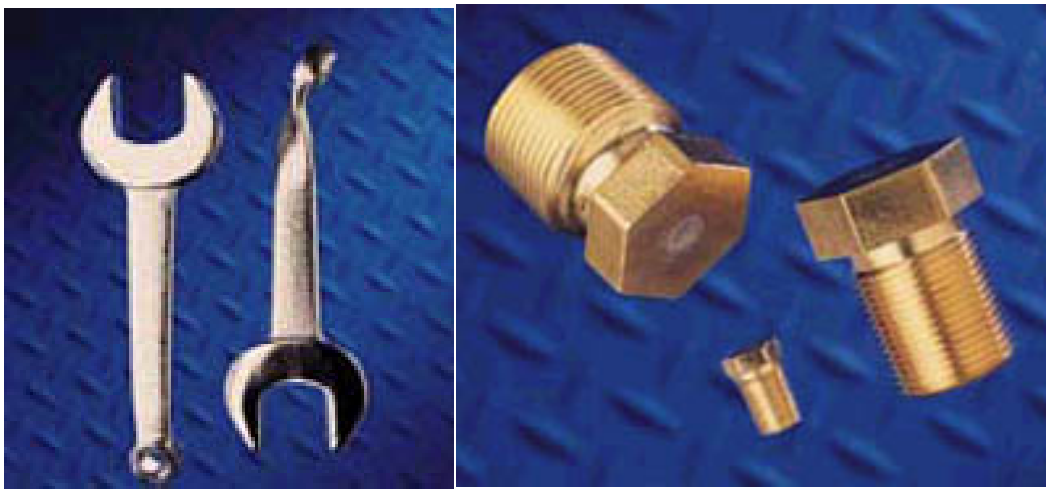
Separate switches for fans and lights shall be outside the room at all entrance or viewing points, and a clear wire-reinforced glass window shall be installed in such a manner as to allow the operator to inspect from the outside of the room.

Heating
Chlorine rooms shall have separate heating systems, if a forced air system is used to heat the building. Hot water heating system for the building will negate the need for a separate heating system for the chlorine room. The heat should be controlled at approximately 15^{o}C. Cylinders or containers shall be protected to ensure that the chlorine maintains its gaseous state when entering the chlorinator.

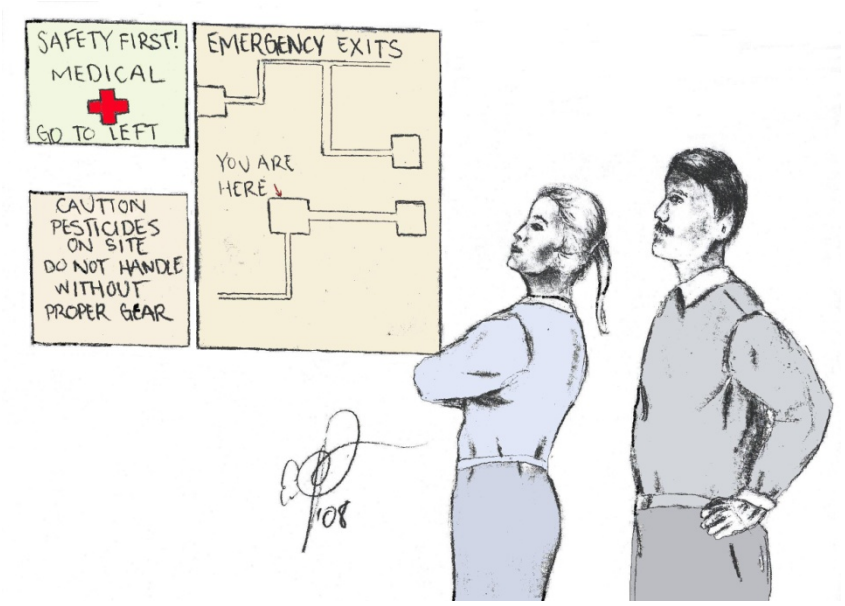
Access
All access to the chlorine room shall only be from the exterior of the building. Visual inspection of the chlorination equipment from inside may be provided by the installation of glass window(s) in the walls of the chlorine room. Windows should be at least 0.20 m2 in area, and be made of clear wire reinforced glass. There should also be a ***'panic bar'*** on the inside of the chlorine room door for emergency exit.

Storage of Chlorine Cylinders
If necessary, a separate storage room may be provided to simply store the chlorine gas cylinders, with no connection to the line. The chlorine cylinder storage room shall have access either to the chlorine room or from the plant exterior, and arranged to prevent the uncontrolled release of spilled gas. Chlorine gas storage room shall have provision for ventilation at thirty air changes per hour. Viewing glass windows and a panic button on the inside of door should also be provided. In very large facilities, entry into the chlorine rooms may be through a vestibule from outside.

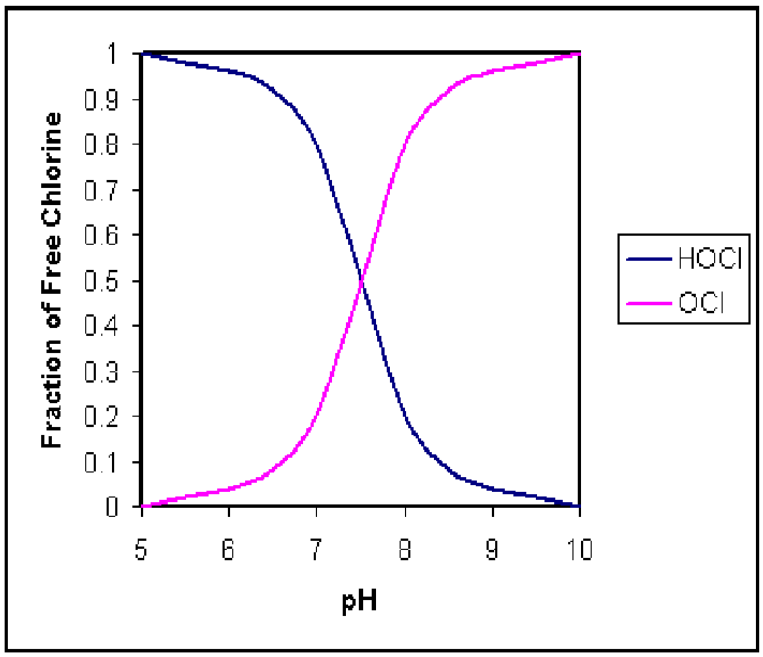
Scrubbers
For facilities located within residential or densely populated areas, consideration shall be given to provide scrubbers for the chlorine room.



Chlorine wrenches and chlorine cylinder fusible plugs. After a couple of months, the wrenches will start corroding from the acid created from the moisture and chlorine gas. In fact, everything will corrode, including your teeth.



Chlorine is a greenish-yellow, noncombustible gas at room temperature and atmospheric pressure. The intermediate water solubility of chlorine accounts for its effect on the upper airway and the lower respiratory tract. Exposure to chlorine gas may be prolonged, because its moderate water solubility may not cause upper airway symptoms for several minutes. In addition, the density of the gas is greater than that of air, causing it to remain near ground level and increasing exposure time. The odor threshold for chlorine is approximately 0.3-0.5 parts per million (ppm); however, distinguishing toxic air levels from permissible air levels may be difficult until irritative symptoms are present.



Troubleshooting Hypochlorination Problems

Problem
1. Chemical feed pump won't run.
2. Low chlorine residual at POE. (Point of Entry)
2. Low chlorine residual at POE.
3. Chemical feed pump won't prime.
4. Loss of prime

Possible Causes
1A. No power.
1B. Electrical problem with signal from well pump or flow sensor.
1C. Motor failure.
2A. Improper procedure for running chlorine residual test or expired chemical reagents.
2B. Pump not feeding an adequate quantity of chlorine.
2C. Change in raw water quality.
2D. Pump **air bound**.
2E. Chlorine supply tank empty.
2F. Reduced effectiveness of chlorine solution.
2G. Damaged suction or discharge lines. (cracks or crimps)
2H. Connection at point of **injection** clogged or leaking.
3A. Speed and stroke setting inadequate.
3B. Suction lift too high due to feed pump relocation.
3C. Discharge pressure too high.
3D. Suction fitting clogged.
3E. Trapped air in suction line.
3F. Suction line not submerged in solution.
4A. Solution tank empty.
4B. Air leaks in suction fittings.
4C. Foot valve not in vertical position.
4D. Air trapped in suction tubing.

Possible Solutions
1A. Check to see if plug is securely in place.
Insure that there is power to the outlet and control systems.
1B. Check pump motor starter. Bypass flow sensor to determine if pump will operate manually.
1C. Check manufacturer's information.
2A Check expiration date on **chemical reagents**. Check test procedure as described in test kit manual. Speed or stroke setting too low.
2B. Damaged **diaphragm** or suction leak.
2C. Test raw water for constituents that may cause increased chlorine demand. (i.e. iron, manganese, etc.)
2D. Check foot valve.
2E. Fill supply tank.
2F. Check date that chlorine was received. Sodium hypochlorite solution may lose effectiveness after 30 days. If that is the case, the feed rate must be increased to obtain the desired residual.
2G. Clean or repair lines with problems.

2H. Flush line and connection with mild acid such as **Acetic** or **Muriatic**. Replace any damaged parts that may be leaking.
3A. Check manufacturers' recommendations for proper settings to prime pump.
3B. Check maximum suction lift for pump and relocate as necessary.
3C. Check well pump discharge pressure.
Check pressure rating on chemical feed pump.
3D. Clean or replace screen.
3E. Insure all fittings are tight.
3F. Add chlorine solution to supply tank.
4A. Fill tank.
4B. Check for cracked fittings.
4C. Adjust foot valve to proper position.
4D. Check connections and fittings.



Chlorine Titration



These chlorine gas containers are unprotected and not fenced in. This is a huge security violation and a huge safety risk to the public. You can see a fence in the rear, but in reality, there was not complete fencing or any type of security in place.

Alternate Disinfectants

Chloramine
Chloramine is a very weak disinfectant for Giardia and virus reduction. It is recommended that it be used in conjunction with a stronger disinfectant. It is best utilized as a stable distribution system disinfectant.

In the production of chloramines, the ammonia residuals in the finished water, when fed in excess of the stoichiometric amount needed, should be limited to inhibit growth of nitrifying bacteria.

Chlorine Dioxide
Chlorine dioxide may be used for either taste and odor control or as a pre-disinfectant. Total residual oxidants (including chlorine dioxide and chlorite, but excluding chlorate) shall not exceed 0.30 mg/L during normal operation or 0.50 mg/L (including chlorine dioxide, chlorite and chlorate) during periods of extreme variations in the raw water supply.

Chlorine dioxide provides good Giardia and virus protection, but its use is limited by the restriction on the maximum residual of 0.5 mg/L ClO_2/chlorite/chlorate allowed in finished water. This limits usable residuals of chlorine dioxide at the end of a process unit to less than 0.5 mg/L.

Where chlorine dioxide is approved for use as an oxidant, the preferred method of generation is to entrain chlorine gas into a packed reaction chamber with a 25% aqueous solution of sodium chlorite ($NaClO_2$).

Warning
Dry sodium chlorite is explosive and can cause fires in feed equipment if leaking solutions or spills are allowed to dry out.

Ozone
Ozone is a very effective disinfectant for both Giardia and viruses. Ozone CT values(contact time) must be determined for the ozone basin alone; an accurate T10 value must be obtained for the contact chamber, residual levels measured through the chamber and an average ozone residual calculated.

Ozone does not provide a system residual and should be used as a primary disinfectant only in conjunction with free and/or combined chlorine.

Ozone does not produce chlorinated byproducts (such as trihalomethanes) but it may cause an increase in such byproduct formation if it is fed ahead of free chlorine; ozone may also produce its own oxygenated byproducts such as aldehydes, ketones, or carboxylic acids. Any installed ozonation system must include adequate ozone leak detection alarm systems, and an ozone off-gas destruction system.

Ozone may also be used as an oxidant for removal of taste and odor, or may be applied as a pre-disinfectant.

Amperometric Titration

The chlorination of water supplies and polluted waters serves primarily to destroy or deactivate disease-producing microorganisms. A secondary benefit, particularly in treating drinking water, is the overall improvement in water quality resulting from the reaction of chlorine with ammonia, iron, manganese, sulfide, and some organic substances.

Chlorination may produce adverse effects. Taste and odor characteristics of phenols and other organic compounds present in a water supply may be intensified. Potentially carcinogenic chloro-organic compounds such as chloroform may be formed.

Combined chlorine formed on chlorination of ammonia- or amine-bearing waters adversely affects some aquatic life. To fulfill the primary purpose of chlorination and to minimize any adverse effects, it is essential that proper testing procedures be used with a foreknowledge of the limitations of the analytical determination.

Chlorine applied to water in its molecular or hypochlorite form initially undergoes hydrolysis to form free chlorine consisting of aqueous molecular chlorine, hypochlorous acid, and hypochlorite ion. The relative proportion of these free chlorine forms is pH- and temperature-dependent. At the pH of most waters, hypochlorous acid and hypochlorite ion will predominate.

Free chlorine reacts readily with ammonia and certain nitrogenous compounds to form combined chlorine. With ammonia, chlorine reacts to form the chloramines: monochloramine, dichloramine, and nitrogen trichloride. The presence and concentrations of these combined forms depend chiefly on pH, temperature, initial chlorine-to-nitrogen ratio, absolute chlorine demand, and reaction time. Both free and combined chlorine may be present simultaneously. Combined chlorine in water supplies may be formed in the treatment of raw waters containing ammonia or by the addition of ammonia or ammonium salts.



Chlorinated wastewater effluents, as well as certain chlorinated industrial effluents, normally contain only combined chlorine. Historically the principal analytical problem has been to distinguish between free and combined forms of chlorine.

Hach's AutoCAT 9000™ Automatic Titrator is the newest solution to hit the disinfection industry – a comprehensive, bench top chlorine-measurement system that does it all: calibration, titration, calculation, real-time graphs, graphic print output, even electrode cleaning. More a laboratory assistant than an instrument, the AutoCAT 9000 gives you, high throughput, performs the titration and calculates concentration, all automatically:

- Forward titration: USEPA-accepted methods for free and total chlorine and chlorine dioxide with chlorite
- Back titration: USEPA-accepted method for total chlorine in wastewater
- Accurate, yet convenient, the easiest way to complete ppb-level amperometric titration

If you're dechlorinating, modifying your current disinfectant delivery, changing over to another chlorine species, or adjusting disinfection processes to meet new regulations, this is the workhorse system that yields the fast, accurate residual readings you need.

Additional Drinking Water Methods (Non-EPA) for Chemical Parameters

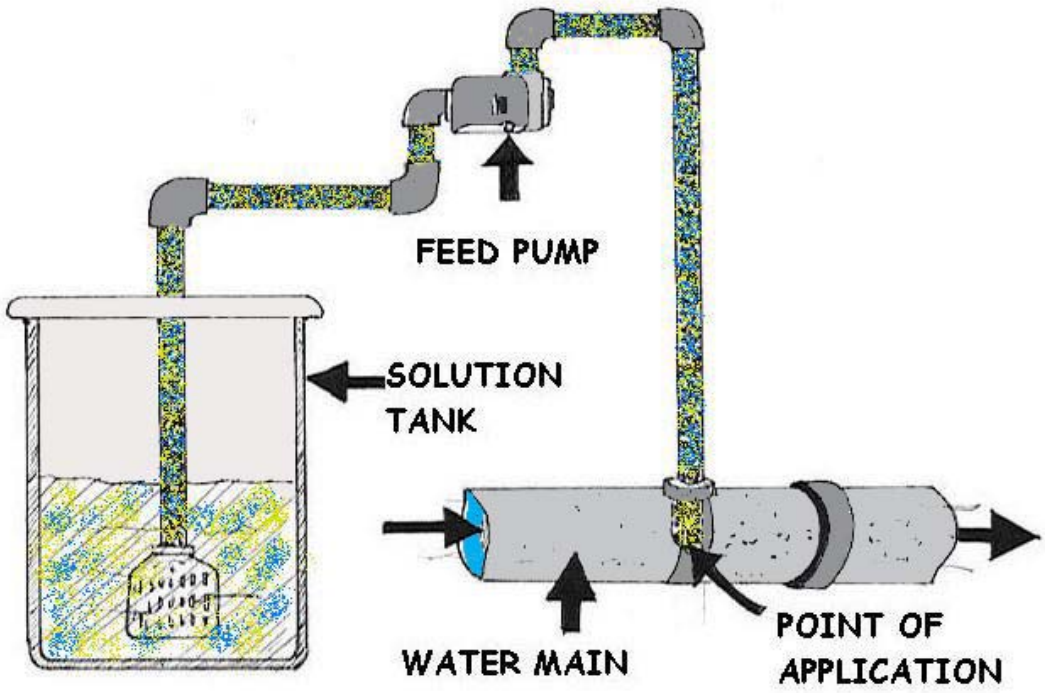
Method	Method Focus	Title	Location	Source
4500-Cl^- B	Chloride by Silver Nitrate Titration	Standard Methods for the Examination of Water and Wastewater, 18th & 19th Ed.	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl^- D	Chloride by Potentiometric Method	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl D	Chlorine Residual by Amperometric Titration (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl E	Chlorine Residual by Low Level Amperometric Titration (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl F	Chlorine Residual by DPD Ferrous Titration (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl G	Chlorine Residual by DPD Colorimetric Method (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl H	Chlorine Residual by Syringaldazine (FACTS) Method (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-Cl I	Chlorine Residual by Iodometric Electrode Technique (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-ClO_2 C	Chlorine Dioxide by the Amperometric Method I	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-ClO_2 D	Chlorine Dioxide by the DPD Method (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**
4500-ClO_2 E	Chlorine Dioxide by the Amperometric Method II (Stage 1 DBP use SM 19th Ed. only)	Standard Methods for the Examination of Water and Wastewater, 18th, 19th & 20th Editions	Included in Standard Methods	American Water Works Assn. **(AWWA)**

Chlorine Dioxide Methods

Most tests for chlorine dioxide rely upon its oxidizing properties. Consequently, numerous test kits are readily available that can be adapted to measure chlorine dioxide. In addition, new methods that are specific for chlorine dioxide are being developed. The following are the common analytical methods for chlorine dioxide:

	DPD glycine	**Chlorophenol Red**	**Direct Absorbance**	**Iodometric Titration**	**Amperometric Titration**
Method Type:	Colorimetric	Colorimetric	Colorimetric	Titrimetric	Titrimetric
How It Works	Glycine removes Cl_2; ClO_2 forms a pink color, whose intensity is proportional to the ClO_2 concentration.	ClO_2 bleaches chlorophenol red indicator. The degree of bleaching is proportional to the concentration of ClO_2.	The direct measurement of ClO_2 is determined between 350 and 450 nM.	Two aliquots are taken one is sparged with N_2 to remove ClO_2. KI is added to the other sample at pH7 and titrated to a colorless endpoint. The pH is lower to 2, the color allowed to reform and the titration continued. These titrations are repeated on the sparged sample.	
Range	0.5 to 5.0 ppm.	0.1 to 1.0 ppm	100 to 1000 ppm	> 1 ppm	< 1ppm
Interferences	Oxidizers	None	Color, turbidity	Oxidizers	
Complexity	Simple	Moderate	Simple	Moderate	High
Equipment Required	Spectrophotometer or Colorimeter			Titration equipment	Amperometric Titrator
EPA Status	Approved	Not approved	Not approved	Not approved	Approved
Recommendation	Marginal	Yes	Marginal	Yes	Marginal

Recommendations for Preparing/Handling/Feeding Sodium Hypochlorite Solutions



As a result of the pressures brought to bear by Health and Safety requirements, some users of gas have chosen to seek alternative forms of disinfectants for their water and wastewater treatment plants. One of these alternative forms is sodium hypochlorite (**NaOCl**)). This is often purchased commercially at 10 to 15% strength.

The handling and storage of NaOCl presents the plant with a new and sometimes unfamiliar, set of equipment installation configurations and operating conditions.

Product Stability The oxidizing nature of this substance means that it should be handled with extreme care. As NaOCl is relatively unstable, it degrades over time.

There are three ways in which NaOCl solutions degrade:
• Chlorate-forming reaction due to age, temperature, light, and minor reduction in pH.
• Oxygen-producing reaction that occurs when metals, such as iron, copper or nickel, or metal oxides are brought into contact with the solution.
• Chlorine-producing reaction when solution pH falls below 6.

There are many factors that affect the stability of a NaOCl solution:
• Initial solution strength.
• pH solution.
• Temperature of the solution.
• Exposure of the solution to sunlight.

Shock Chlorination — Well Maintenance
Shock chlorination is a relatively inexpensive and straightforward procedure used to control bacteria in water wells. Many types of bacteria can contaminate wells, but the most common are iron and sulfate-reducing bacteria.

Health Problems
Although not a cause of health problems in humans, bacteria growth will coat the inside of the well casing, water piping, and pumping equipment, creating problems such as:

- Reduced well yield
- Restricted water flow in distribution lines
- Staining of plumbing fixtures and laundry
- Plugging of water treatment equipment
- *"Rotten egg"* odor.

Bacteria may be introduced during drilling of a well or when pumps are removed for repair and laid on the ground. However, iron and sulfate-reducing bacteria (as well as other bacteria) can exist naturally in groundwater. A well creates a direct path for oxygen to travel into the ground where it would not normally exist. When a well is pumped, the water flowing in will also bring in nutrients that enhance bacterial growth.

Note: All iron staining problems are not necessarily caused by iron bacteria. The iron naturally present in the water can be the cause.

Ideal Conditions for Iron Bacteria
Water wells provide ideal conditions for iron bacteria. To thrive, iron bacteria require 0.5-4 mg/L of dissolved oxygen, as little as 0.01 mg/L dissolved iron and a temperature range of 5 to 15°C. Some iron bacteria use dissolved iron in the water as a food source.



Signs of Iron and Sulfate-Reducing Bacteria
There are a number of signs that indicate the presence of iron and sulfate-reducing bacteria. They include:

- Slime growth
- Rotten egg odor
- Increased staining.

Slime Growth
The easiest way to check a well and water system for iron bacteria is to examine the inside surface of the toilet flush tank. If you see a greasy slime or growth, iron bacteria are probably present. Iron bacteria leave this slimy by-product on almost every surface the water is in contact with.

Rotten Egg Odor
Sulfate-reducing bacteria can cause a rotten egg odor in water. Iron bacteria aggravate the problem by creating an environment that encourages the growth of sulfate-reducing bacteria in the well. Sulfate-reducing bacteria prefer to live underneath the slime layer that the iron bacteria form. Some of these bacteria produce hydrogen sulfide as a by-product, resulting in a "***rotten egg***" or sulfur odor in the water. Others produce small amounts of sulfuric acid which can corrode the well casing and pumping equipment.

Increased Staining Problems
Iron bacteria can concentrate iron in water sources with low iron content. It can create a staining problem where one never existed before or make an iron staining problem worse as time goes by. Use the following checklist to determine if you have an iron or sulfate-reducing bacteria problem. The first three are very specific problems related to these bacteria. The last two problems can be signs of other problems as well.

Checklist to Determine an Iron or Sulfate-Reducing Bacteria Problem

- Greasy slime on inside surface of toilet flush tank
- Increased red staining of plumbing fixtures and laundry
- Sulfur odor
- Reduced well yield
- Restricted water flow

Mixing a Chlorine Solution
Add a half gallon of bleach to a clean pail with about 3 gallons of water. This is generally sufficient to disinfect a 4 inch diameter well 100 feet deep or less. For wells greater than 100 feet deep or with a larger casing diameter, increase the amount of bleach proportionately.

If you have a dug well with a diameter greater than 18 inches, use 2 to 4 gallons of bleach added directly to the well. Please note that many dug wells are difficult or impossible to disinfect due to their unsanitary construction.

Shock Chlorination — Well Maintenance

Shock Chlorination Method
Shock chlorination is used to control iron and sulfate-reducing bacteria, and to eliminate fecal coliform bacteria in a water system. To be effective, shock chlorination must disinfect the following:

- The entire well depth
- The formation around the bottom of the well
- The pressure system
- Some water treatment equipment
- The distribution system.

To accomplish this, a large volume of super chlorinated water is siphoned down the well to displace all the water in the well and some of the water in the formation around the well.

Effectiveness of Shock Chlorination
With shock chlorination, the entire system (from the water-bearing formation, through the well-bore and the distribution system) is exposed to water which has a concentration of chlorine strong enough to kill iron and sulfate reducing bacteria. Bacteria collect in the pore spaces of the formation and on the casing or screened surface of the well. To be effective, you must use enough chlorine to disinfect the entire cased section of the well and adjacent water-bearing formation. The procedure described below does not completely eliminate iron bacteria from the water system, but it will hold it in check.

To control the iron bacteria, you may have to repeat the procedure each spring and fall as a regular maintenance procedure.

If your well has never been shock chlorinated or has not been done for some time, it may be necessary to use a stronger chlorine solution, applied two or three times, before you notice a significant improvement in the water. You might also consider hiring a drilling contractor to thoroughly clean and flush the well before chlorinating in order to remove any buildup on the casing. In more severe cases, the pump may have to be removed and chemical solutions added to the well and vigorous agitation carried out using special equipment. This is to dislodge and remove the bacterial slime, and should be done by a drilling contractor.

Shock Chlorination Procedure for Small Drilled Wells
A modified procedure is also provided for large diameter wells.

Caution: If your well is low-yielding or tends to pump any silt or sand, you must be very careful using the following procedure because over pumping may damage the well. When pumping out the chlorinated solution, monitor the water discharge for sediment.



Don't mix acids with chlorine. This is a dangerous practice.

Chlorine Exposure Limits

This information is often necessary to pass your certification exam.

*** OSHA PEL 1 PPM - IDLH 10 PPM and Fatal Exposure Limit 1,000 PPM**

The current Occupational Safety and Health Administration (**OSHA**) permissible exposure limit (**PEL**) for chlorine is 1 ppm (3 milligrams per cubic meter ($mg/m^{(3)}$)) as a ceiling limit. A worker's exposure to chlorine shall at no time exceed this ceiling level. *** IDLH 10 PPM**

Physical and chemical properties of chlorine: A yellowish green, nonflammable and liquefied gas with an unpleasant and irritating smell. Can be readily compressed into a clear, amber-colored liquid, a noncombustible gas, and a strong oxidizer. Solid chlorine is about 1.5 times heavier than water and gaseous chlorine is about 2.5 times heavier than air. Atomic number of chlorine is 17. Cl is the elemental symbol and Cl_2 is the chemical formula.

Monochloramine, dichloramine, and trichloramine are also known as Combined Available Chlorine. $Cl_2 + NH_4$.

HOCl and OCl-; the **OCL-** is the hypochlorite ion and both of these species are known as free available chlorine, they are the two main chemical species formed by chlorine in water. They are known by collectively as hypochlorous acid and the hypochlorite ion. When chlorine gas is added to water, it rapidly hydrolyzes. The chemical equations best describes this reaction is **$Cl_2 + H_2O$ --> H+ + Cl- + HOCl.** Hypochlorous acid is the most germicidal of the chlorine compounds with the possible exception of chlorine dioxide.



Yoke-type connectors should be used on a chlorine cylinder's valve, assuming that the threads on the valve may be worn.

The connection from a chlorine cylinder to a chlorinator should be replaced by using a new, approved gasket on the connector. Always follow your manufacturer's instructions.

On a 1 ton chlorine gas container, the chlorine pressure reducing valve should be located downstream of the evaporator when using an evaporator. This is the liquid chlorine supply line and it is going to be made into chlorine gas.

In water treatment, chlorine is added to the effluent before the contact chamber (before the clear well) for complete mixing. One reason for not adding it directly to the chamber is that the chamber has very little mixing due to low velocities.

Here are several safety precautions when using chlorine gas: in addition to protective clothing and goggles, chlorine gas should be used only in a well-ventilated area so that any leaking gas cannot concentrate. Emergency procedures in the case of a large uncontrolled chlorine leak are to: notify local emergency response team, warn and evacuate people in adjacent areas, and be sure that no one enters the leak area without adequate self-contained breathing equipment.

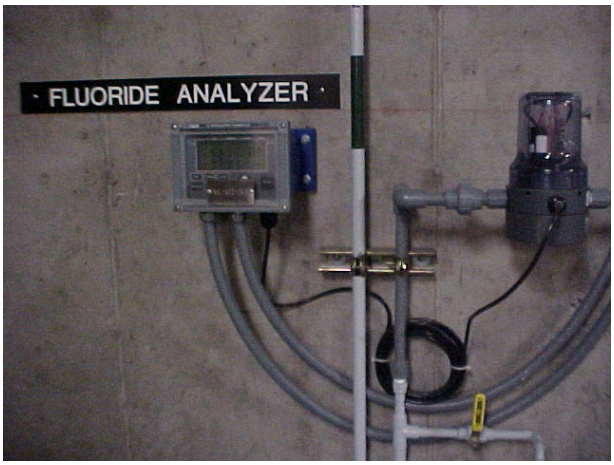
Here are several symptoms of chlorine exposure: Burning of eyes, nose, and mouth, coughing, sneezing, choking, nausea and vomiting, headaches and dizziness, fatal pulmonary edema, pneumonia and skin blisters. A little Cl_2 will corrode the teeth and then progress to throat cancer.



Approved method for storing a 150 - 200 pound chlorine cylinder: secure each cylinder in an upright position, attach the protective bonnet over the valve, and firmly secure each cylinder. Never store near heat. Always store the empty in an upright, secure position with proper signage. Bottom photograph Chlorine wrenches that have be near Chlorine gas. It takes just a few weeks for a very small undetectable chlorine gas leak to oxidize steel or human teeth.



Fluoride



Some water providers will add fluoride to the water to help prevent cavities in children. Too much fluoride will mottle the teeth.

Chemical Feed
The equipment used for feeding the fluoride to water shall be accurately calibrated before being placed in operation, and at all times shall be capable of maintaining a rate of feed within 5% of the rate at which the machine is set.

The following chemical feed practices apply:
1. Where a dry feeder of the volumetric or gravimetric type is used, a suitable weighing mechanism shall be provided to check the daily amount of chemical feed.
2. Hoppers should be designed to hold a 24 hour supply of the fluoride compound and designed such that the dust hazard to operators is minimized.
3. Vacuum dust filters shall be installed with the hoppers to prevent dust from rising into the room when the hopper is filled.
4. Dissolving chambers are required for use with dry feeders, and the dissolving chambers shall be designed such that at the required rate of feed of the chemical the solution strength will not be greater than 1/4 of that of a saturated solution at the temperature of the dissolving water. The construction material of the dissolving chamber and associated piping shall be compatible with the fluoride solution to be fed.
5. Solution feeders shall be of the positive displacement type and constructed of material compatible with the fluoride solution being fed.
6. The weight of the daily amount of fluoride fed to water shall be accurately determined.
7. Feeders shall be provided with anti-siphon valves on the discharge side. Wherever possible, positive anti-siphon breakers other than valves shall be provided.
8. A "***day tank***" capable of holding a 24 hour supply of solution should be provided.
9. All equipment shall be sized such that it will be operated in the 20 to 80 percent range of the scale, and be capable of feeding over the entire pumpage range of the plant.
10. Alarm signals are recommended to detect faulty operation of equipment; and,
11. The fluoride solution should be added to the water supply at a point where the fluoride will not be removed by any following treatment processes and where it will be mixed with the water. It is undesirable to inject the fluoride compound or solution directly on-line unless there are provisions for adequate mixing.

Metering
Metering of the total water to be fluoridated shall be provided, and the operation of the feeding equipment is to be controlled. Control of the feed rate shall be automatic/ proportional controlled, whereby the fluoride feed rate is automatically adjusted in accordance with the flow changes to provide a constant pre-established dosage for all rates of flow, or (2) automatic/ residual controlled, whereby a continuous automatic fluoride analyzer determines the residual fluoride level and adjusts the rate of feed accordingly, or compound loop controlled, whereby the feed rate is controlled by a flow proportional signal and residual analyzer signal to maintain a constant residual.

Alternate Compounds
Any one of the following fluoride compounds may be used:
1. Hydrofluosilicic acid,
2. Sodium fluoride or,
3. Sodium silicofluoride*.*
Other fluoride compounds may be used, if approved by the EPA.

Chemical Storage and Ventilation
The fluoride chemicals shall be stored separately from other chemicals, and the storage area shall be marked "***FLUORIDE CHEMICALS ONLY***". The storage area should be in close proximity to the feeder, kept relatively dry, and provided with pallets (if using bagged chemical) to allow circulation of air and to keep the containers off the floor.

Record of Performance
Accurate daily records shall be kept. These records shall include:
1. The daily reading of the water meter which controls the fluoridation equipment or that which determines the amount of water to which the fluoride is added.
2. The daily volume of water fluoridated.
3. The daily weight of fluoride compound in the feeder.
4. The daily weight of fluoride compound in stock.
5. The daily weight of the fluoride compound fed to the water; and,
6. The fluoride content of the raw and fluoridated water determined by laboratory analysis, with the frequency of measurement as follows:
    (i) treated water being analyzed continuously or once daily, and
    (ii) raw water being analyzed at least once a week.

Sampling
In keeping the fluoride records, the following sampling procedures are required:
1. A sample of raw water and a sample of treated water shall be forwarded to an approved independent laboratory for fluoride analysis once a month.
2. On new installations or during start-ups of existing installations, weekly samples of raw and treated water for a period of not less than four consecutive weeks.
3. In addition to the reports required, the EPA may require other information that is deemed necessary.

Fluoride Safety
The following safety procedures shall be maintained:
1. All equipment shall be maintained at a high standard of efficiency, and all areas and appliances shall be kept clean and free of dust. Wet or damp cleaning methods shall be employed wherever practicable.
2. Personal protective equipment shall be used during the clean-up, and appropriate covers shall be maintained over all fluoride solutions.
3. At all installations, safety features are to be considered and the necessary controls built into the installation to prevent an overdose of fluoride in the water. This shall be done either by use of day tanks or containers, anti-siphon devices, over-riding flow switches, sizing of pump and feeders, determining the length and duration of impulses, or other similar safety devices.
4. Safety features shall also be provided to prevent spills and overflows.
5. Individual dust respirators, chemical safety face shields, rubber gloves, and protective clothing shall be worn by all personnel when handling or being exposed to the fluoride dust.
6. Chemical respirators, rubber gloves, boots, chemical safety goggles and acid proof aprons shall be worn where acids are handled.
7. After use, all equipment shall be thoroughly cleaned and stored in an area free of fluoride dusts. Rubber articles shall be washed in water, and hands shall be washed after the equipment is stored; and,

8. All protective devices, whether for routine or emergency use, shall be inspected periodically and maintained in good operating condition.

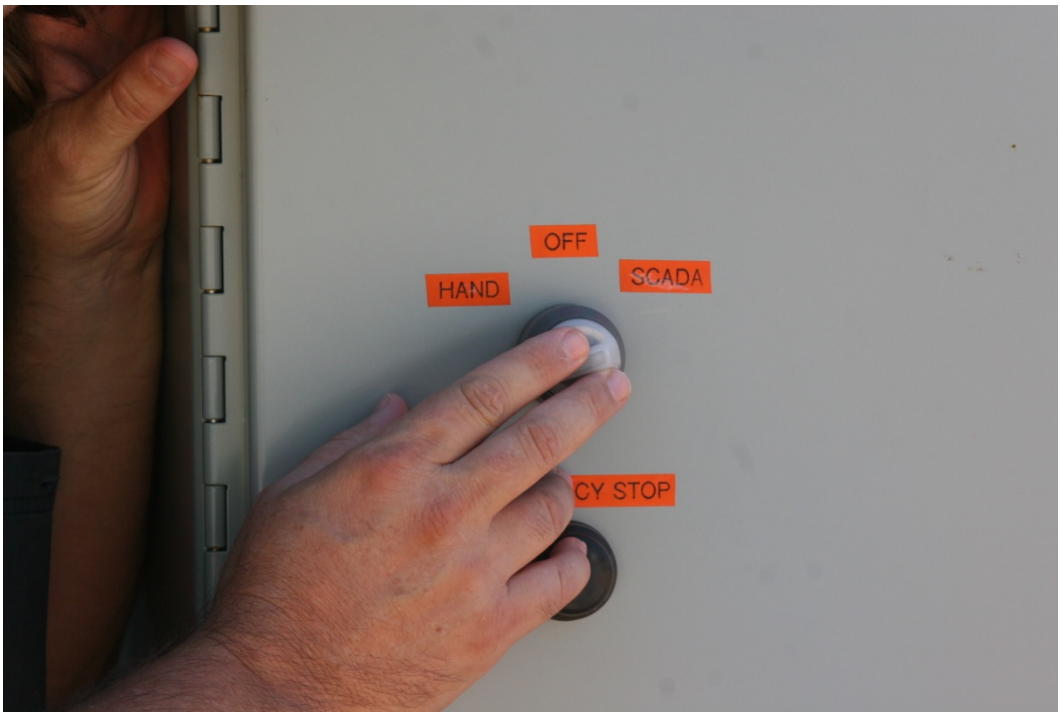
Repair and Maintenance
Upon notifying the appropriate local board of health, a fluoridation program may be discontinued when necessary to repair or replace equipment, but shall be placed in operation immediately after the repair replacement is complete. Records shall be maintained and submitted during the period that the equipment is not in operation.



Sample sink



Here is a small groundwater production well that utilizes a submersible pump instead of a vertical turbine pump. Bottom, a soft-start electrical panel.



Disinfection Summary

Chlorine

Upon adding chlorine to water, two chemical species, known together as free chlorine, are formed. These species, hypochlorous acid (HOCl, electrically neutral) and hypochlorite ion (OCl-, electrically negative), behave very differently. Hypochlorous acid is not only more reactive than the hypochlorite ion, but is also a stronger disinfectant and oxidant.

The ratio of hypochlorous acid to hypochlorite ion in water is determined by the pH. At low pH (higher acidity), hypochlorous acid dominates while at high pH hypochlorite ion dominates. Thus, the speed and efficacy of chlorine disinfection against pathogens may be affected by the pH of the water being treated. Fortunately, bacteria and viruses are relatively easy targets of chlorination over a wide range of pH. However, treatment operators of surface water systems treating raw water contaminated by the parasitic protozoan Giardia may take advantage of the pH-hypochlorous acid relationship and adjust the pH to be effective against Giardia, which is much more resistant to chlorination than either viruses or bacteria.

Another reason for maintaining a predominance of hypochlorous acid during treatment has to do with the fact that pathogen surfaces carry a natural negative electrical charge. These surfaces are more readily penetrated by the uncharged, electrically neutral hypochlorous acid than the negatively charged hypochlorite ion. Moving through slime coatings, cell walls and resistant shells of waterborne microorganisms, hypochlorous acid effectively destroys these pathogens. Water is made microbiologically safe as pathogens either die or are rendered incapable of reproducing. A typical bacterium has a negatively charged slime coating on its exterior cell wall, which is effectively penetrated by electrically neutral hypochlorous acid, favored by lower pH's.

Factors in Chlorine Disinfection: Concentration and Contact Time

In an attempt to establish more structured operating criteria for water treatment disinfection, the CXT concept came into use in 1980. Based on the work of several researchers, CXT values [final free chlorine concentration (mg/L) multiplied by minimum contact time (minutes)], offer water operators guidance in computing an effective combination of chlorine concentration and chlorine contact time required to achieve disinfection of water at a given temperature. The CXT formula demonstrates that if an operator chooses to decrease the chlorine concentration, the required contact time must be lengthened. Similarly, as higher strength chlorine solutions are used, contact times may be reduced (Connell, 1996).

Chloramines

Chloramines are chemical compounds formed by combining a specific ratio of chlorine and ammonia in water. Because chloramines are relatively weak as a disinfectant, they are almost never used as a primary disinfectant. Chloramines provide a durable residual, and are often used as a secondary disinfectant for long distribution lines and where free chlorine demand is high. Chloramines may also be used instead of chlorine in order to reduce chlorinated byproduct formation and to remove some taste and odor problems.

Advantages

- Reduced formation of THMs, HAAs
- Will not oxidize bromide to bromine forming brominated byproducts
- More stable residual than free chlorine
- Excellent secondary disinfectant, has been found to be better than free chlorine at controlling coliform bacteria and biofilm growth
- Lower taste and odor than free chlorine

Limitations

- Weak disinfectant and oxidant
- Requires shipment and handling of ammonia or ammonia compounds as well as chlorinating chemicals
- Ammonia is toxic to fish, and may pose problems for aquarium owners
- Will cause problems for kidney dialysis if not removed from water

Chlorine Dioxide

Chlorine dioxide (ClO_2) is generated on-site at water treatment facilities. In most generators sodium chlorite and elemental chlorine are mixed in solution, which almost instantaneously forms chlorine dioxide. Chlorine dioxide characteristics are quite different from chlorine. In solution it is a dissolved gas, which makes it largely unaffected by pH but volatile and relatively easily stripped from solution. Chlorine dioxide is also a strong disinfectant and a selective oxidant. While chlorine dioxide does produce a residual it is only rarely used for this purpose.

Advantages

- ✓ Effective against Cryptosporidium
- ✓ Up to five times faster than chlorine at inactivating Giardia
- ✓ Disinfection is only moderately affected by pH
- ✓ Will not form chlorinated byproducts (THMs, HAAs)
- ✓ Does not oxidize bromide to bromine (can form bromate in sunlight)
- ✓ More effective than chlorine in treating some taste and odor problems
- ✓ Selective oxidant used for manganese oxidation and targeting some chlorine resistant organics

Limitations

- ✓ Inorganic byproduct formation (chlorite, chlorate)
- ✓ Highly volatile residuals
- ✓ Requires on-site generation equipment and handling of chemicals (chlorine and sodium chlorite)
- ✓ Requires a high level of technical competence to operate and monitoring equipment, product and residuals
- ✓ Occasionally poses unique odor and taste problems
- ✓ High operating cost (chlorite chemical cost is high)

Understanding Chlorine Basics

Chlorine is applied to water in one of three forms: elemental chlorine (chlorine gas), hypochlorite solution (bleach), or dry calcium hypochlorite. All three forms produce free chlorine in water.

Advantages

- ✓ Highly effective against most pathogens
- ✓ Provides a residual to protect against recontamination and to reduce bio-film growth in the distribution system
- ✓ Easily applied, controlled, and monitored
- ✓ Strong oxidant meeting most preoxidation objectives
- ✓ Operationally the most reliable
- ✓ The most cost-effective disinfectant

Limitations

- ✓ Byproduct formation (THMs, HAAs)
- ✓ Will oxidize bromide to bromine, forming brominated organic byproducts
- ✓ Not effective against Cryptosporidium
- ✓ Requires transport and storage of chemicals

Elemental Chlorine

Elemental chlorine is the most commonly used form of chlorine. It is transported and stored as a liquefied gas under pressure. Water treatment facilities typically use chlorine in 100 and 150-lb cylinders or one-ton containers. Some large systems use railroad tank cars or tanker trucks.

Advantages

- ✓ Lowest cost of chlorine forms
- ✓ Unlimited shelf-life

Limitations

- ✓ Hazardous gas requires special handling and operator training
- ✓ Additional regulatory requirements, including EPA's Risk Management Program and the Occupational Safety and Health Administration's Process Safety Management program

Factors in Chlorine Disinfection: Concentration and Contact Time

In an attempt to establish more structured operating criteria for water treatment disinfection, the CXT concept came into use in 1980. Based on the work of several researchers, CXT values [final free chlorine concentration (mg/L) multiplied by minimum contact time (minutes)], offer water operators guidance in computing an effective combination of chlorine concentration and chlorine contact time required to achieve disinfection of water at a given temperature. The CXT formula demonstrates that if an operator chooses to decrease the chlorine concentration, the required contact time must be lengthened. Similarly, as higher strength chlorine solutions are used, contact times may be reduced (Connell, 1996).

Disinfection and Bioterrorism

Disinfection is crucial to water system security, providing the 'front line' of defense against biological contamination. Normal filtration and disinfection processes would dampen or remove the threats posed by a number of potential bioterrorism agents. In addition, water systems should maintain an ability to increase disinfection doses in response to a particular threat. However, conventional treatment barriers in no way guarantee safety from biological attacks. For many potential bioterrorism agents, there is little scientific information about what levels of reduction can be achieved with chlorine or other disinfectants. In addition, contamination of water after it is treated could overwhelm the residual disinfectant levels in distribution systems. Furthermore, typical water quality monitoring does not provide real-time data to warn of potential problems (Rose 2002). Additional research and funding are needed to improve prevention, detection, and responses to potential threats.

Protecting Chlorine and Other Treatment Chemicals

As part of its vulnerability assessment, each water system must consider its transportation, storage and use of treatment chemicals. These chemicals are both critical assets (necessary for delivering safe water) and potential vulnerabilities (may pose significant hazards, if released). For example, a release of chlorine gas would pose an immediate threat to system operators, and a large release may pose a danger to the surrounding community. As part of its vulnerability assessment, a water system using chlorine must determine if existing layers of protection are adequate. If not, a system should consider additional measures to reduce the likelihood of an attack or to mitigate the potential consequences.

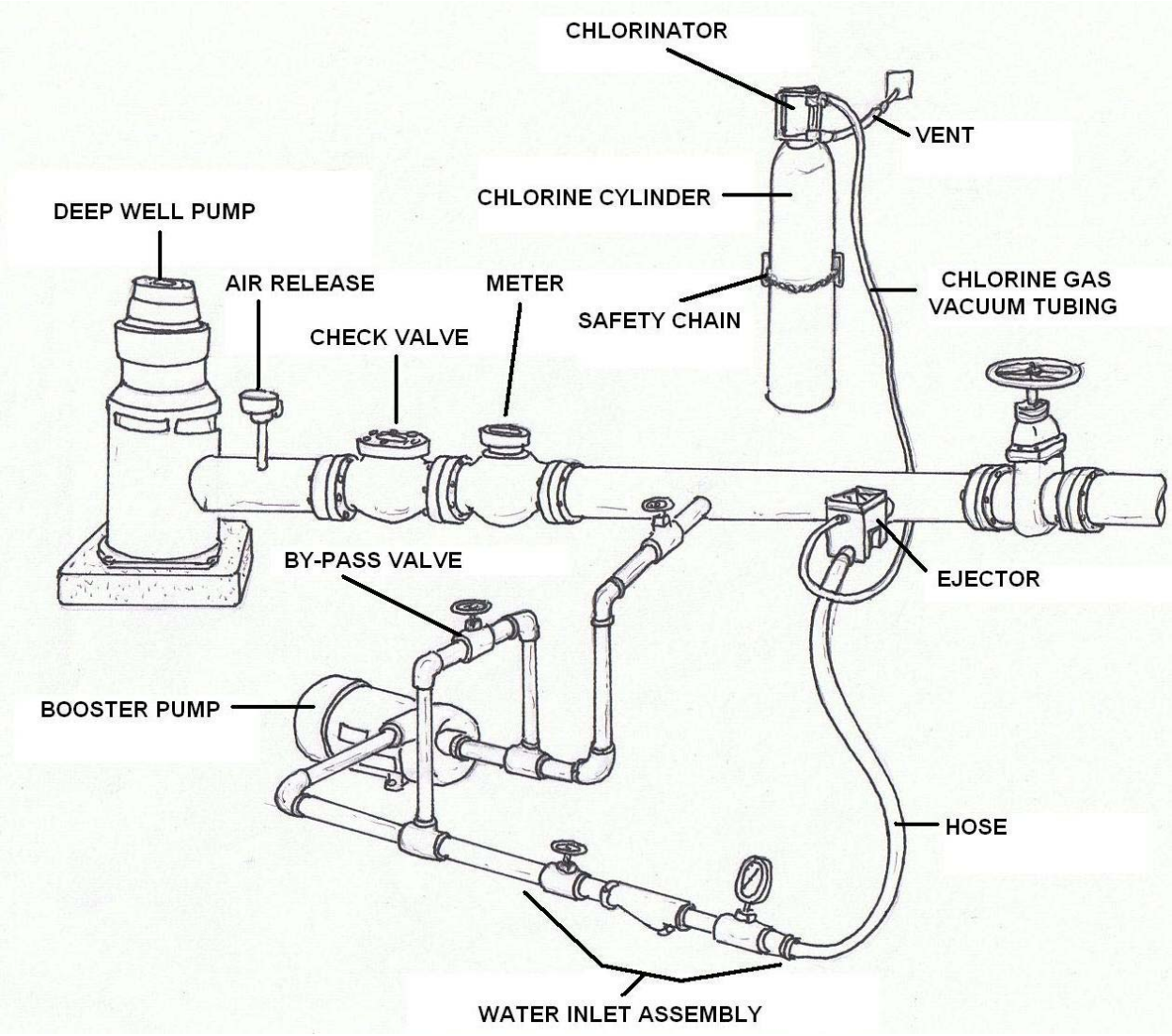
Possible measures to address chlorine security include: enhanced physical barriers (e.g., constructing secure chemical storage facilities), policy changes (e.g., tightening procedures for receiving chemical shipments), reducing quantities stored on site, or adopting alternative disinfection methods. These options must be weighed and prioritized, considering the unique characteristics and resources of each system. Water system officials must evaluate the risk-tradeoffs associated with each option. For example, reducing the chemical quantities on-site may reduce a system's ability to cope with an interruption of chemical supplies. Furthermore, changing disinfection technologies will not necessarily improve overall safety and security.

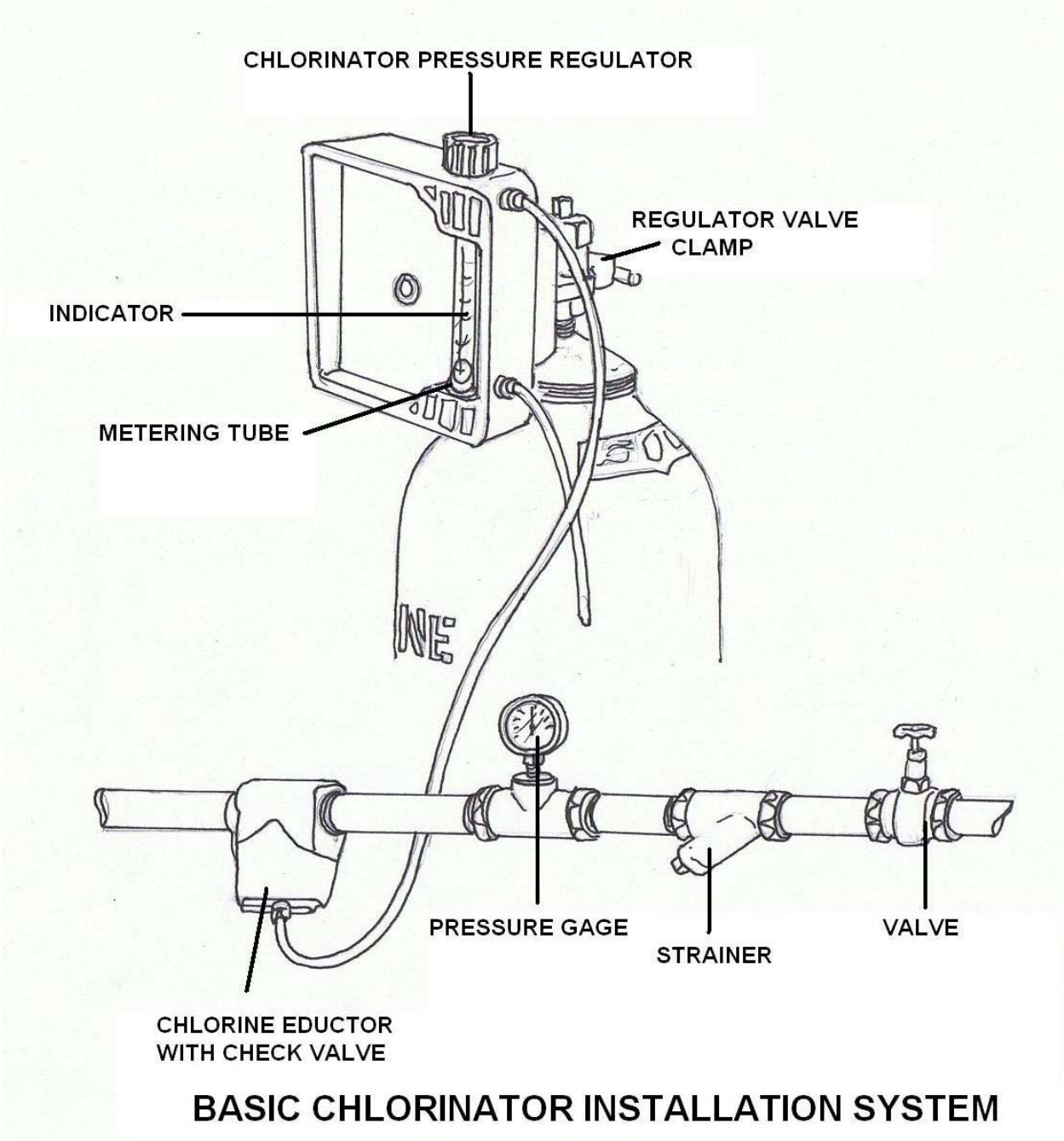
Understanding Calculation and Reporting of CT Data

Basically, log inactivation is a measurement of how effective a disinfection process is at killing microorganisms in a specific environment. Operationally, directly measuring log inactivation is not practical, but determining the microbial inactivation for an individual water treatment plant (WTP) can be achieved using the log inactivation calculations. The log inactivation calculation adjusts the WTP's CT value to account for the disinfection chemical reaction process variables that influence the disinfection process efficiency.

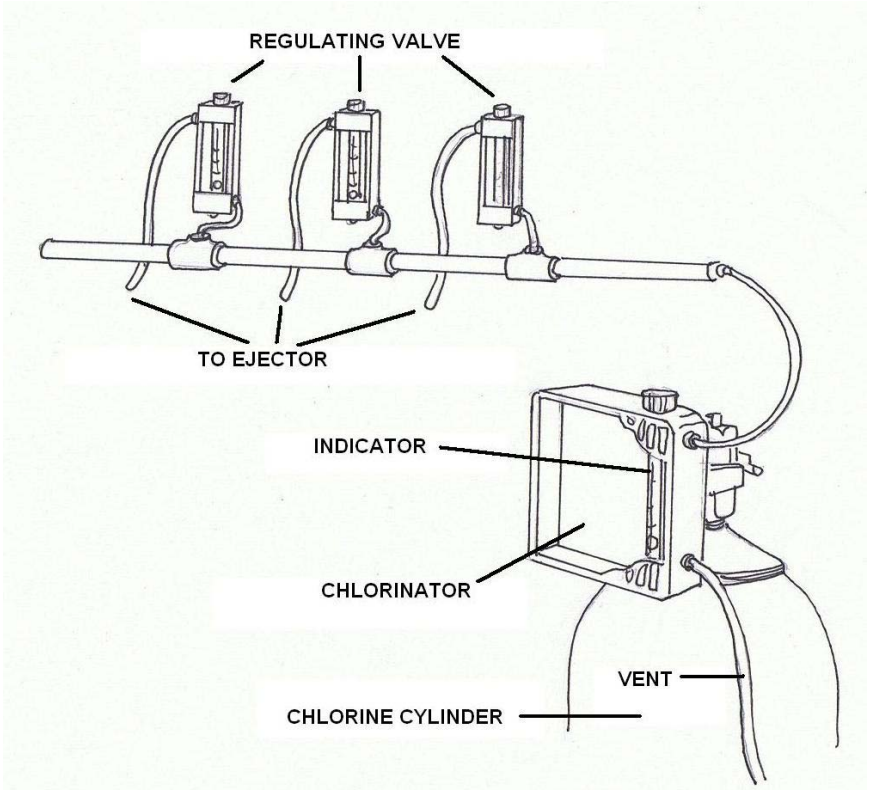
Log Inactivation

"Log inactivation" is a convenient way to express the number or percent of microorganisms inactivated (killed or unable to replicate) through the disinfection process. For example, a 3 log inactivation value means that 99.9% of microorganisms of interest have been inactivated. Log inactivation measures the effectiveness of the disinfection process, which is influenced by variables including disinfectant concentration, temperature, pH and disinfectant type (e.g., lower temperature results in less inactivation since the reactions slow down as temperature decreases).

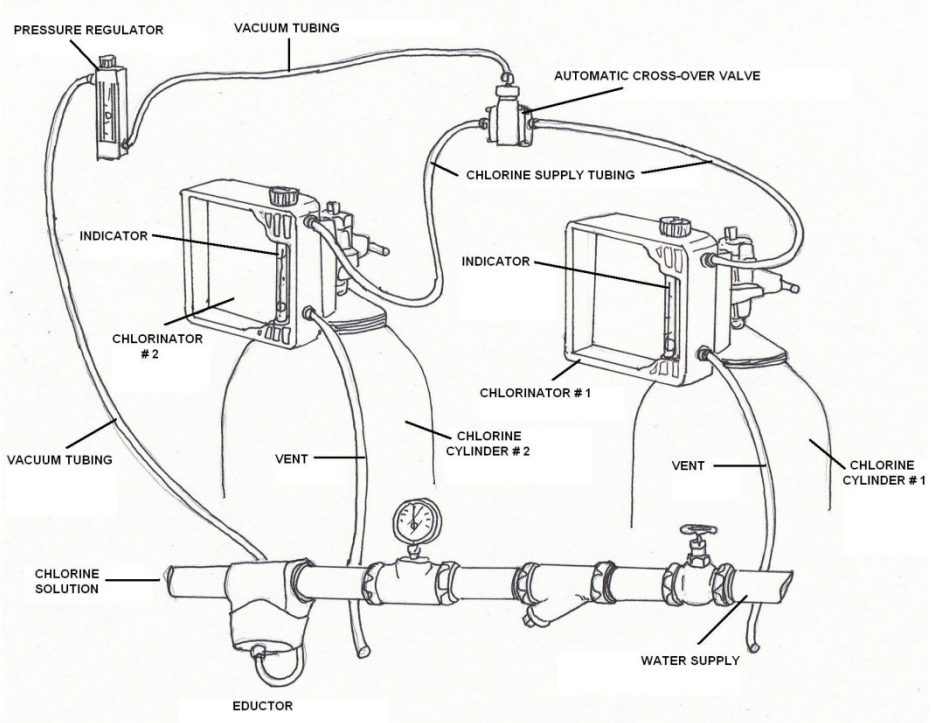




BASIC CHLORINATOR INSTALLATION SYSTEM



TYPICAL REMOTE AND MULTI-POINT SYSTEM



TYPICAL AUTOMATIC CROSS-OVER SYSTEM

CT and Log Inactivation Calculation Overview

This reference takes you step by step through the CT and log inactivation calculation procedure, through an example calculation, and presents the disinfection segment concept.

"CT" (minutes•mg/L) in the context of water treatment is defined as the product of: C, for "residual disinfectant concentration" in mg/L (determined before or at the first customer) and T, for the corresponding "disinfectant contact time" in minutes. CT is a measure of the disinfection process reaction time, but CT is only one of several variables that control the effectiveness of the disinfection process.

CTCALC = Concentration Time, Calculated Value (minutes•mg/L)

C = Residual disinfectant concentration measured during peak flow (mg/L)

T = Actual Detention Time (minutes)

CTCALC = C × T

TDT = Theoretical Detention Time (minutes)

V = Volume, based on low water level (gallons)

Q = Peak hourly flow (gpm)

TDT = V/Q

Volume Equations:
Cylindrical: π x r2 x d Pipeline: π x r2 x l
Rectangular: l x w x d
d = minimum water depth
π = 3.1416

Disinfection Segments
Total inactivation = Σ log inactivation from each disinfection segment
Disinfection Profile
Almost all community and non-transient, non-community public water systems that use Surface Water or Ground Water Under the Direct Influence of Surface Water sources are required to develop a disinfection profile. Systems are required to retain the disinfection profile in graphic form and it must be available for review by the state as part of a sanitary survey.

Disinfection Profile and Benchmark
• A disinfection profile is a graphical representation of a system's level of *Giardia lamblia* or virus inactivation measured, at least weekly, during the course of a year.
• A benchmark is the lowest monthly average microbial inactivation during the disinfection profile time period.

The EPA has developed a disinfection profile spreadsheet calculator that calculates and graphs the disinfection profile for *Giardia* and viruses. The spreadsheet can be downloaded from: http://www.epa.gov/safewater/mdbp/lt1eswtr.html.

Understanding Chlorine Demand
The amount of chlorine used by reactions with substances that oxidize in the water before chlorine residual can be measured. It is the difference between the amount of chlorine added to wastewater and the amount of chlorine residual remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and the type and amount of pollutants in the water.

The presence of chlorine residual in drinking water indicates that: 1) a sufficient amount of chlorine was added initially to the water to inactivate the bacteria and some viruses that cause diarrheal disease; and, 2) the water is protected from recontamination during storage. The presence of free residual chlorine in drinking water is correlated with the absence of disease-causing organisms, and thus is a measure of the potability of water.

While chlorine's most important attributes are its broad-spectrum germicidal potency and persistence in water distribution systems, its ability to efficiently and economically address many other water treatment concerns has also supported its wide use. Chlorine-based compounds are the only major disinfectants exhibiting lasting residual properties. Residual protection guards against microbial regrowth and prevents contamination of the water as it moves from the treatment plant to household taps.

Definitions
When chlorine is added to water, some of the chlorine reacts first with organic materials and metals in the water and is not available for disinfection (this is called the chlorine demand of the water). The remaining chlorine concentration after the chlorine demand is accounted for is called total chlorine. Total chlorine is further divided into: 1) the amount of chlorine that has reacted with nitrates and is unavailable for disinfection which is called combined chlorine and, 2) the free chlorine, which is the chlorine available to inactivate disease-causing organisms, and thus a measure to determine the potability of water.

For example, if using completing clean water the chlorine demand will be zero, and there will be no nitrates present, so no combined chlorine will be present. Thus, the free chlorine concentration will be equal to the concentration of chlorine initially added. In natural waters, especially surface water supplies such as rivers, organic material will exert a chlorine demand, and nitrates will form combined chlorine. Thus, the free chlorine concentration will be less than the concentration of chlorine initially added.

Chlorine Dose, Demand, and Residual
Most water treatment plants are required to disinfect the water, a process used to kill harmful bacteria. The most frequently used method of disinfection is the addition of chlorine. Here, we will briefly introduce three terms used during chlorination - chlorine dose, chlorine demand, and chlorine residual. These three characteristics are related to each other using the following equation:

(Chlorine demand) = (Chlorine dose) - (Chlorine residual)

The amount of chlorine added to the water is known as the chlorine dose. This is a measured quantity chosen by the operator and introduced into the water using a chlorinator or hypochlorinator.

As the chlorine reacts with bacteria and chemicals in the water, some of the chlorine is used up. The amount of chlorine used up by reacting with substances in the water is known as the chlorine demand. If nothing reacts with the chlorine (as would be the case in distilled water), then the chlorine demand is zero. However, in most cases the operator should count on some of the chlorine dose being used up when it reacts with substances in the water.

The amount of chlorine remaining in the water after some of the chlorine reacts with substances in the water is known as the chlorine residual. This lab introduces a test which can be used to calculate the chlorine residual. The chlorine residual is the most important of these three values - dose, demand, and residual - because it represents the actual amount of chlorine remaining in the water to act as a disinfectant.

The test for chlorine residual is performed frequently at most water treatment plants. Since regulations require a certain level of chlorine in water at the far ends of the distribution system, operators should be sure to test the chlorine residual in the distribution system as well as in the clear well.

Combined residual chlorination involves the addition of chlorine to water to produce, with natural ammonia present or with ammonia added, a combined available chlorine residual. Combined available chlorine forms have lower oxidation potentials than free available chlorine forms and are less effective as oxidants. They are also less effective as disinfectants. In fact, 25 times more combined available residual chlorine must be obtained to meet the same disinfectant level as a free available residual. The contact time has to be up to 100 times greater to obtain the same level of bacterial kill at the same pH and temperature conditions.

When a combined available chlorine residual is desired, the character of the water determines how it can be accomplished. These conditions may have to be considered:
1. If the water contains sufficient ammonia to produce the desired level of combined residual, the application of sufficient chlorine alone is all that is needed.
2. If the water contains too little or no ammonia, then addition of both chlorine and ammonia is required.
3. If the water has a free available chlorine, the addition of ammonia alone is all that is required. A combined chlorine residual should contain little or no free available chlorine.

The practice of combined residual chlorination is the most effective way of maintaining a stable residual throughout the distribution system to the point of consumer use. Combined residuals in the distribution system are generally longer-lasting and will carry farther into the system, but they are not as effective as free residuals are at disinfecting. The levels required by the regulatory agencies, when using combined residuals, is 1.0 ppm to 2.0 ppm.

Understanding Chlorine Residual
The amount of available chlorine present in wastewater after a given contact time (20 minutes at peak flow; 30 minutes at average flow), and under specific conditions including pH and temperature.

For effective water treatment, the water supply industry has recognized the need for adequate exposure to the disinfectant and sufficient disinfectant dosage for a certain amount of time. In the 1980s, the two functions were combined with the development of the CT values for various disinfectants.

CT represents the combination of the disinfectant dosage and the length of time water has been exposed to a minimum amount of the disinfectant residual.

> Mathematically it is represented as CT = concentration x time
> concentration = final disinfectant concentration in mg/l
> time = minimum exposure time in minutes

In an assessment of disinfection effectiveness, two types of organisms have been chosen as disinfection surrogates – the protozoan Giardia and viruses. CT values established for disinfection of surface waters require treatment plants to achieve a three-log or 99.9% reduction in Giardia and a four-log or 99.99% virus reduction. It is important to recognize that the use of chlorine as the disinfectant is only one part of the treatment process. Equally important is the need for improved filtration to remove organisms. A combination of proper disinfection and filtration is most effective in providing safe drinking water. Recent experiments in controlling Cryptosporidium also suggest the effectiveness of filtration in the water treatment process.

Free residual chlorination involves the application of chlorine to water to produce--either directly or by first destroying any naturally present ammonia--a free available chlorine residual and to maintain this residual through part or all of the water treatment plant and distribution system. Free available residual forms have higher oxidation potentials than combined available chlorine forms and are more effective as disinfectants.

When free available chlorine residuals are desired, the characteristics of the water will determine how this will be accomplished. This may have to be considered:
1. If the water contains no ammonia or other nitrogen compounds, any application of chlorine will yield a free residual once it has reacted with any bacteria, virus and other microorganisms present in the water.
2. If the water contains ammonia, it results in the formation of a combined residual, which must be destroyed by applying an excess of chlorine.

Breakpoint Chlorination
Breakpoint chlorination is the name of the process of adding chlorine to water until the chlorine demand has been satisfied. Chlorine demand equals the amount of chlorine used up before a free available chlorine residual is produced. Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies normally chlorinate past the breakpoint.

When chlorine is initially added to water, the following may happen:
1. If the water contains some iron, manganese, organic matter, and ammonia, the chlorine reacts with these materials and no residual is formed, meaning that no disinfection has taken place.
2. If additional chlorine is added at this point, it will react with the organics and ammonia to form chloramines. The chloramines produce a combined chlorine residual. As the chlorine is combined with other substances, it loses some of the disinfection strength. Combined residuals have poor disinfection power and may be the cause of taste and odor problems.
3. With a little more chlorine added, the chloramines and some of the chlororganics are destroyed.
4. With still more chlorine added, a free chlorine residual is formed, free in the sense that it can react quickly.

Free available chlorine is the best residual for disinfection. It disinfects faster and without the swimming-pool odor of combined residual chlorine. The free available residual forms at the breakpoint; therefore, the process is called breakpoint chlorination. The common practice today is to go just beyond the breakpoint to a residual of about .2 to .5 ppm.

A variety of reactions take place during chlorination. When chlorine is added to a water containing ammonia (NH_3), the ammonia reacts with hypochlorous acid (HOCL) to form monochloramine, dichloramine, and trichloramine. The formation of these chloramines depends on the pH of the water and the initial chlorine-ammonia ratio.

Ammonia + Hypochlorous acid ----> Chloramine + Water
NH3 + HOC1----------> NH2C1 + H20 Monochloramine
NH2C1 + HOC1---------- > NHC12 + H20 Dichloramine
NHC12 + HOC1---------- > NC13 + H20 Trichloramine

At the pH of most natural water (pH 6.5 to 7.5), monochloramine and dichloramine exist together. At pH levels below 5.5, dichloramine exists by itself. Below pH 4.0, trichloramine is the only compound found. The monochloramine and dichloramine forms have a definite disinfection power. Dichloramine is a more effective disinfecting agent than monochloramine. However, dichloramine is not recommended as a disinfectant due to the possibility of the formation of taste and odor compounds. Chlorine reacts with phenol and salicylic acid to form chlorophenol, which has an intense medicinal odor. This reaction is much slower in the presence of monochloramines.

Both the chlorine residual and the contact time are essential for effective disinfection. It is important to have complete mixing. The operator also needs to be aware that changes in the pH may affect the ability of the chlorine to disinfect the water. The operator must examine the application and select the best point of feed and the best contact time to achieve the results desired. The operator needs to consider:
1. Whether the injection point and the method of mixing is designed so that the disinfectant is able to get into contact with all of the water to be disinfected. This also depends on whether pre- and/or post-chlorination is being used.
2. Contact time. In situations of good initial mixing, the longer the contact time, the more effective the disinfection.
3. Effectiveness of upstream treatment processes. The lower the turbidity of the water, the more effective the disinfection.
4. Temperature. At higher temperatures the rate of disinfection is more rapid.
5. Dosage and type of chemical. Usually the higher the dose, the quicker the disinfection rate. The form of disinfectant (chloramine or free chlorine) and the type of chemical used influence the disinfection rate.
6. pH. The lower the pH, the better the disinfection.

Emergency Disinfection of Drinking Water

USE ONLY WATER THAT HAS BEEN PROPERLY DISINFECTED FOR DRINKING, COOKING, MAKING ANY PREPARED DRINK, OR FOR BRUSHING TEETH

1. Use bottled water that has not been exposed to flood waters if it is available.
2. If you don't have bottled water, you should boil water to make it safe. Boiling water will kill most types of disease-causing organisms that may be present. If the water is cloudy, filter it through clean cloths or allow it to settle, and draw off the clear water for boiling. Boil the water for one minute, let it cool, and store it in clean containers with covers.
3. If you can't boil water, you can disinfect it using household bleach. Bleach will kill some, but not all, types of disease-causing organisms that may be in the water. If the water is cloudy, filter it through clean cloths or allow it to settle, and draw off the clear water for disinfection. Add 1/8 teaspoon (or 8 drops) of regular, unscented, liquid household bleach for each gallon of water, stir it well and let it stand for 30 minutes before you use it. Store disinfected water in clean containers with covers.
4. If you have a well that has been flooded, the water should be tested and disinfected after flood waters recede. If you suspect that your well may be contaminated, contact your local or state health department or agriculture extension agent for specific advice.

(U.S. federal agencies and the Red Cross recommend these same four steps to disinfect drinking water in an emergency.

Please, read the text below for important details about disinfection.
More information about disinfection

- ✓ In times of crisis, follow advice from local officials. Local health departments or public water systems may urge consumers to use more caution or to follow additional measures than the information provided here.

- ✓ Look for other sources of potable water in and around your home.

- ✓ When your home water supply is interrupted by natural or other forms of disaster, you can obtain limited amounts of water by draining your hot water tank or melting ice cubes. In most cases, well water is the preferred source of drinking water. If it is not available and river or lake water must be used, avoid sources containing floating material and water with a dark color or an odor. Generally, flowing water is better quality than stagnant water.

Examine the physical condition of the water.

When emergency disinfection is necessary, disinfectants are less effective in cloudy, murky or colored water. Filter murky or colored water through clean cloths or allow it to settle. It is better to both settle and filter. After filtering until it is clear, or allowing all dirt and other particles to settle, draw off the clean and clear water for disinfection. Water prepared for disinfection should be stored only in clean, tightly covered, containers, not subject to corrosion.

- ✓ Choose a disinfection method.

- ✓ Boiling and chemical treatment are two general methods used to effectively disinfect small quantities of filtered and settled water.

Boiling
Boiling is the surest method to make water safe to drink and kill disease-causing microorganisms like Giardia lamblia and Cryptosporidium, which are frequently found in rivers and lakes. These disease-causing organisms are less likely to occur in well water (as long as it has not been affected by flood waters). If not treated properly and neutralized, Giardia may cause diarrhea, fatigue, and cramps after ingestion. Cryptosporidium is highly resistant to disinfection. It may cause diarrhea, nausea and/or stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals.

Boil filtered and settled water vigorously for one minute (at altitudes above one mile, boil for three minutes). To improve the flat taste of boiled water, aerate it by pouring it back and forth from one container to another and allow it to stand for a few hours, or add a pinch of salt for each quart or liter of water boiled.

If boiling is not possible, chemical disinfection of filtered and settled water collected from a well, spring, river, or other surface water body will still provide some health benefits and is better than no treatment at all.

Chemical Treatment
When boiling is not practical, certain chemicals will kill most harmful or disease-causing organisms. For chemical disinfection to be effective, the water must be filtered and settled first. Chlorine and iodine are the two chemicals commonly used to treat water. They are somewhat effective in protecting against exposure to Giardia, but may not be effective in controlling more resistant organisms like Cryptosporidium. Chlorine is generally more effective than iodine in controlling Giardia, and both disinfectants work much better in warm water. You can use a non-scented, household chlorine bleach that contains a chlorine compound to disinfect water. Do not use non-chlorine bleach to disinfect water. Typically, household chlorine bleaches will be 5.25% available chlorine. Follow the procedure written on the label. When the necessary procedure is not given, find the percentage of available chlorine on the label and use the information in the following table as a guide. (Remember, 1/8 teaspoon and 8 drops are about the same quantity.)

Available Chlorine

Drops per Quart/Gallon of Clear Water Drops per Liter of Clear Water
1% 10 per Quart - 40 per Gallon 10 per Liter
4-6% 2 per Quart - 8 per Gallon (1/8 teaspoon) 2 per Liter
7-10% 1 per Quart - 4 per Gallon 1 per Liter

(If the strength of the bleach is unknown, add ten drops per quart or liter of filtered and settled water. Double the amount of chlorine for cloudy, murky or colored water or water that is extremely cold.)

Mix the treated water thoroughly and allow it to stand, preferably covered, for 30 minutes. The water should have a slight chlorine odor. If not, repeat the dosage and allow the water to stand for an additional 15 minutes. If the treated water has too strong a chlorine taste, allow the water to stand exposed to the air for a few hours or pour it from one clean container to another several times.

You can use granular calcium hypochlorite to disinfect water.

Add and dissolve one heaping teaspoon of high-test granular calcium hypochlorite (approximately ¼ ounce) for each two gallons of water, or 5 milliliters (approximately 7 grams) per 7.5 liters of water. The mixture will produce a stock chlorine solution of approximately 500 milligrams per liter, since the calcium hypochlorite has available chlorine equal to 70 percent of its weight. To disinfect water, add the chlorine solution in the ratio of one part of chlorine solution to each 100 parts of water to be treated. This is roughly equal to adding 1 pint (16 ounces) of stock chlorine to each 12.5 gallons of water or (approximately ½ liter to 50 liters of water) to be disinfected. To remove any objectionable chlorine odor, aerate the disinfected water by pouring it back and forth from one clean container to another.

You can use chlorine tablets to disinfect filtered and settled water.

Chlorine tablets containing the necessary dosage for drinking water disinfection can be purchased in a commercially prepared form. These tablets are available from drug and sporting goods stores and should be used as stated in the instructions. When instructions are not available, use one tablet for each quart or liter of water to be purified.

You can use tincture of iodine to disinfect filtered and settled water.

Common household iodine from the medicine chest or first aid kit may be used to disinfect water. Add five drops of 2 percent U.S. or your country's approved Pharmacopeia tincture of iodine to each quart or liter of clear water. For cloudy water add ten drops and let the solution stand for at least 30 minutes.

You can use iodine tablets to disinfect filtered and settled water.

Purchase commercially prepared iodine tablets containing the necessary dosage for drinking water disinfection at drug and sporting goods stores. Use as stated in instructions. When instructions are not available, use one tablet for each quart or liter of filtered and settled water to be purified.

ONLY USE WATER THAT HAS BEEN PROPERLY DISINFECTED FOR DRINKING, COOKING, MAKING ANY PREPARED DRINK, OR FOR BRUSHING TEETH.

Summary and Illustration of Key Points

- ✓ Filter murky or colored water through clean cloths or allow it to settle. It is better to both settle and filter.
- ✓ Boiling is the surest method to make water safe to drink and kill disease-causing microorganisms like Giardia lamblia and Cryptosporidium, which are frequently found in rivers and lakes.
- ✓ To improve the flat taste of boiled water, aerate it by pouring it back and forth from one container to another and allow it to stand for a few hours, or add a pinch of salt for each quart or liter of water boiled.
- ✓ When boiling is not practical, certain chemicals will kill most harmful or disease-causing organisms. Chlorine (in the form of unscented bleach) and iodine are the two chemicals commonly used to treat water.
- ✓ You can use a non-scented, household chlorine bleach that contains a chlorine compound to disinfect water. (Remember, 1/8 teaspoon and 8 drops are about the same quantity.)
- ✓ You can use tincture of iodine to disinfect filtered and settled water. Common household iodine from the medicine chest or first aid kit may be used to disinfect water.
- ✓ Tincture of iodine. For cloudy water add ten drops and let the solution stand for at least 30 minutes.

Understanding Combined Chlorine Residual

The residual consisting of chlorine that is combined with ammonia, nitrogen, or nitrogenous compounds (chloramines).

Understanding Free Available Chlorine
The residual consisting of hypochlorite ions (OCl-), hypochlorous acid (HOCl) or a combination of the two. These are the most effective in killing bacteria.

Total Combined Chlorine Residual
The total amount of chlorine present in a sample. This is the sum of the free chlorine residual and the combined available chlorine residual.

Understanding Pre-Chlorination
Chlorination is the application of chlorine to water to accomplish some definite purpose. In this lesson, we will be concerned with the application of chlorine for the purpose of disinfection, but you should be aware that chlorination can also be used for taste and odor control, iron and manganese removal, and to remove some gases such as ammonia and hydrogen sulfide. Chlorination is currently the most frequently used form of disinfection in the water treatment field. However, other disinfection processes have been developed. These alternatives will be discussed at the end of this lesson.

Pre-Chlorination and Post-Chlorination
Like several other water treatment processes, chlorination can be used as a pretreatment process (prechlorination) or as part of the primary treatment of water (postchlorination). Treatment usually involves either postchlorination only or a combination of prechlorination and postchlorination.

Pre-chlorination is the act of adding chlorine to the raw water. The residual chlorine is useful in several stages of the treatment process - aiding in coagulation, controlling algae problems in basins, reducing odor problems, and controlling mudball formation. In addition, the chlorine has a much longer contact time when added at the beginning of the treatment process, so prechlorination increases safety in disinfecting heavily contaminated water.

Post-chlorination is the application of chlorine after water has been treated but before the water reaches the distribution system. At this stage, chlorination is meant to kill pathogens and to provide a chlorine residual in the distribution system. Post-chlorination is nearly always part of the treatment process, either used in combination with prechlorination or used as the sole disinfection process.

Until the middle of the 1970s, water treatment plants typically used both prechlorination and post-chlorination. However, the longer contact time provided by prechlorination allows the chlorine to react with the organics in the water and produce carcinogenic substances known as trihalomethanes. As a result of concerns over trihalomethanes, prechlorination has become much less common in the United States. Currently, prechlorination is only used in plants where trihalomethane formation is not a problem.

Understanding Breakpoint Chlorination
Addition of chlorine to water until the chlorine demand has been satisfied. Since ammonia is present in all domestic wastewaters, the reaction of ammonia with chlorine is a great significance. When chlorine is added to waters containing ammonia, the ammonia reacts with hypochlorous acid (HOCl) to form monochloramine, dichloramine and trichloramine. The formation of these chloramines depends on the pH of the solution and the initial chlorine-ammonia ratio.

Chlor-Alkali Membrane Process
The chloralkali process (also chlor-alkali and chlor alkali) is an industrial process for the electrolysis of sodium chloride solution (brine). Depending on the method, several products besides hydrogen can be produced. If the products are separated, chlorine and sodium hydroxide (caustic soda) are the products; by mixing, sodium hypochlorite or sodium chlorate are produced, depending on the temperature. Higher temperatures are needed for the production of sodium chlorate instead of sodium hypochlorite. Industrial scale production began in 1892. When using calcium chloride or potassium chloride, the products contain calcium or potassium instead of sodium.

The process has a high energy consumption, for example over 4 billion kWh per year in West Germany in 1985, and produces equal (molar) amounts of chlorine and sodium hydroxide, which makes it necessary to find a use for the product for which there is less demand, usually the chlorine. There are three production methods in use. While the mercury cell method produces chlorine-free sodium hydroxide, the use of several tons of mercury leads to serious environmental problems. In a normal production cycle a few hundred pounds of mercury per year are emitted, which accumulate in the environment. Additionally, the chlorine and sodium hydroxide produced via the mercury-cell chloralkali process are themselves contaminated with trace amounts of mercury. The membrane and diaphragm method use no mercury, but the sodium hydroxide contains chlorine, which must be removed.

Understanding Chlorine's Effectiveness
In 1881, German bacteriologist Robert Koch demonstrated under controlled laboratory conditions that pure cultures of bacteria could be destroyed by hypochlorite (bleach). The bulk of chlorine disinfection research, which was conducted from the 1940s to the 1970s with a focus on bacteria, provided observations as to how chlorine kills the microorganism. The observations that (1) bacterial cells dosed with chlorine release nucleic acids, proteins and potassium and (2) membrane functions such as respiration and active transport are affected more by chlorine than are cytoplasmic processes, directed researchers' attention to the surface of the bacterial cell. The hypothesis was that the bacterial cell wall, under environmental stress, could interact with chlorine.

Chlorine exposure appears to cause physical, chemical, and biochemical alterations to the cell wall, thus destroying the cell's protective barrier, terminating vital functions, resulting in death of the microorganism. A possible sequence of events during chlorination would be: (1) disruption of the cell wall barrier by reactions of chlorine with target sites at the cell surface, (2) release of vital cellular constituents from the cell, (3) termination of membrane-associated functions, and (4) termination of cellular functions within the cell. During the course of this sequence of events, the microorganism dies, meaning it is no longer capable of growing or causing disease.

Understanding Chlorine Solubility Effects
Chlorine is only slightly soluble in water; its maximum solubility is approximately one percent at 49° C. At temperatures below this point it combines with water to form chlorine ice, a crystalline substance. When the water supply to a gas chlorinator is below normal room temperature, it may cool the chlorine gas to the point at which chlorine ice is formed and accumulates on the needle valve and gas outlet tube, resulting in erratic feed results. Because the vapor pressure of chlorine increases with rising temperatures, its solubility also decreases. At 212° F. chlorine is insoluble in water.

Chlorine dissolved in water forms a weak corrosive mixture of hydrochloric and hypochlorous acid. The corrosivity of chlorine solutions in water creates problems in handling chlorine spills and chlorine containers. Chlorine reacts with many compounds. Because of its great affinity for hydrogen, it removes hydrogen from some compounds, such as hydrogen sulfide. It also reacts with ammonia or other nitrogen-containing compounds to form various mixtures of chloramines. It reacts with organic materials, sometimes with explosive violence.

Chemicals like chlorine, bromine, and ozone are examples of oxidizers. It is their ability to oxidize or steal electrons from other substances that makes them good water sanitizers. As soon as the oxidizing agent is added to the water, it begins to combine with microorganisms like bacteria, algae, and whatever else the water may contain.

Now the free and available oxidizer is combining with contaminants and its effectiveness is reduced according to how much combining took place. Although the hydrogen ion does not play a direct reduction role on copper surfaces, pH can influence copper corrosion by altering the equilibrium potential of the oxygen reduction half-reaction and by changing the speciation of copper in solution (Reiber, 1989). Copper corrosion increases rapidly as the pH drops below 6; in addition, uniform corrosion rates can be high at low pH values (below about pH 7), causing metal thinning. At higher pH values (above about pH 8), copper corrosion problems are almost always associated with non-uniform or pitting corrosion processes (Edwards et al., 1994a; Ferguson et al., 1996). Edwards et al. (1994b) found that for new copper surfaces exposed to simple solutions that contained bicarbonate, chloride, nitrate, perchlorate or sulphate, increasing the pH from 5.5 to 7.0 roughly halved corrosion rates, but further increases in pH yielded only subtle changes.

The prediction of copper levels in drinking water relies on the solubility and physical properties of the cupric oxide, hydroxide and basic carbonate solids that comprise most scales in copper water systems (Schock et al., 1995). In the cupric hydroxide model of Schock et al. (1995), a decrease in copper solubility with higher pH is evident. Above a pH of approximately 9.5, an upturn in solubility is predicted, caused by carbonate and hydroxide complexes increasing the solubility of cupric hydroxide. Examination of experience from 361 utilities reporting copper levels under the U.S. EPA Lead and Copper Rule revealed that the average 90th-percentile copper levels were highest in waters with pH below 7.4 and that no utilities with pH above 7.8 exceeded the U.S. EPA's action level for copper of 1.3 mg/L (Dodrill and Edwards, 1995). However, problems associated with copper solubility were also found to persist up to about pH 7.9 in cold, high-alkalinity and high-sulphate groundwater (Edwards et al., 1994a).

In the pH range of 7-9, both the corrosion rate and the degree of tuberculation of iron distribution systems generally increase with increasing pH (Larson and Skold, 1958; Stumm, 1960; Hatch, 1969; Pisigan and Singley, 1987). Iron levels, however, were usually reported to decrease with increasing pH (Karalekas et al., 1983; Kashinkunti et al., 1999; Broo et al., 2001; Sarin et al., 2003). In a pipe loop system constructed from 90- to100-year-old unlined cast iron pipes taken from a Boston distribution system, iron concentrations were found to steadily decrease when the pH was raised from 7.6 to 9.5 (Sarin et al., 2003). Similarly, when iron was measured in the distribution system following a pH increase from 6.7 to 8.5, a consistent downward trend in iron concentrations was found over 2 years (Karalekas et al., 1983). These observations are consistent with the fact that the solubility of iron-based corrosion by-products decreases with increasing pH.

Water with low pH, low alkalinity and low calcium is particularly aggressive towards cement materials. The water quality problems that may occur are linked to the chemistry of the cement. Lime from the cement releases calcium ions and hydroxyl ions into the drinking water. This, in turn, may result in a substantial pH increase, depending on the buffering capacity of the water (Leroy et al., 1996). Pilot-scale tests were conducted to simulate low-flow conditions of newly lined cement mortar pipes carrying low-alkalinity water (Douglas et al., 1996). In the water with an initial pH of 7.2, alkalinity of 14 mg/L as calcium carbonate and calcium at 13 mg/L as calcium carbonate, measures of pH as high as 12.5 were found.

Similarly, in the water with an initial pH of 7.8, alkalinity of 71 mg/L as calcium carbonate and calcium at 39 mg/L as calcium carbonate, measures of pH as high as 12 were found. The most significant pH increases were found during the 1st week of the experiment, and pH decreased slowly with aging of the lining. In a series of field and test rig trials to determine the impact of in situ cement mortar lining on water quality, Conroy et al. (1994) observed that in low-flow and low-alkalinity water (around 10 mg/L as calcium carbonate), pH increases exceeding 9.5 could occur for over 2 years following the lining.

Understanding Amperometric Titration

It appears that DPD colorimetric determination and amperometric titration as described in Standard Methods are the procedures most commonly used for routine measurement of total chlorine. Few studies have been conducted to evaluate these or other total residual chlorine measurement techniques. Bender5 studied approximately 10 test procedures and found that results using the DPD colorimetric procedure were consistently higher than those using amperometric titration. Brooks and Seegert6 described an amperometric titration procedure employing a recording polargraph and microburette, which was reported to be accurate and free from interference. The reliability of the DPD colorimetric method for free chlorine has been increasingly questioned in recent years. The suitability of that procedure for accurate total chlorine determinations appears to the authors to be questionable, as well. Amperometric titration as described in Standard Methods cannot be used to measure total chlorine concentrations less than about 0.05 mg/L, which is at least an order of magnitude greater than levels of concern in natural waters for potential toxicity to aquatic organisms. A reliable, simple procedure for low-level total chlorine determinations is clearly needed.

Analytical Procedure
Section 409C of Standard Methods includes a General Discussion section on amperometric titration for the determination of chlorine in aqueous solutions. That discussion is applicable to the procedure used by the authors. Also included in Standard Methods is a section concerning the titration apparatus. Basically, the titration equipment consists of a buret capable of accurately delivering 0.01 mL of titrant, a sample cup, and a stirring device in which is housed a platinum electrode and a KCl reference electrode. Several companies manufacture amperometric titrators that fit this general description. The experience of the senior author is that some of the commercial titrators are less suitable than others, primarily because of the small surface area of some of the electrodes employed. A Wallace and Tiernan amperometric titrator was used by the authors in developing and applying the procedure described below.

Reagents
a. Chlorine-free water. Only distilled or demineralized water that is free of chlorine should be used in preparing reagents. Chlorine-free water may be prepared by passing distilled or demineralized water through a suitable activated carbon filter adsorption column. The water may be tested for the presence of chlorine by titrating a sample as described in the Procedure section. Any deflection in the meter upon the addition of PAO titrant indicates the presence of chlorine or other oxidants that would interfere in the titration procedure.
b. Standard phenylarsine oxide (PAO), 0.00564 N. See Standard Methods Section 409B, paragraph 3a.
Standardization – Dilute 50.00 mL of freshly prepared 0.0002256 N potassium biniodate to 200 mL in chlorine-free water. Add approximately 1.5 g KI and stir to dissolve. Add 1 mL acetate buffer and allow to stand in the dark for 6 minutes. Titrate using the amperometric titrator and determine the equivalence point as detailed in the Procedure section. If the standard PAO is 0.00564 N, exactly 2.00 mL of PAO will be required to reach the equivalence point.
c. Phenylarsine oxide titrant, 0.000564 N. Dilute 10.00 mL of 0.00564 N PAO to 100.0 mL in chlorine-free water.
Standardization – Dilute 5.00 mL of 0.0002256 N potassium biniodate to 200 mL with chlorine-free water. Add approximately 1.5 g KI and stir to dissolve. Add 1 mL acetate buffer and allow to stand in the dark for 6 minutes. Titrate using the amperometric titrator and determine the equivalence point as detailed in the Procedure section below. If the PAO titrant is 0.000564 N, exactly 2.00 mL of PAO will be required to reach the equivalence point.
d. Potassium biniodate, 0.0002256 N. Dissolve 0.7332 g reagent grade $KH(IO_3)2$ in 500 mL chlorine-free water and dilute to 1.00 L. Dilute 10.00 mL of that solution to 100.0 mL with chlorine-free water. That solution is used for the standardization of the PAO and should be freshly prepared.
e. Acetate buffer solution, pH 4. See Standard Methods1 Section 409B, paragraph 3e.
f. Potassium iodide, (KI), reagent grade crystals.

Procedure

a. Titrant selection. Normally a 200-mL sample is used in titration. Each 0.1 mL of 0.000564 N PAO corresponds to 0.01 mg/L in a 200-mL sample. The titrant normality should be selected such that no more than about 4 mL of titrant will be required to reach the equivalence point. Thus, if the chlorine concentration in the majority of the samples to be titrated is less than about 0.4 mg/L, use 0.000564 N PAO as the titrant. If only samples containing chlorine concentrations in excess of 0.4 mg/L are to be analyzed, use 0.00564 N PAO as the titrant. If samples containing concentrations of chlorine in excess of about 0.4 mg/L are to be titrated only occasionally and the volume of 0.000564 N PAO required for titration is found to be excessive, a suitable subsample may be used and diluted to 200 mL with chlorine-free water.

b. Titration procedure (total residual chlorine). Prior to beginning the titration, rinse the buret with PAO titrant by filling it completely and allowing the titrant to run into an empty sample cup. Repeating this operation three or four times will ensure that the correct titrant concentration reaches the sample cup. Remove the sample cup and rinse with distilled water and with the sample to be titrated. Add 200 mL of the sample to the sample cup. Add approximately 1.5 g (± 0.2 g) crystalline KI and allow to dissolve, using the agitator on the titrator for mixing.

The exact amount of KI added is not critical, but the analyst should weigh 1.5 g of this reagent periodically to become familiar with the approximate amount required. Add 1 mL of acetate buffer and allow the microammeter on the titrator to reach a stable reading; the titration should be started within about 30 seconds following the addition of the KI to the sample.

Full-scale deflection on the microammeter is 100 units. The meter should be initially adjusted to read between 90 and 100 units. Record the initial reading prior to the addition of titrant. Titrate by adding suitable volumes of titrant and recording the titrant volume added and the resultant current reading. At least three (and preferably five to ten) readings of current and titrant volume added should be obtained prior to passing the equivalence point; then add excess titrant to ensure that there is no further meter deflection. Record the final meter reading. If, during the titration, the meter reading falls to near or below 10 units, record the low reading, re-adjust the meter to read between 90 and 100 units, record the high reading, and continue the titration. This approach allows calculation of the total meter deflection, which is used in determining the equivalence point.

The equivalence point is determined by plotting the total meter deflection as a function of titrant volume added. It is important that the total meter deflection be used in preparing this plot. A straight line is drawn through the first few points in the plot and a second straight line is drawn parallel to the abscissa and corresponding to the final total deflection in the meter reading. The equivalence point is determined by the intersection of those two lines. When 0.000564 N PAO is used as the titrant, the chlorine concentration is 0.1-times the titrant volume at the equivalence point. This plotting procedure is also outlined in the ASTM Water Manual8 under procedures ASTM D1253 (Tests for Residual Chlorine in Water) and ASTM D1427 (Tests for Residual Chlorine in Waste Water).

c. Sample storage and handling. Chlorine measurements should be made as soon after sample collection as possible. Samples to be analyzed for chlorine should be stored in the dark and packed on ice if they must be held for more than a few minutes before analysis. Chlorine compounds are highly reactive and may be rapidly lost from samples due to the effects of volatilization, phototransformation, and chlorine demand. Storage of samples on ice and in the dark between sampling and analysis will help minimize the rate of dissipation. It is important to estimate the changes that occur in chlorine content in the subject water between sample collection and analysis.

This can be accomplished by performing a “time-lag” test. To perform a time-lag test, a single large (approximately 2-L) sample of the water being analyzed is collected. The chlorine concentration in that sample is determined six to ten times over a period of one to three hours, depending on the normal sample holding time. The measured concentrations are then plotted as a function of time, normally on semilog paper. In most cases, the decrease in chlorine concentration over time can be described by first-order reaction kinetics.

The original chlorine content in any sample can be computed given the measured concentration and the holding time. A time-lag study should be performed on a regular basis for each type of water being analyzed because of variability in water compositions. The sample set used for the study should be

handled in the same way as other samples (i.e., the samples should be kept cold and in the dark). Even when time-lag studies are made a part of the routine analytical procedure, it is important that the delay between sample collection and chlorine analysis be held to a minimum.

Sodium Hypochlorite
Sodium Hypochlorite, or bleach, is produced by adding elemental chlorine to sodium hydroxide. Typically, hypochlorite solutions contain from 5 to 15% chlorine, and are shipped by truck in one- to 5,000- gallon containers.

Advantages
- ✓ Solution is less hazardous and easier to handle than elemental chlorine
- ✓ Fewer training requirements and regulations than elemental chlorine

Limitations
- ✓ Limited shelf-life
- ✓ Potential to add inorganic byproducts (chlorate, chlorite and bromate) to water
- ✓ Corrosive to some materials and more difficult to store than most solution chemicals
- ✓ Higher chemical costs than elemental chlorine

Calcium Hypochlorite
- ✓ Calcium hypochlorite is another chlorinating chemical used primarily in smaller applications. It is a white, dry solid containing approximately 65% chlorine, and is commercially available in granular and tablet forms.

Advantages
- ✓ More stable than sodium hypochlorite, allowing longer storage
- ✓ Fewer training requirements and regulations than elemental chlorine

Limitations
- ✓ Dry chemical requires more handling than sodium hypochlorite
- ✓ Precipitated solids formed in solution complicate chemical feeding
- ✓ Higher chemical costs than elemental chlorine
- ✓ Fire or explosive hazard if handled improperly
- ✓ Potential to add inorganic byproducts (chlorate, chlorite and bromate) to water

Onsite Hypochlorite Generation

In recent years some municipalities have installed on-site hypochlorite generators that produce weak hypochlorite solutions (~0.8%) using an electrolytic cell and a solution of salt water.

Advantages

- ✓ Minimal chemical storage and transport

Limitations

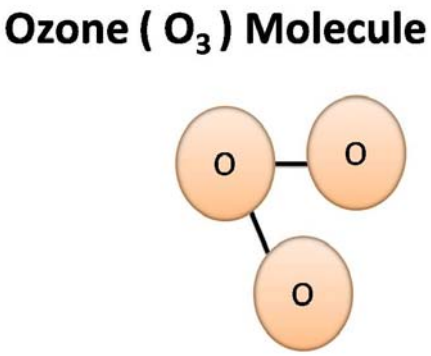
- ✓ More complex and requires a higher level of maintenance and technical expertise
- ✓ High capital cost
- ✓ Operating costs are often higher than for commercial hypochlorite
- ✓ Requires careful control of salt quality
- ✓ Weak solution requires high volume chemical feed and control
- ✓ Byproducts in generated hypochlorite may be difficult to monitor and control
- ✓ System backup may be more difficult and costly

Ozone

Ozone (O_3) is generated on-site at water treatment facilities by passing dry oxygen or air through a system of high voltage electrodes. Ozone is one of the strongest oxidants and disinfectants available. Its high reactivity and low solubility, however, make it difficult to apply and control. Contact chambers are fully contained and non-absorbed ozone must be destroyed prior to release to avoid corrosive and toxic conditions. Ozone is more often applied for oxidation rather than disinfection purposes.

Advantages

- ✓ Strongest oxidant/disinfectant available
- ✓ Produces no chlorinated THMs, HAAs
- ✓ Effective against Cryptosporidium at higher concentrations
- ✓ Used with Advanced Oxidation processes to oxidize refractory organic compounds



Limitations

- ✓ Process operation and maintenance requires a high level of technical competence
- ✓ Provides no protective residual
- ✓ Forms brominated byproducts (bromate, brominated organics)
- ✓ Forms non-halogenated byproducts (ketenes, organic acids, aldehydes)
- ✓ Breaks down more complex organic matter; smaller compounds can enhance microbial re-growth in distribution systems and increase DBP formation during secondary disinfection processes.
- ✓ Higher operating and capital costs than chlorination
- ✓ Difficult to control and monitor particularly under variable load conditions

Ultraviolet Radiation

Ultraviolet (UV) radiation, generated by mercury arc lamps, is a non-chemical disinfectant. When UV radiation penetrates the cell wall of an organism, it damages genetic material, and prevents the cell from reproducing. Although it has a limited track record in drinking water applications, UV has been shown to effectively inactivate many pathogens while forming limited disinfection byproducts.

Advantages

- ✓ Effective at inactivating most viruses, spores and cysts
- ✓ No chemical generation, storage, or handling
- ✓ Effective against Cryptosporidium
- ✓ No known byproducts at levels of concern

Limitations

- ✓ No residual protection
- ✓ Low inactivation of some viruses (reoviruses and rotaviruses)
- ✓ Difficult to monitor efficacy
- ✓ Irradiated organisms can sometimes repair and reverse the destructive effects of UV through a process known as photo-reactivation
- ✓ May require additional treatment steps to maintain high-clarity water
- ✓ Does not provide oxidation, or taste and odor control
- ✓ High cost of adding backup/emergency capacity
- ✓ Mercury lamps may pose a potable water and environmental toxicity risk

Alternative Disinfectants

Up until the late 1970s, chlorine was virtually the only disinfectant used to treat drinking water. Chlorine was considered an almost ideal disinfectant, based on its proven characteristics:

- ✓ Effective against most known pathogens
- ✓ Provides a residual to prevent microbial re-growth and protect treated water throughout the distribution system
- ✓ Suitable for a broad range of water quality conditions
- ✓ Easily monitored and controlled

Test Methods Available for Residual Chlorine

Residual Chlorine can be measured using different methods. Iodometric and DPD colorimetric methods are the most common methods. Each method has its own set of reagents and concentration range.

Iodometric Method
Residual Chlorine by Iodometric has a minimum detectable concentration of 40ppb if 0.01N sodium thiosulfate is used. Prepare the sample for titration by adding 5mL of acetic acid and 1g of potassium iodide to the sample. Titrate the sample with 0.01N sodium thiosulfate. Concentrations below 1 mg/L should be measured by using either 0.00564N sodium thiosulfate or 0.00564N phenylarsine oxide.

DPD Colorimetric Method
Residual Chlorine can also be measured by the DPD Colorimetric method. This method has a minimum detectable concentration of 10ppb. In this method, the calibration is either made up from a chlorine solution or a potassium permanganate solution. The typical calibration range for this method is 0.05 to 4mg/L. The reagents used in this method are a phosphate buffer and N,N-diethyl-p-phenylenediamine indicator solution. The samples are mixed with the reagents and then read on a spectrophotometer at a wavelength of 515nm.

Chlorine in water solutions is not stable. As a result, its concentration in samples decreases rapidly. Exposure to sunlight or other strong light, air, or agitation will further reduce the quantity of chlorine present in solutions. Samples to be analyzed for chlorine cannot be stored or preserved. Tests must be started immediately after sampling. Therefore, samples taken for the chlorine residual test must be grab samples only and excessive agitation must be avoided.

It is not necessary to use special sampling devices or containers for the chlorine residual test. However, the sampling container should be capable of collecting samples from a representative sampling point following chlorine contact, and should be made of resistant materials that will not rust or corrode, and which can be easily cleaned.

NOTE: A long handled aluminum dipper attached to a wooden handle, or an equivalent device, is acceptable for collecting samples. Do not use coffee cans, bleach bottles, etc.

Preparation of Chemicals
At a minimum, hand and eye protection should be used when handling any of the chemicals mentioned in this section. Before working with any chemical, consult the appropriate Material Safety Data Sheet (MSDS) to determine if other safety precautions are necessary.

Chlorine Residual Reagents
Iodometric and Amperometric Methods:
I. Standard Phenylarsine Oxide (PAO) Solution, 0.00564 N

A. Prepare 0.3 N sodium hydroxide solution (NaOH) by dissolving 12.0 g NaOH in 800 mL distilled water and diluting to 1 liter.

B. Prepare a 6.0 N hydrochloric acid solution (HCl) by adding 108 mL concentrated HCl to 800 mL distilled water and diluting to 1 liter. (Caution: Concentrated HCl fumes can burn eyes and lungs—do not breathe fumes!)

C. Prepare an approximately 0.00564 N solution of PAO using the following procedures:

1. Dissolve approximately 0.8 g PAO powder in 150 mL of 0.3 N NaOH solution, and allow to settle.

2. Decant 110 mL into 800 mL distilled water and mix thoroughly.

3. Bring to pH 6 to 7 with 6N HCl and dilute to 950 mL with distilled water. (Caution: PAO is poisonous. Wash thoroughly after use and do not ingest.)

D. Standardization

1. Accurately measure 5 to 10 mL freshly standardized 0.0282 N iodine solution into a flask and add 1 mL potassium iodide solution (50g KI dissolved and diluted to 1 L with freshly boiled and cooled distilled water.

2. Titrate with PAO solution, using starch solution as an indicator, until blue disappears.

3. Normality (N) of PAO = (mL iodine solution x 0.0282)/mL PAO titrated.

4. Adjust PAO to 0.00564 N and recheck.

II. Standard Sodium Thiosulfate Solution, 0.00564 N

A. Prepare a 0.1 N sodium thiosulfate solution by dissolving 25 g $Na_2S_2O_3$ $5H_2O$ in 1000 mL of freshly boiled distilled water. Store reagent for at least 2 weeks to allow oxidation of any bisulfite ion present. Add a few mL of chloroform ($CHCl_3$) to minimize bacterial decomposition.

Standardize by one of the following methods:

1. Iodate Method

a. Dissolve 3.249 g anhydrous primary standard quality potassium bi-iodate ($KH(IO_3)2$) or 3.567 g potassium iodate (KIO_3) dried at 103 +/-2°C for 1 hour in distilled water and dilute to 1000 mL to yield a 0.1000 N iodate solution. Store in a glass stoppered bottle.

b. Add, with constant stirring, 1 mL concentrated sulfuric acid (H_2SO_4), 10 mL 0.1000 N iodate solution, and 1 g potassium iodide (KI) to 80 mL distilled water. Titrate immediately with 0.1 N sodium thiosulfate ($Na_2S_2O_3$) until the yellow color of the liberated iodine is almost discharged. Add 1 mL starch indicator solution and continue titration until the blue color disappears.

c. The normality (N) of the sodium thiosulfate is calculated as follows: N of $Na_2S_2O_3$ = 1/mL $Na_2S_2O_3$ for titration

2. Dichromate Method

A. Dissolve 4.904 g anhydrous primary standard grade potassium dichromate ($K_2Cr_2O_7$) in distilled water and dilute to 1000 mL to yield a 0.1000 N dichromate solution. Store in a glass stoppered bottle.

B. For maximum stability of the standard 0.00564 N sodium thiosulfate solution, prepare by diluting an aged 0.1N $Na_2S_2O_3$ standard solution with freshly boiled distilled water. Add 10 mg Mercuric iodide and 4 g of sodium borate per liter of solution. Standardize daily using 0.00564 N potassium dichromate or iodate solution.

III. Standard Iodine Solution (I_2), 0.1 N

A. Dissolve 40 g potassium iodide (KI) in 25 mL chlorine-demand-free water.

B. Add 13 g resublimed iodine (I_2) and stir until dissolved.

C. Transfer to a 1 liter volumetric flask and dilute to the mark.

D. Standardization

1. Volumetrically measure 40 to 50 mL 0.1 N arsenite solution into a flask.

2. Titrate with 0.1 N iodine solution using starch solution as an indicator.

3. Just before end-point is reached, add a few drops of hydrochloric acid solution to liberate sufficient carbon dioxide (CO_2) to saturate the solution.

4. Titrate until blue color first appears and remains.

5. Normality (N) of iodine = (mL of arsenite solution used x 0.1)/mL of iodine titrated

IV. Standard Iodine Titrant (I_2), 0.0282 N

A. Dissolve 25 g KI in a bottle of distilled water in a 1L volumetric flask.

B. Add the correct amount of the exactly standardized 0.1 N iodine solution to yield a 0.0282 N solution.

C. Dilute to one liter with chlorine-demand-free water.

D. Store iodine solutions in amber bottles or in the dark, and protect from exposure to direct sunlight. Do not use rubber stoppers; keep iodine from all contact with rubber.

E. Check titrant normality daily against 0.00564 N PAO or sodium thiosulfate solution. A procedure for calculating a correction factor for this titrant is given in Appendix C.

V. Standard Potassium Iodate Titrant (KIO3), 0.00564 N

A. Dissolve 201.2 mg primary standard grade potassium iodate (KIO_3), dried for 1 hour at 103°C, or 183.3 mg primary standard grade anhydrous potassium bi-iodate ($KH(IO_3)2V$) in distilled water.

B. Dilute to 1 liter volumetrically.

C. Store in glass bottles in the dark and protect from exposure to direct sunlight.

VI. Potassium Iodide Solution (KI), 5% W/V

A. Dissolve 50 g KI in freshly boiled and cooled distilled water and dilute to 1 liter.

B. Store in a brown glass-stoppered bottle in the dark, preferably at 4°C.

C. Discard when solution becomes yellow.

VII. Acetate Buffer Solution, pH 4.0

A. Dissolve 146 g anhydrous sodium acetate ($NaC_2H_3O_2\ 3H_2O$) in 400 mL distilled water.

B. CAREFULLY add 458 mL concentrated (glacial) acetic acid.

C. Dilute to 1 liter with chlorine-demand-free water.

VIII. Standard Arsenite Solution (As_2O_3), 0.1N

A. Accurately weigh a dried, cooled stoppered weighing bottle.

NOTE: Use forceps or tongs—do not handle weighing bottle with fingers.

B. In weighing bottle, weigh out approximately 4.95 g arsenic trioxide (As_2O_3).

C. Transfer without loss to a 1 liter volumetric flask

NOTE: Do not attempt to brush out remaining arsenic trioxide).

D. Reweigh bottle and record weight of arsenic trioxide transferred.

E. Add enough distilled water to moisten the arsenic trioxide.

F. Add 15 g sodium hydroxide (NaOH) and 100 mL distilled water.

G. Swirl flask gently until As_2O_3 is dissolved.

H. Dilute to 250 mL and saturate the solution with carbon dioxide (CO_2) by bubbling CO_2 gas through the solution for a few minutes.

NOTE: This converts the sodium hydroxide (NaOH) to sodium bicarbonate ($NaHCO_3$).

I. Dilute to the 1 liter mark, stopper, and mix thoroughly.

J. This solution has an almost indefinite shelf life.

CAUTION: This solution is highly poisonous and is a suspected cancer causing agent: handle carefully!

IX. Starch Indicator

A. Weigh out 5 g soluble or potato starch.

B. Add enough distilled water to make a thin paste.

C. Pour into 1 liter boiling distilled water, stir and let settle overnight.

D. Transfer clear supernatant into a storage container and preserve by adding 1.25 g salicylic acid, 4 g zinc chloride, or a combination of 4 g sodium propionate and 2 g sodium azide per liter of starch solution.

E. Some commercial starch substitutes or powder indicators are acceptable.

X. Phosphoric Acid solution (H_3PO_4), 1 + 9

A. Carefully add 100 mL of phosphoric acid (H_3PO_4), 85%, to 900 mL of freshly boiled distilled water.

B. Caution should be used when handling this solution, as it can be corrosive.

XI. Phosphoric Acid—Sulfamic Acid Solution

A. Dissolve 20 g sulfamic acid (NH_2SO_3H) in 1 liter of 1 + 9 phosphoric acid (H_3PO_4).

DPD Titrimetric Method

I. Phosphate Buffer Solution

A. Dissolve 24 g anhydrous disodium hydrogen phosphate (Na_2HPO_4) in 400 to 500 mL distilled water.

B. Add 46 g anhydrous potassium dihydrogen phosphate (KH_2PO_4).

C. Dissolve 800 mg disodium ethylenediaminetetraacetate dihydrate (EDTA) in a separate container.

NOTE: This chemical is also known as (ethylenediamine) tetraacetic acid sodium salt.

D. Combine the 2 solutions and dilute to 1 liter.

E. Add 20 mg mercuric chloride to prevent mold growth.

F. Caution: Mercuric chloride is toxic. Take care to avoid ingestion.

II. DPD Indicator Solution

A. Add 8 mL of a 1 + 3 sulfuric acid solution (H_2SO_4) into 500 mL distilled water. Prepare by mixing one part concentrated H_2SO_4 to 3 parts distilled water. (For example, 5 mL H_2SO_4 to 15 mL distilled water.)

B. Add 200 mg EDTA (disodium ethylenediaminetetraacetate dihydrate).

C. Add 1 g DPD Oxalate (N, N-Diethyl-p-phenylenediamine oxalate).

D. Dilute to 1 liter and store in a brown glass-stoppered bottle and discard when discolored.

CAUTION: The DPD oxalate is poisonous, handle carefully!

III. Standard Ferrous Ammonium Sulfate (FAS) Titrant, 0.00282 N

A. Add 1 mL of 1 + 3 sulfuric acid solution (H2SO4) to 500 mL of freshly boiled and cooled distilled water. Prepare by adding one part concentrated H2SO4 to 3 parts distilled water.

B. Dissolve 1.106 g ferrous ammonium sulfate ($Fe(NH_4)2(SO_4)2\ 6H_2O$)

C. Dilute to 1 liter.

D. This standard can be used for 1 month before replacement.

E. Standardize weekly using the following procedure:

1. Measure 100 mL of FAS standard solution into an Erlenmeyer flask.

2. Add 10 mL of 1 + 5 sulfuric acid. Prepare by adding one part concentrated H_2SO_4 to 5 parts distilled water.

3. Add 5 mL concentrated phosphoric acid.

4. Add 2 mL 0.1% barium diphenylamine sulfonate indicator. Prepare by dissolving 0.1 g ($C_6H_5NHC_6H_4$-4-SO_3) Ba in 100 mL distilled water.

5. Titrate with 0.100N potassium dichromate (see iodometric and amperometric section for preparation directions) to a violet end-point that persists for 30 seconds.

DPD Colorimetric Method

I. Phosphate Buffer Solution

(see DPD Titrimetric Method chemicals)

II. DPD Indicator Solution

(see DPD Titrimetric Method chemicals)

III. Potassium Permanganate Stack Solution

A. Dissolve 891 mg potassium permanganate ($KMnO_4$) in distilled water and dilute to 1000 mL.

IV. Potassium Permanganate Standard Solution

A. Dilute 10 mL of stock solution to 100 mL in a volumetric flask.

B. 1 mL of the standard solution diluted to 100 mL with distilled water will be equivalent to 1.0 mg/L chlorine residual in a DPD reaction.

C. Prepare standard solutions by diluting appropriate volumes to 100 mL with distilled water.

If a direct concentration readout colorimeter is used, the DPD and buffer reagents should be prepared or ordered in accordance with the instrument manufacturer's instructions. If the Hach DR100 colorimeter is used, the prepared DPD powder pillows used with the Hach direct reading colorimeters may be purchased from the Hach Company at the following address:

Hach Company
P.O. Box 389
Loveland, Colorado 80539

More recently, drinking water providers have faced an array of new challenges, including:

- ✓ Treating resistant pathogens such as Giardia and Cryptosporidium
- ✓ Minimizing disinfection byproducts
- ✓ New environmental and safety regulations
- ✓ Strengthening security at treatment facilities

To meet these new challenges, water system managers must design unique disinfection approaches to match each system's characteristics and source water quality. While chlorination remains the most commonly used disinfection method by far, water systems may use alternative disinfectants, including chloramines, chlorine dioxide, ozone, and ultraviolet radiation. No single disinfection method is right for all circumstances, and in fact, water systems may use a variety of methods to meet overall disinfection goals at the treatment plant, and to provide residual protection throughout the distribution system.

In response to new regulations, emerging science on microbial contaminants, as well as safety and security concerns related to treatment chemicals, water system managers will continue to evaluate chlorine and other disinfection methods.

Despite these challenges, a number of factors indicate that drinking water chlorination will remain a corner-stone of waterborne disease prevention.

- ✓ Disinfection is unquestionably the most important step in drinking water treatment, and chlorine's wide range of benefits cannot be provided by any other single disinfectant.
- ✓ It is uncertain that alternative disinfectants reduce potential DBP risks significantly (IPCS 2000). All chemical disinfectants produce byproducts. Generally, the best approach to control disinfection byproducts is to remove natural organic precursors prior to disinfection (EPA 2001). To comply with the forthcoming Long Term 2 Enhanced Surface Water Treatment Rule, some systems with high levels of Cryptosporidium in their source water may choose to adopt alternative disinfection methods (e.g., chlorine dioxide, ozone, or UV). However, most water systems are expected to meet disinfection requirements without changing treatment technologies.
- ✓ The U.S. EPA's forthcoming Groundwater Rule, as well as efforts to strengthen Canadian drinking water standards following the E coli. outbreak in Walkerton, ON will likely increase the use of chlorination for ground water systems.
- ✓ Only chlorine-based disinfectants provide residual protection, an important part of the multi-barrier approach to preventing waterborne disease.
- ✓ World leaders increasingly recognize safe drinking water as a critical building block of sustainable development (see Sidebar). Chlorination can provide cost-effective disinfection for remote rural villages and large cities alike, helping to bring safe water to those in need.

Microscopic Waterborne Agents

It is easy to take for granted the safety of modern municipal drinking water, but prior to widespread filtration and chlorination, contaminated drinking water presented a significant public health risk. The microscopic waterborne agents of cholera, typhoid fever, dysentery and hepatitis A killed thousands of U.S. residents annually before disinfection methods were employed routinely, starting about a century ago. Although these pathogens are defeated regularly now by technologies such as chlorination, they should be thought of as ever-ready to stage a come-back given conditions of inadequate or no disinfection.

Understanding Bacteria
Bacteria are microorganisms often composed of single cells shaped like rods, spheres or spiral structures. Prior to widespread chlorination of drinking water, bacteria like Vibrio cholerae, Salmonella typhii and several species of Shigella routinely inflicted serious diseases such as cholera, typhoid fever and bacillary dysentery, respectively. As recently as 2000, a drinking water outbreak of E. coli in Walkerton, Ontario sickened 2,300 residents and killed seven when operators failed to properly disinfect the municipal water supply.

While developed nations have largely conquered water-borne bacterial pathogens through the use of chlorine and other disinfectants, the developing world still grapples with these public health enemies

Understanding Viruses
Viruses are infectious agents that can reproduce only within living host cells. Shaped like rods, spheres or filaments, viruses are so small that they pass through filters that retain bacteria. Enteric viruses, such as hepatitis A, Norwalk virus and rotavirus are excreted in the feces of infected individuals and may contaminate water intended for drinking. Enteric viruses infect the gastrointestinal or respiratory tracts, and are capable of causing a wide range of illness, including diarrhea, fever, hepatitis, paralysis, meningitis and heart disease (American Water Works Association, 1999).

Understanding Protozoan Parasites
Protozoan parasites are single-celled microorganisms that feed on bacteria found in multicellular organisms, such as animals and humans. Several species of protozoan parasites are transmitted through water in dormant, resistant forms, known as cysts and oocysts. According to the World Health Organization, Cryptosporidium parvum oocysts and Giardia lamblia cysts are introduced to waters all over the world by fecal pollution. The same durable form that permits them to persist in surface waters makes these microorganisms resistant to normal drinking water chlorination (WHO, 2002b). Water systems that filter raw water may successfully remove protozoan parasites.

Emerging Pathogens
An emerging pathogen is one that gains attention because it is one of the following:

- a newly recognized disease-causing organism
- a known organism that starts to cause disease
- an organism whose transmission has increased

Understanding Oxidizing Agents
Oxidizing agents act by oxidizing the cell membrane of microorganisms, which results in a loss of structure and leads to cell lysis and death. A large number of disinfectants operate in this way. Chlorine and oxygen are strong oxidizers, so their compounds figure heavily here.

- ✓ Sodium hypochlorite is very commonly used. Common household bleach is a sodium hypochlorite solution and is used in the home to disinfect drains, toilets, and other surfaces. In more dilute form, it is used in swimming pools, and in still more dilute form, it is used in drinking water. When pools and drinking water are said to be chlorinated, it is actually sodium hypochlorite or a related compound—not pure chlorine—that is being used. Chlorine partly reacts with proteinaceous liquids such as blood to form non-oxidizing N-chloro compounds, and thus higher concentrations must be used if disinfecting surfaces after blood spills. Commercial solutions with higher concentrations contain substantial amounts of sodium hydroxide for stabilization of the concentrated hypochlorite, which would otherwise decompose to chlorine, but the solutions are strongly basic as a result.

- ✓ Other hypochlorites such as calcium hypochlorite are also used, especially as a swimming pool additive. Hypochlorites yield an aqueous solution of hypochlorous acid that is the true disinfectant. Hypobromite solutions are also sometimes used.

- ✓ Electrolyzed water or "Anolyte" is an oxidizing, acidic hypochlorite solution made by electrolysis of sodium chloride into sodium hypochlorite and hypochlorous acid. Anolyte has an oxidation-

reduction potential of +600 to +1200 mV and a typical pH range of 3.5—8.5, but the most potent solution is produced at a controlled pH 5.0–6.3 where the predominant oxychlorine species is hypochlorous acid.

- ✓ Chloramine is often used in drinking water treatment.

- ✓ Chloramine-T is antibacterial even after the chlorine has been spent, since the parent compound is a sulfonamide antibiotic.

- ✓ Chlorine dioxide is used as an advanced disinfectant for drinking water to reduce waterborne diseases. In certain parts of the world, it has largely replaced chlorine because it forms fewer byproducts. Sodium chlorite, sodium chlorate, and potassium chlorate are used as precursors for generating chlorine dioxide.

- ✓ Hydrogen peroxide is used in hospitals to disinfect surfaces and it is used in solution alone or in combination with other chemicals as a high level disinfectant. Hydrogen peroxide is sometimes mixed with colloidal silver. It is often preferred because it causes far fewer allergic reactions than alternative disinfectants. Also used in the food packaging industry to disinfect foil containers. A 3% solution is also used as an antiseptic.

- ✓ Hydrogen peroxide vapor is used as a medical sterilant and as room disinfectant. Hydrogen peroxide has the advantage that it decomposes to form oxygen and water thus leaving no long term residues, but hydrogen peroxide as with most other strong oxidants is hazardous, and solutions are a primary irritant. The vapor is hazardous to the respiratory system and eyes and consequently the OSHA permissible exposure limit is 1 ppm (29 CFR 1910.1000 Table Z-1) calculated as an eight hour time weighted average and the NIOSH immediately dangerous to life and health limit is 75 ppm. Therefore, engineering controls, personal protective equipment, gas monitoring etc. should be employed where high concentrations of hydrogen peroxide are used in the workplace. Vaporized hydrogen peroxide is one of the chemicals approved for decontamination of anthrax spores from contaminated buildings, such as occurred during the 2001 anthrax attacks in the U.S. It has also been shown to be effective in removing exotic animal viruses, such as avian influenza and Newcastle disease from equipment and surfaces.

- ✓ The antimicrobial action of hydrogen peroxide can be enhanced by surfactants and organic acids. The resulting chemistry is known as Accelerated Hydrogen Peroxide and is produced by Virox Technologies Inc. A 2% solution, stabilized for extended use, achieves high-level disinfection in 5 minutes, and is suitable for disinfecting medical equipment made from hard plastic, such as in endoscopes.[19] The evidence available suggests that products based on Accelerated Hydrogen Peroxide, apart from being good germicides, are safer for humans and benign to the environment.

- ✓ Iodine is usually dissolved in an organic solvent or as Lugol's iodine solution. It is used in the poultry industry. It is added to the birds' drinking water. In human and veterinary medicine, iodine products are widely used to prepare incision sites prior to surgery. Although it increases both scar tissue formation and healing time, tincture of iodine is used as an antiseptic for skin cuts and scrapes, and remains among the most effective antiseptics known.

- ✓ Ozone is a gas used for disinfecting water, laundry, foods, air, and surfaces. It is chemically aggressive and destroys many organic compounds, resulting in rapid decolorization and deodorization in addition to disinfection. Ozone decomposes relatively quickly, however, so that tap water chlorination cannot be entirely replaced by ozonation, as the ozone would decompose already in the water piping. Instead, it is used to remove the bulk of oxidizable matter from the water, which would produce small amounts of organochlorides if treated with chlorine only.

- ✓ Peracetic acid is a disinfectant produced by reacting hydrogen peroxide with acetic acid. It is broadly effective against microorganisms and is not deactivated by catalase and peroxidase, the enzymes that break down hydrogen peroxide. It also breaks down to food safe and environmentally friendly residues (acetic acid and hydrogen peroxide), and therefore can be used in non-rinse applications. It can be used over a wide temperature range (0-40°C), wide pH range (3.0-7.5), in clean-in-place (CIP) processes, in hard water conditions, and is not affected by protein residues.

- ✓ Performic acid is the simplest and most powerful perorganic acid. Formed from the reaction of hydrogen peroxide and formic acid, it reacts more rapidly and powerfully than peracetic acid before breaking down to water and carbon dioxide.

- ✓ Potassium permanganate ($KMnO_4$) is a purplish-black crystalline powder that colors everything it touches, through a strong oxidizing action. This includes staining "stainless" steel, which somehow limits its use and makes it necessary to use plastic or glass containers. It is used to disinfect aquariums and is also widely used in community swimming pools to disinfect ones feet before entering the pool. Typically, a large shallow basin of KMnO4/water solution is kept near the pool ladder. Participants are required to step in the basin and then go into the pool. Additionally, it is widely used to disinfect community water ponds and wells in tropical countries, as well as to disinfect the mouth before pulling out teeth. It can be applied to wounds in dilute solution.

Understanding Waterborne Viruses

More than 100 types of human pathogenic viruses may be present in fecal-contaminated waters (Havelaar and others, 1993). Treatment processes and watershed management strategies designed on the basis of bacteriological criteria do not necessarily protect against viral infection because viruses are generally more persistent in the environment and are not removed as completely by treatment. In addition, because of their smaller size, viruses (0.023 to 0.080 µm) are transported further in ground water than bacteria (0.5 to 3µ m) or protozoan pathogens (4 to 15 µm) (Abbaszadegan and others, 1998). Because of the importance of viruses as a major public health concern, new methods for detection of enteric viruses and the search for indicators of viral contamination continue.

The current method for culturing enteric viruses under the ICR (U.S. Environmental Protection Agency, 1996c) is recognized as being difficult to implement; therefore, the ICR does not preclude the use of additional methods for research purposes. In addition, cell-culture methods are not available or suitable for all viruses of public health concern. One method, reverse-transcriptase-polymerase chain reaction (RT-PCR), a gene-probe method that amplifies and recognizes the nucleic acids of target viruses, has been adequately validated by the USEPA (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997) and is becoming widely used for environmental monitoring of enteric viruses. The RTPCR method, however, does not determine the infectivity of the virus, and it is technically demanding, time consuming, and costly for routine use.

Because monitoring of enteric viruses is recognized as being difficult and time consuming, some researchers advocate the use of coliphage as indicator viruses for fecal contamination (Sobsey and others, 1995). Coliphages are bacteriophages that infect and replicate in coliform bacteria. The two main groups of coliphages that are considered as candidates for viral indicators are somatic and F-specific coliphages.

Somatic coliphages infect coliform bacteria by attachment to the outer cell membrane or cell wall. They are widely distributed in both fecal-contaminated and uncontaminated waters; therefore, they may not be reliable indicators of fecal contamination (Sobsey and others, 1995). F-specific coliphages attach only to the F-pilus of coliforms that carry the F+ plasmid; F-pili are made only by bacteria grown at higher temperatures.

Hence, F-specific coliphages found in environmental samples presumably come from warm-blooded animals or sewage (Handzel and others 1993). Although somatic and F-specific coliphages are not consistently found in feces, they are found in high numbers in sewage and are thought to be reliable indicators of the sewage contamination of waters (International Association of Water Pollution Research and Control, 1991). Coliphage is also recognized to be representative of the survival and transport of viruses in the environment. To date, however, coliphage has not been found to correlate with the presence of pathogenic viruses.

Sampling Procedures

Streamwater Sample Collection

When designing a sampling plan, consider that the spatial and temporal distribution of microorganisms in surface water can be as variable as the distribution of suspended sediment because microorganisms are commonly associated with solid particles. The standard samplers used in by the majority of samplers can be used to collect streamwater samples for bacterial and viral indicators, Cryptosporidium, and Giardia providing that the equipment coming in contact with the water is properly cleaned and sterilized. For streamwater samples, these include the US-D77TM, US-D95, US-DH81, and weighted- and open-bottle samplers with autoclavable Teflon, glass, or polypropylene components.

- Prepare a separate set of sterile equipment (bottles nozzles, and caps) for sampling at each site.
- Follow sampling techniques given in Shelton (1994) to ensure that a sample is representative of the flow in the cross section. Use equal-width increment (EWI) or equal-discharge-increment (EDI) methods described in Edwards and Glysson (1988), unless site characteristics dictate otherwise.
- Because churn and cone splitters cannot be autoclaved, use a sterile 3-L bottle to composite subsamples for bacterial and viral indicators when using EDI and EWI methods. If possible, composite by collecting subsamples at vertical locations in the cross section without overfilling the bottle.
- Alternatively, if the stream depth and (or) velocity is not sufficient to use depth-width integrating techniques, collect a sample by a hand-dip method (Myers and Sylvester, 1997).

• Collect approximately 1 L of streamwater for bacterial and viral indicators. Process the sample for E. coli and enterococci; send the remainder (at least 500 mL) on ice to the laboratory for C. perfringens and coliphage analysis.

Cryptosporidium and Giardia Analysis

For Cryptosporidium and Giardia analysis by Method 1623 (U.S. Environmental Protection Agency, 1999c), collect 10 L of streamwater for each protozoan pathogen using standard sampling techniques described in Myers and Sylvester (1997). Special sterilization procedures are needed for equipment used in the collection of samples for Cryptosporidium and Giardia. Autoclaving is not effective in neutralizing the epitopes on the surfaces of the oocysts and cysts that will react with the antibodies used for detection.

• Wash and scrub the equipment with soap and warm tap water to remove larger particulates and rinse with deionized water. Submerge the equipment in a vessel containing 12 percent hypochlorite solution for 30 minutes. Wash the equipment free of residual sodium hypochlorite solution with three rinses of filter-sterilized water; do not de-chlorinate the equipment using sodium thiosulfate. This procedure is best done in the office with dedicated sampling equipment for each site; however, it may be done in the field as long as the hypochlorite solution is stored and disposed of properly.

• Composite the sample in a 10-L cubitainer that is pre-sterilized by the manufacturer. The cubitainer is sent in a cardboard box to laboratory for Cryptosporidium analysis. The sample does not have to be kept on ice during transport. At this time, two methods are recommended for analysis of water samples for enteric viruses: (1) the reverse-transcriptase, polymerase chain reaction (RTPCR) method (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997) and (2) the cell-culture method (U.S. Environmental Protection Agency, 1996c). Sampling and equipment cleaning procedures are more thoroughly described elsewhere (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997; U.S. Environmental Protection Agency, 1996c). Briefly, 100 L of streamwater is pumped by means of a specially designed sampling apparatus and passed through a Virosorb1 1MDS filter (Cuno, Meriden, Conn.).The 1MDS filters, which remove viruses present in the water by charge interactions, are kept on ice and sent to a central laboratory for virus elution, concentration, and detection.

Ground-Water Sample Collection

Collecting

Ground-water samples by use of sterile techniques requires knowledge of the type of well, its use, its construction, and its condition.

• Swab the electronic tape used for water-level measurements with isopropyl or ethyl alcohol.

• In sampling subunit survey wells, once purging criteria have been met as described in Koterba and others (1995), collect the sample directly from the tap into a sterile container.

• Remove screens, filters, other devices from the tap before collecting the sample, and do not sample from leaking taps.

Because we are interested in the microbial population in the ground water and not in the distribution system, it is best to sample directly from the wellhead using a pump with sterile tubing, if possible.

Disinfection of Water and Wastewater

The disinfection of potable water and wastewater provides a degree of protection from contact with pathogenic organisms including those causing cholera, polio, typhoid, hepatitis and a number of other bacterial, viral and parasitic diseases. Disinfection is a process where a significant percentage of pathogenic organisms are killed or controlled. As an individual pathogenic organism can be difficult to detect in a large volume of water or wastewater, disinfection efficacy is most often measured using "indicator organisms" that coexist in high quantities where pathogens are present. The most common indicator organism used in the evaluation of drinking water is Total Coliform (TC), unless there is a reason to focus on a specific pathogen.

The most common indicator organism for wastewater evaluation is fecal coliform but there has been discussion regarding the use of Escherichia coli (E. coli) or Total Coliform. As domestic wastewater contains approximately 1,000 times more indicator organisms than typical surface water, understanding wastewater disinfection will make it easier to understand water disinfection.

Chlorine gas is primarily a respiratory irritant and concentrations in air above one ppm can usually be detected by most persons. Chlorine causes varying degrees of irritation of the skin, mucus membranes, and the respiratory system, depending on the concentration and the duration of exposure. Severe exposure can cause death, but the severe irritating effect makes it unlikely that anyone would remain in the chlorine-containing atmosphere unless trapped or unconscious.

Liquid chlorine may cause skin and eye burns upon contact with these tissues. Chlorine produces no known cumulative or chronic effect, and complete recovery usually can be expected to occur shortly following mild, short term exposure. An eight-hour time-weighted exposure of one ppm and a one-hour weighted exposure are the current federal Occupational Safety and Health Administration (OSHA) standards.

Understanding Bacteriophage

Bacteriophages may have a lytic cycle or a lysogenic cycle, and a few viruses are capable of carrying out both. With lytic phages such as the T4 phage, bacterial cells are broken open (lysed) and destroyed after immediate replication of the virion. As soon as the cell is destroyed, the phage progeny can find new hosts to infect. Lytic phages are more suitable for phage therapy. Some lytic phages undergo a phenomenon known as lysis inhibition, where completed phage progeny will not immediately lyse out of the cell if extracellular phage concentrations are high. This mechanism is not identical to that of temperate phage going dormant and is usually temporary.

In contrast, the lysogenic cycle does not result in immediate lysing of the host cell. Those phages able to undergo lysogeny are known as temperate phages. Their viral genome will integrate with host DNA and replicate along with it fairly harmlessly, or may even become established as a plasmid. The virus remains dormant until host conditions deteriorate, perhaps due to depletion of nutrients; then, the endogenous phages (known as prophages) become active. At this point they initiate the reproductive cycle, resulting in lysis of the host cell. As the lysogenic cycle allows the host cell to continue to survive and reproduce, the virus is reproduced in all of the cell's offspring. An example of a bacteriophage known to follow the lysogenic cycle and the lytic cycle is the phage lambda of E. coli.

Sometimes prophages may provide benefits to the host bacterium while they are dormant by adding new functions to the bacterial genome in a phenomenon called lysogenic conversion. An eminent example is the conversion of a harmless strain of Vibrio cholerae by a phage into a highly virulent one, which causes cholera.

Attachment and Penetration

To enter a host cell, bacteriophages attach to specific receptors on the surface of bacteria, including lipopolysaccharides, teichoic acids, proteins, or even flagella. This specificity means a bacteriophage can infect only certain bacteria bearing receptors to which they can bind, which in turn determines the phage's host range. Host growth conditions also influence the ability of the phage to attach and invade them. As phage virions do not move independently, they must rely on random encounters with the right receptors when in solution (blood, lymphatic circulation, irrigation, soil water, etc.).

Myovirus bacteriophages use a hypodermic syringe-like motion to inject their genetic material into the cell. After making contact with the appropriate receptor, the tail fibers flex to bring the base plate closer to the surface of the cell; this is known as reversible binding. Once attached completely, irreversible binding is initiated and the tail contracts, possibly with the help of ATP present in the tail, injecting genetic material through the bacterial membrane. Podoviruses lack an elongated tail sheath similar to that of a myovirus, so they instead use their small, tooth-like tail fibers to enzymatically degrade a portion of the cell membrane before inserting their genetic material.

Virions

A virion is a complete functional virus that has the capacity to infect living tissue. This means that it includes the genetic material, the capsid, the enveloppe and the membrane proteins that allow the virus to bind to its host and enter it. A virus will not have an enveloppe within a cell. If the cell was burst artificially, then these virus particles cannot be called virion because they will lack certain proteins that will make them infectious even though the genetic material is present. Not all viruses have enveloppes, but most viruses have certain proteins that are necessary to permit them to enter the host cell.

Biomolecules found in virions: genetic material, either DNA or RNA, single or double stranded, nucleoprotein capsid, maybe an enveloppe usually receptor proteins or enzymes that permit binding or entry into the host. A viroid is a plant pathogen consisting of a circular piece of RNA without a protein coat.

Understanding Disinfection

Wastewater Disinfection
There are a number of chemicals and processes that will disinfect wastewater, but none are universally applicable. Most septic tanks discharge into various types of subsurface wastewater infiltration systems (SWIS), such as tile fields or leach fields. These applications rely on the formation of a biomat at the gravel-soil interface where "biodegradation and filtration combine to limit the travel of pathogens." Aerobic treatment processes reduce pathogens, but not enough to qualify as a disinfection process. "Chlorination/dechlorination has been the most widely used disinfection technology in the U.S.; ozonation and UV light are emerging technologies." Each of these three methods have different considerations for the disinfection of wastewater.

Water Disinfection
Disinfection is usually the final stage in the water treatment process in order to limit the effects of organic material, suspended solids and other contaminants. Like the disinfection of wastewater, the primary methods used for the disinfection of water in very small (25-500 people) and small (501-3,300 people) treatment systems are ozone, ultraviolet irradiation (UV) and chlorine. There are numerous alternative disinfection processes that have been less widely used in small and very small water treatment systems, including chlorine dioxide, potassium permanganate, chloramines and peroxone (ozone/hydrogen peroxide).

Surface waters have been the focal point of water disinfection regulations since their inception, as groundwaters (like wells) have been historically considered to be free of microbiological contamination. Current data indicates this to not be true. Amendments to the Safe Drinking Water Act in 1996 mandate the development of regulations to require disinfection of groundwater "as necessary." While these regulations will apply to very small systems serving twenty-five people at least 60 days out of the year, the rules will not apply to private wells. However, the EPA recommends that wells be tested at least once per year and disinfected as necessary. While these proposed regulations have not yet been finalized, they will likely include; testing by each state, identification of contaminated water supplies, corrective action requiring disinfection and compliance monitoring. The rules are currently scheduled to be implemented in July 2003.

Residual Disinfection
The EPA requires a residual level of disinfection of water in pipelines to prevent microbial re-growth and help protect treated water throughout the distribution system. EPA”s maximum residual disinfection levels (MRDLs) are 4 mg/l for chlorine, 4 mg/l for chloramines and 0.8 mg/l for chlorine dioxide. Although chlorine levels are usually significantly lower in tap water, EPA believes that levels as high as the MRDLs pose no risk of adverse health effects, allowing for an adequate margin of safety (U.S. EPA, 1998a).

Chlorate Ion
The chlorate anion has the formula ClO-3. In this case, the chlorine atom is in the +5 oxidation state. "Chlorate" can also refer to chemical compounds containing this anion; chlorates are the salts of chloric acid. "Chlorate", when followed by a roman numeral in parentheses, e.g. chlorate (VII), refers to a particular oxyanion of chlorine. As predicted by VSEPR, chlorate anions have trigonal pyramidal structures.

Chlorates are powerful oxidizers and should be kept away from organics or easily oxidized materials. Mixtures of chlorate salts with virtually any combustible material (sugar, sawdust, charcoal, organic solvents, metals, etc.) will readily deflagrate. Chlorates were once widely used in pyrotechnics for this reason, though their use has fallen due to their instability. Most pyrotechnic applications which formerly used chlorates in the past now use the more stable perchlorates instead

Examples of chlorates include

- ✓ potassium chlorate, $KClO_3$
- ✓ sodium chlorate, $NaClO_3$
- ✓ magnesium chlorate, $Mg(ClO_3)2$

Chloride Ion

The chloride ion is formed when the element chlorine, a halogen, gains an electron to form an anion (negatively-charged ion) Cl-. The salts of hydrochloric acid contain chloride ions and can also be called chlorides. The chloride ion, and its salts such as sodium chloride, are very soluble in water. It is an essential electrolyte located in all body fluids responsible for maintaining acid/base balance, transmitting nerve impulses and regulating fluid in and out of cells.

The word chloride can also form part of the name of chemical compounds in which one or more chlorine atoms are covalently bonded. For example, methyl chloride, more commonly called chloromethane, (CH_3Cl) is an organic covalently bonded compound, which does not contain a chloride ion.

Chloride is used to form salts that can preserve food such as sodium chloride. Other salts such as calcium chloride, magnesium chloride, potassium chloride have varied uses ranging from medical treatments to cement formation.

An example is table salt, which is sodium chloride with the chemical formula NaCl. In water, it dissociates into Na+ and Cl- ions.

Examples of inorganic covalently bonded chlorides that are used as reactants are:

- ✓ Phosphorus trichloride, phosphorus pentachloride, and thionyl chloride, all three of which reactive chlorinating reagents that have been used in a laboratory.
- ✓ Disulfur dichloride (S_2Cl_2), used for vulcanization of rubber.

A chloride ion is also the prosthetic group present in the amylase enzyme. Another example is calcium chloride with the chemical formula $CaCl_2$. Calcium chloride is a salt that is marketed in pellet form for removing dampness from rooms. Calcium chloride is also used for maintaining unpaved roads and for sanite fortifying roadbases for new construction. In addition, Calcium chloride is widely used as a deicer since it is effective in lowering the melting point when applied to ice.

In the petroleum industry, the chlorides are a closely monitored constituent of the mud system. An increase of the chlorides in the mud system may be an indication of drilling into a high-pressure saltwater formation. Its increase can also indicate the poor quality of a target sand. Chloride is also a useful and reliable chemical indicator of river / groundwater fecal contamination, as chloride is a non-reactive solute and ubiquitous to sewage & potable water. Many water regulating companies around the world utilize chloride to check the contamination levels of the rivers and potable water sources.

Chlorite Ion

The chlorite ion is ClO_2-. A chlorite (compound) is a compound that contains this group, with chlorine in oxidation state +3. Chlorites are also known as salts of chlorous acid. Chlorine can assume oxidation states of -1, +1, +3, +5, or +7 within the corresponding anions Cl-, ClO-, ClO_2-, ClO_3-, or ClO_4-, known commonly and respectively as chloride, hypochlorite, chlorite, chlorate, and perchlorate. An additional oxidation state of +4 is seen in the neutral compound chlorine dioxide ClO_2, which has a similar structure to chlorite ClO_2- (oxidation state +3) and the cation chloryl (ClO_2+) (oxidation state +5).

Chlorine Dioxide

Chlorine dioxide is a chemical compound with the formula ClO_2. This yellowish-green gas crystallizes as bright orange crystals at -59 °C. As one of several oxides of chlorine, it is a potent and useful oxidizing agent used in water treatment and in bleaching. The molecule ClO2 has an odd number of valence electrons and it is therefore a paramagnetic radical. Its electronic structure has long baffled chemists because none of the possible Lewis structures are very satisfactory. In 1933 L.O. Brockway proposed a structure that involved a three-electron bond.

Chemist Linus Pauling further developed this idea and arrived at two resonance structures involving a double bond on one side and a single bond plus three-electron bond on the other. In Pauling's view the latter combination should represent a bond that is slightly weaker than the double bond. In molecular orbital theory this idea is commonplace if the third electron is placed in an anti-bonding orbital. Later work has confirmed that the HOMO is indeed an incompletely-filled orbital.

Chlorine dioxide is a highly endothermic compound that can decompose extremely violently when separated from diluting substances. As a result, preparation methods that involve producing solutions of it without going through a gas phase stage are often preferred. Arranging handling in a safe manner is essential.

In the laboratory, ClO_2 is prepared by oxidation of sodium chlorite:

$$2\ NaClO_2 + Cl_2 - 2\ ClO_2 + 2\ NaCl$$

Over 95% of the chlorine dioxide produced in the world today is made from sodium chlorate and is used for pulp bleaching. It is produced with high efficiency by reducing sodium chlorate in a strong acid solution with a suitable reducing agent such as methanol, hydrogen peroxide, hydrochloric acid or sulfur dioxide. Modern technologies are based on methanol or hydrogen peroxide, as these chemistries allows the best economy and do not co-produce elemental chlorine. The overall reaction can be written;

Chlorate + Acid + reducing agent - Chlorine Dioxide + By-products

The reaction of sodium chlorate with hydrochloric acid in a single reactor is believed to proceed via the following pathway:

$$HClO_3 + HCl - HClO_2 + HOCl$$

$$HClO_3 + HClO_2 - 2\ ClO_2 + Cl_2 + 2\ H_2O$$

$$HOCl + HCl - Cl_2 + H_2O$$

The commercially more important production route uses methanol as the reducing agent and sulfuric acid for the acidity. Two advantages by not using the chloride-based processes are that there is no formation of elemental chlorine, and that sodium sulfate, a valuable chemical for the pulp mill, is a side-product. These methanol-based processes provide high efficiency and can be made very safe.

A much smaller, but important, market for chlorine dioxide is for use as a disinfectant. Since 1999 a growing proportion of the chlorine dioxide made globally for water treatment and other small-scale applications has been made using the chlorate, hydrogen peroxide and sulfuric acid method, which can produce a chlorine-free product at high efficiency.

Traditionally, chlorine dioxide for disinfection applications has been made by one of three methods using sodium chlorite or the sodium chlorite - hypochlorite method:

$$2\ NaClO_2 + 2\ HCl + NaOCl - 2\ ClO_2 + 3\ NaCl + H_2O$$

or the sodium chlorite - hydrochloric acid method:

$$5\ NaClO_2 + 4\ HCl - 5\ NaCl + 4\ ClO_2 + 2\ H_2O$$

All three sodium chlorite chemistries can produce chlorine dioxide with high chlorite conversion yield, but unlike the other processes the chlorite-HCl method produces completely chlorine-free chlorine dioxide but suffers from the requirement of 25% more chlorite to produce an equivalent amount of chlorine dioxide. Alternatively, hydrogen peroxide may efficiently be used also in small scale applications.

Very pure chlorine dioxide can also be produced by electrolysis of a chlorite solution:

$$2\ NaClO_2 + 2\ H_2O - 2\ ClO_2 + 2\ NaOH + H_2$$

High purity chlorine dioxide gas (7.7% in air or nitrogen) can be produced by the Gas: Solid method, which reacts dilute chlorine gas with solid sodium chlorite.

$$2\ NaClO_2 + Cl_2 - 2\ ClO_2 + 2\ NaCl$$

These processes and several slight variations have been reviewed.

Haloacetic Acids
Haloacetic acids are carboxylic acids in which a halogen atom takes the place of a hydrogen atom in acetic acid. Thus, in a monohaloacetic acid, a single halogen would replace a hydrogen atom. For example, chloroacetic acid would have the structural formula CH_2ClCO_2H. In the same manner, in dichloroacetic acid two chlorine atoms would take the place of two hydrogen atoms ($CHCl_2CO_2H$). The inductive effect caused by the electronegative halogens often result in the higher acidity of these compounds by stabilizing the negative charge of the conjugate base.

Contaminants in Drinking Water
Haloacetic acids (HAAs) are a common undesirable by-product of drinking water chlorination. Exposure to such disinfection by-products in drinking water has been associated with a number of health outcomes by epidemiological studies, although the putative agent in such studies has not been identified.

In water, HAAs are stable, with the five most common being:

- ✓ monochloroacetic acid (MCA) $ClCH_2COOH$;
- ✓ dichloroacetic acid (DCA) $Cl_2CHCOOH$;
- ✓ trichloroacetic acid (TCA) Cl_3CCOOH;
- ✓ monobromoacetic acid (MBA) $BrCH_2COOH$;
- ✓ dibromoacetic acid (DBA) $Br_2CHCOOH$.

Collectively, these are referred to as the HAA5. HAAs can be formed by chlorination, ozonation or chloramination of water with formation promoted by slightly acidic water, high organic matter content and elevated temperature. Chlorine from the water disinfection process can react with organic matter and small amounts of bromide present in water to produce various HAAs. A study published in August 2006 found that total levels of HAAs in drinking water were not affected by storage or boiling, but that filtration was effective in decreasing levels.

Hypochlorites
Hypochlorites are calcium or sodium salts of hypochlorous acid and are supplied either dry or in liquid form (as, for instance, in commercial bleach). The same residuals are obtained as with gas chlorine, but the effect on the pH of the treated water is different. Hypochlorite compounds contain an excess of alkali and tend to raise the pH of the water. Calcium hypochlorite tablets are the predominant form in use in the United States for swimming pools. Sodium hypochlorite is the only liquid hypochlorite disinfectant in current use. There are several grades and proprietary forms available. Pound-for-pound of available chlorine, hypochlorite compounds have oxidizing powers equal to gas chlorine and can be employed for the same purposes in water treatment. Gas chlorination requires a larger initial investment for feed equipment than what is needed for hypochlorite compounds.

Calcium hypochlorite materials used in the water industry are chemically different from those materials variously marketed for many years as bleaching powder, chloride of lime, or chlorinated lime. Materials now in common use are high-test calcium hypochlorites containing about 70 percent available chlorine and marketed under several trade names.

High-test calcium hypochlorites are white corrosive solids that give off a strong chlorine odor. Granular powdered or tablet forms are commercially available and all are readily soluble in water.

Sodium hypochlorite is sold only as a liquid and is normally referred to as liquid bleach. It is generally available in concentrations of 5 to 15 percent available chlorine. These solutions are clear, light yellow, strongly alkaline, and corrosive in addition to having a strong chlorine smell.

High-test hypochlorites, though highly active, are relatively stable throughout production, packaging, distribution, and storage. Storage at 86° F. for a year may reduce the available chlorine by about 10 percent. Storing at lower temperatures reduces the loss. All sodium-hypochlorite solutions are unstable to some degree and deteriorate more rapidly than the dry compounds. Most producers recommend a shelf life of 60 to 90 days. Because light and heat accelerate decomposition, containers should be stored in a dry, cool, and dark area.

Disinfection Byproducts
Disinfection byproducts are formed when disinfectants used in water treatment plants react with bromide and/or natural organic matter (i.e., decaying vegetation) present in the source water. Different disinfectants produce different types or amounts of disinfection byproducts. Disinfection byproducts for which regulations have been established have been identified in drinking water, including trihalomethanes, haloacetic acids, bromate, and chlorite.

Trihalomethanes (THM)
Trihalomethanes (THM) are a group of four chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The trihalomethanes are chloroform, bromodichloromethane, dibromochloromethane, and bromoform. EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate total trihalomethanes (TTHM) at a maximum allowable annual average level of 80 parts per billion. This standard will replace the current standard of a maximum allowable annual average level of 100 parts per billion in December 2001 for large surface water public water systems. The standard will become effective for the first time in December 2003 for small surface water and all ground water systems.

Haloacetic Acids (HAA5)
Haloacetic Acids (HAA5) are a group of chemicals that are formed along with other disinfection byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water. The regulated haloacetic acids, known as HAA5, are: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate HAA5 at 60 parts per billion annual average. This standard will become effective for large surface water public water systems in December 2001 and for small surface water and all ground water public water systems in December 2003.

Bromate is a chemical that is formed when ozone used to disinfect drinking water reacts with naturally occurring bromide found in source water. EPA has established the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate bromate at annual average of 10 parts per billion in drinking water. This standard will become effective for large public water systems by December 2001 and for small surface water and all ground public water systems in December 2003.

Chlorite
Chlorite is a byproduct formed when chlorine dioxide is used to disinfect water. EPA has published the Stage 1 Disinfectants/Disinfection Byproducts Rule to regulate chlorite at a monthly average level of 1 part per million in drinking water. This standard will become effective for large surface water public water systems in December 2001 and for small surface water and all ground water public water systems in December 2003.

Chloroform
Chloroform, typically the most prevalent THM measured in chlorinated water, is probably the most thoroughly studied disinfection byproduct. Toxicological studies have shown that high levels of chloroform can cause cancer in laboratory animals. Extensive research conducted since the early 1990s provides a clearer picture of what this means for humans exposed to far lower levels through drinking water.

One study (Larson et al. 1994a) conducted by the Centers for Health Research (CIIT) observed that a very large dose of chloroform, when given to mice once per day into the stomach (a procedure known as gavage), produced liver damage and eventually cancer. In a second CIIT cancer study (Larson et al., 1994b), mice were given the same daily dose of chloroform through the animals' drinking water. This time, no cancer was produced. Follow-up research showed that the daily gavage doses overwhelmed the capability of the liver to detoxify the chloroform, causing liver damage, cell death and regenerative cell growth, thereby increasing risks for cell mutation and cancer in exposed organs. When chloroform was given through drinking water, however, the liver could continually detoxify the chloroform as the mice sipped the water throughout the day. Without the initial liver toxicity, there was no cancer in the liver, kidney or other exposed organs (Butterworth et al., 1998).

In its most recent risk assessment, EPA considered the wealth of available information on chloroform, including the important work done at CIIT. EPA concludes that exposure to chloroform below the threshold level that causes cell damage is unlikely to increase the risk of cancer. While chloroform is likely to be carcinogenic at a high enough dose, exposures below a certain dose range are unlikely to pose any cancer risk to humans (US EPA, 2002a). For drinking water meeting EPA standards, chloroform is unlikely to be a health concern.

Sodium Chlorate
Sodium chlorate is a chemical compound with the chemical formula ($NaClO_3$). When pure, it is a white crystalline powder that is readily soluble in water. It is hygroscopic. It decomposes above 250 °C to release oxygen and leave sodium chloride. Industrially, sodium chlorate is synthesized from the electrolysis of a hot sodium chloride solution in a mixed electrode tank:

$$NaCl + 3H_2O - NaClO_3 + 3H_2$$

It can also be synthesized by passing chlorine gas into a hot sodium hydroxide solution. It is then purified by crystallization.

Chemical Oxygen Generation
Chemical oxygen generators, such as those in commercial aircraft, provide emergency oxygen to passengers to protect them from drops in cabin pressure by catalytic decomposition of sodium chlorate. The catalyst is normally iron powder. Barium peroxide (BaO_2) is used to absorb the chlorine which is a minor product in the decomposition. Iron powder is mixed with sodium chlorate and ignited by a charge which is activated by pulling on the emergency mask. The reaction produces more oxygen than is required for combustion. Similarly, the Solidox welding system used pellets of sodium chlorate mixed with combustible fibers to generate oxygen.

Toxicity in Humans
Due to its oxidative nature, sodium chlorate can be very toxic if ingested. The oxidative effect on hemoglobin leads to methaemoglobin formation, which is followed by denaturation of the globin protein and a cross-linking of erythrocyte membrane proteins with resultant damage to the membrane enzymes.

This leads to increased permeability of the membrane, and severe hemolysis. The denaturation of hemoglobin overwhelms the capacity of the G6PD metabolic pathway. In addition, this enzyme is directly denatured by chlorate reducing its activity. Therapy with ascorbic acid and methylene blue are frequently used in the treatment of methemoglobinemia. However, since methylene blue requires the presence of NADPH that requires normal functioning of G6PD system, it is less effective than in other conditions characterized by hemoglobin oxidation.

Acute severe hemolysis results, with multi-organ failure, including DIC and renal failure. In addition there is a direct toxicity to the proximal renal tubule. The treatment will consist of exchange transfusion, peritoneal dialysis or hemodialysis.

Developmental and Reproductive Effects
Several epidemiology studies have reported a possible association between disinfection byproducts and adverse reproductive outcomes, including spontaneous abortion (miscarriage). One study of women in several California communities (Waller et al. 1998) found a stronger association with bromodichloromethane (BDCM) than with other byproducts. Because the available studies have significant limitations, EPA and the American Water Works Association Research Foundation are sponsoring a new epidemiology study to replicate the 1998 Waller study.

When the Waller study was published, the available toxicology data on reproductive and developmental effects of some DBPs was quite limited. It was recognized that BDCM, in particular, should be thoroughly studied for a potential causal relationship to reproductive and developmental toxicity. The Research Foundation for Health and Environmental Effects, a tax-exempt foundation established by the Chlorine Chemistry Division of the American Chemistry Council, sponsored a set of animal studies (Christian et al. 2001, 2002) including two developmental toxicity studies on BDCM, a reproductive toxicity study on BDCM, and a reproductive toxicity study on dibromoacetic acid (DBA). The studies, published in the International Journal of Toxicology, found no adverse effects from BDCM and DBA at dose levels thousands of times higher than what humans are exposed to through drinking water. The studies were designed to comply with stringent EPA guidelines, and each study was independently monitored and peer reviewed.

Formulations
Sodium chlorate comes in dust, spray and granule formulations. There is a risk of fire and explosion in dry mixtures with other substances, especially organic materials, and other herbicides, sulfur, phosphorus, powdered metals, strong acids. In particular, when mixed with sugar, it has explosive properties. If accidentally mixed with one of these substances it should not be stored in human dwellings. Marketed formulations contain a fire retardant, but this has little effect if deliberately ignited. Most commercially available chlorate weedkillers contain approximately 53% sodium chlorate with the balance being a fire depressant such as sodium metaborate or ammonium phosphates.

Sodium Chlorite
Sodium chlorite, like many oxidizing agents, should be protected from inadvertent contamination by organic materials to avoid the formation of an explosive mixture. The chemical explodes on percussive impact, and will ignite if combined with a strong reducing agent.

Toxicity
Sodium chlorite is a strong oxidant and can therefore be expected to cause clinical symptoms similar to the well-known sodium chlorate: methemoglobinemia, hemolysis, renal failure. A dose of 10-15 grams of sodium chlorate can be lethal. Methemoglobemia had been demonstrated in rats and cats, and recent studies by the EMEA have confirmed that the clinical symptomatology is very similar to the one caused by sodium chlorate in the rat, mouse, rabbit, and the green monkey. There is only one human case in the medical literature of chlorite poisoning. It seems to confirm that the toxicity is equal to sodium chlorate. From the analogy with sodium chlorate, even small amounts of about 1 gram can be expected to cause nausea, vomiting and even life-threatening hemolysis in Glucose-6-Phosphate Dehydrogenase deficient persons. The EPA has set a maximum contaminant level of 1 milligram of chlorite per liter (1 mg/L) in drinking water.

Manufacture
The free acid, chlorous acid, $HClO_2$, is only stable at low concentrations. Since it cannot be concentrated, it is not a commercial product. However, the corresponding sodium salt, sodium chlorite, $NaClO_2$ is stable and inexpensive enough to be commercially available. The corresponding salts of heavy metals (Ag+, Hg+, Tl+, Pb2+, and also Cu2+ and NH_4+) decompose explosively with heat or shock. Sodium chlorite is derived indirectly from sodium chlorate, $NaClO_3$. First, the explosive (only at concentrations greater than 10% in atmosphere) chlorine dioxide, ClO_2 is produced by reducing sodium chlorate in a strong acid solution with a suitable reducing agent (for example, sodium sulfite, sulfur dioxide, or hydrochloric acid). The chlorine dioxide is then absorbed into an alkaline solution and reduced with hydrogen peroxide (H_2O_2), yielding sodium chlorite.

Stachybotrys
Stachybotrys is a genus of molds, or asexually-reproducing, filamentous fungi. Closely related to the genus Memnoniella, most Stachybotrys species inhabit materials rich in cellulose. The genus has a widespread distribution, and contains about 50 species. The most infamous species, S. chartarum (also known as S. atra) and S. chlorohalonata are known as "black mold" or "toxic black mold" in the U.S. and are frequently associated with poor indoor air quality that arises after fungal growth on water-damaged building materials

Symptoms of Stachybotrys Exposure in Humans
Exposure to the mycotoxins present in Stachybotrys chartarum or Stachybotrys atra can have a wide range of effects. Depending on the length of exposure and volume of spores inhaled or ingested, symptoms can manifest as chronic fatigue or headaches, fever, irritation to the eyes, mucous membranes of the mouth, nose and throat, sneezing, rashes, and chronic coughing. In severe cases of exposure or cases exacerbated by allergic reaction, symptoms can be extreme including nausea, vomiting, and bleeding in the lungs and nose.

Understanding Commonly Used Water Disinfectants
Almost all U.S. systems that disinfect their water use some type of chlorine-based process, either alone or in combination with other disinfectants. In addition to controlling disease-causing organisms, chlorination offers a number of benefits including:

- Reduces many disagreeable tastes and odors;
- Eliminates slime bacteria, molds and algae that commonly grow in water supply reservoirs, on the walls of water mains and in storage tanks;
- Removes chemical compounds that have unpleasant tastes and hinder disinfection; and
- Helps remove iron and manganese from raw water.

As importantly, only chlorine-based chemicals provide “residual disinfectant” levels that prevent microbial re-growth and help protect treated water throughout the distribution system.

The Risks of Waterborne Disease
Where adequate water treatment is not readily available, the impact on public health can be devastating. Worldwide, about 1.2 billion people lack access to safe drinking water, and twice that many lack adequate sanitation. As a result, the World Health Organization estimates that 3.4 million people, mostly children, die every year from water-related diseases.

Even where water treatment is widely practiced, constant vigilance is required to guard against waterborne disease outbreaks. Well-known pathogens such as E. coli are easily controlled with chlorination, but can cause deadly outbreaks given conditions of inadequate or no disinfection. A striking example occurred in May 2000 in the Canadian town of Walkerton, Ontario. Seven people died and more than 2,300 became ill after E. coli and other bacteria infected the town’s water supply. A report published by the Ontario Ministry of the Attorney General concludes that, even after the well was contaminated, the Walkerton disaster could have been prevented if the required chlorine residuals had been maintained.
Some emerging pathogens such as Cryptosporidium are resistant to chlorination and can appear even in high quality water supplies. Cryptosporidium was the cause of the largest reported drinking water outbreak in U.S. history, affecting over 400,000 people in Milwaukee in April 1993. More than 100 deaths are attributed to this outbreak. New regulations from the U.S. Environmental Protection Agency (EPA) will require water systems to monitor Cryptosporidium and adopt a range of treatment options based on source water Cryptosporidium concentrations. Most water systems are expected to meet EPA requirements while continuing to use chlorination.

The Benefits of Chlorine

Potent Germicide

Chlorine disinfectants can reduce the level of many disease-causing microorganisms in drinking water to almost immeasurable levels. Chlorine is added to drinking water to destroy pathogenic (disease-causing) organisms. It can be applied in several forms: elemental chlorine (chlorine gas), sodium hypochlorite solution (bleach) and dry calcium hypochlorite.

When applied to water, each of these forms "free chlorine" (see Sidebar: How Chlorine Kills Pathogens). One pound of elemental chlorine provides approximately as much free available chlorine as one gallon of sodium hypochlorite (12.5% solution) or approximately 1.5 pounds of calcium hypochlorite (65% strength). While any of these forms of chlorine can effectively disinfect drinking water, each has distinct advantages and limitations for particular applications. Almost all water systems that disinfect their water use some type of chlorine-based process, either alone or in combination with other disinfectants.

Taste and Odor Control

Chlorine disinfectants reduce many disagreeable tastes and odors. Chlorine oxidizes many naturally occurring substances such as foul-smelling algae secretions, sulfides and odors from decaying vegetation.

Biological Growth Control

Chlorine disinfectants eliminate slime bacteria, molds and algae that commonly grow in water supply reservoirs, on the walls of water mains and in storage tanks.

Chemical Control

Chlorine disinfectants destroy hydrogen sulfide (which has a rotten egg odor) and remove ammonia and other nitrogenous compounds that have unpleasant tastes and hinder disinfection. They also help to remove iron and manganese from raw water.

Water Treatment

Every day, approximately 170,000 (U.S. EPA, 2002) public water systems treat and convey billions of gallons of water through approximately 880,000 miles (Kirmeyer, 1994) of distribution system piping to U.S. homes, farms and businesses. Broadly speaking, water is treated to render it suitable for human use and consumption. While the primary goal is to produce a biologically (disinfected) and chemically safe product, other objectives also must be met, including: no objectionable taste or odor; low levels of color and turbidity (cloudiness); and chemical stability (non-corrosive and non-scaling). Individual facilities customize treatment to address the particular natural and manmade contamination characteristic of their raw water.

Surface water usually presents a greater treatment challenge than groundwater, which is naturally filtered as it percolates through sediments. Surface water is laden with organic and mineral particulate matter, and may harbor protozoan parasites such as Cryptosporidium parvum and Giardia lamblia.

Water Distribution

In storage and distribution, drinking water must be kept safe from microbial contamination. Frequently, slippery films of bacteria, known as biofilms, develop on the inside walls of pipes and storage containers. Among disinfection techniques, chlorination is unique in that a pre-determined chlorine concentration may be designed to remain in treated water as a measure of protection against harmful microbes encountered after leaving the treatment facility. In the event of a significant intrusion of pathogens resulting, for example, from a broken water main, the level of the average "chlorine residual" will be insufficient to disinfect contaminated water. In such cases, it is the monitoring of the sudden drop in the chlorine residual that provides the critical indication to water system operators that there is a source of contamination in the system.

The Challenge of Disinfection Byproducts
While protecting against microbial contamination is the top priority, water systems must also control disinfection byproducts (DBPs), chemical compounds formed unintentionally when chlorine and other disinfectants react with natural organic matter in water. In the early 1970s, EPA scientists first determined that drinking water chlorination could form a group of byproducts known as trihalomethanes (THMs), including chloroform. EPA set the first regulatory limits for THMs in 1979. While the available evidence does not prove that DBPs in drinking water cause adverse health effects in humans, high levels of these chemicals are certainly undesirable. Cost-effective methods to reduce DBP formation are available and should be adopted where possible.

Chemical Safety (IPCS 2000) Strongly Cautions:
The health risks from these byproducts at the levels at which they occur in drinking water are extremely small in comparison with the risks associated with inadequate disinfection. Thus, it is important that disinfection not be compromised in attempting to control such byproducts. Recent EPA regulations have further limited THMs and other DBPs in drinking water. Most water systems are meeting these new standards by controlling the amount of natural organic material prior to disinfection.

Chlorine and Water System Security
The prospect of a terrorist attack has forced all water systems, large and small, to re-evaluate and upgrade existing security measures. Since September 11th, 2001, water system managers have taken unprecedented steps to protect against possible attacks such as chemical or biological contamination of the water supply, disruption of water treatment or distribution, and intentional release of treatment chemicals.

With passage of the Public Health Security and Bioterrorism Response Act of 2002, Congress required community water systems to assess their vulnerability to a terrorist attack and other intentional acts. As part of these vulnerability assessments, systems assess the transportation, storage and use of treatment chemicals. These chemicals are both critical assets (necessary for delivering safe water) and potential vulnerabilities (may pose significant hazards, if released). Water systems using elemental chlorine, in particular, must determine whether existing protection systems are adequate. If not, they must consider additional measures to reduce the likelihood of an attack or to mitigate the potential consequences.

Disinfection is crucial to water system security, providing the “front line” of defense against biological contamination. However, conventional treatment barriers in no way guarantee safety from biological attacks. Additional research and funding are needed to improve prevention, detection and responses to potential threats.

The Future of Chlorine Disinfection
Despite a range of new challenges, drinking water chlorination will remain a cornerstone of waterborne disease prevention. Chlorine’s wide array of benefits cannot be provided by any other single disinfectant. While alternative disinfectants (including chlorine dioxide, ozone, and ultraviolet radiation) are available, all disinfection methods have unique benefits, limitations, and costs. Water system managers must consider these factors, and design a disinfection approach to match each system’s characteristics and source water quality.

Understanding Disinfection Byproducts (DBPS)

Chlorine and other chemical disinfectants have been widely used by public water systems (along with filtration) to protect the public from microbial pathogens in drinking water. DBPs are formed when certain disinfectants react with DBP precursors (organic and inorganic materials) in source waters. In most cases, natural organic matter (NOM) is an important factor that affects the levels of DBPs that form (NOM is usually measured as TOC). The levels of DBPs in drinking water can vary significantly from one point in a distribution system to another, as many continue to form in the distribution system. DBP levels are generally higher in surface water systems because surface water usually contains higher DBP precursor levels and requires stronger disinfection.

Updating the Safe Drinking Water Act Regulations
EPA has regulated DBPs in drinking water since 1979. The first DBP standards limited THM levels to 100 parts per billion (ppb) for systems serving more the 10,000 people. In the 1996 Safe Drinking Water Act (SDWA) reauthorization, Congress called for EPA to revise its standards for disinfectants and DBPs in two stages. The revised regulations are designed to reduce potential DBP risks, while ensuring that drinking water is protected from microbial contamination.

Stage 1 DBP Rule
In December 1998 USEPA issued the Stage 1 Disinfectants and Disinfection Byproducts (Stage 1 DBP) rule. The regulations are based on an agreement between members of a Federal Advisory Committee that included representatives from water utilities, the Chlorine Chemistry Division of the American Chemistry Council, public health officials, environmentalists and other stakeholder groups. This diverse group of experts developed a consensus set of recommendations to cost-effectively reduce DBP levels, without compromising protection from microbial contaminants.

The Stage 1 DBP rule mandates a process called enhanced coagulation to remove natural organic matter, reducing the potential for DBPs to form. The rule also sets enforceable Maximum Contaminant Levels (MCLs) for total trihalomethanes at 80 ppb and the sum of five Haloacetic Acids (HAAs) at 60 ppb. These MCLs are based on system-wide running annual averages, meaning that concentrations may be higher at certain times and at certain points in the system, as long as the system-wide average for the year is below the MCL. In developing the Stage 1 DBP rule, EPA was very cautious about encouraging the use of alternative disinfectants. The Agency recognized that alternative disinfectants might reduce THMs and HAAs, but produce other, less understood, byproducts. The Agency also avoided making recommendations that would encourage utilities to reduce the level of disinfection currently being practiced.

Large water systems (those serving more than 10,000 persons) were required to comply with the Stage 1 DBP rule by December 2001. Systems serving fewer than 10,000 persons must comply by December 2003.

Stage 2 DBP Rule
As the Stage 1 rule is coming into full force, EPA is completing work on its Stage 2 DBP rule. The Stage 2 rule is being developed simultaneously with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) in order to address the risk trade-offs between pathogen control and exposure to DBPs. The LT2 rule deals primarily with controlling Cryptosporidium and other resistant pathogens discussed in Chapter 3. Again, the EPA sought recommendations from an advisory group, the Stage 2 Microbial and Disinfection Byproducts Federal Advisory Committee.

As outlined in the advisory committee's September 2000 Agreement in Principle, the MCLs for THMs and five HAAs will remain 80 ppb and 60 ppb respectively, based on each utility's system-wide running annual averages. However, the Stage 2 rule will also limit DPB levels at specific locations within distribution systems. When fully implemented, these locational running annual average limits will mean that no part of the distribution system will be allowed to exceed the MCLs for these substances.

Total Trihalomethanes
Trihalomethanes (THMs) are chemical compounds in which three of the four hydrogen atoms of methane (CH4) are replaced by halogen atoms. Many trihalomethanes find uses in industry as solvents or refrigerants. THMs are also environmental pollutants, and many are considered carcinogenic. Trihalomethanes with all the same halogen atoms are called haloforms. Trihalomethanes are formed as a by-product predominantly when chlorine is used to disinfect water for drinking. They represent one group of chemicals generally referred to as disinfection by-products. They result from the reaction of chlorine and/or bromine with organic matter present in the water being treated. The THMs produced have been associated through epidemiological studies with some adverse health effects. Many governments set limits on the amount permissible in drinking water. However, trihalomethanes are only one group of many hundreds of possible disinfection by-products—the vast majority of which are not monitored—and it has not yet been clearly demonstrated which of these are the most plausible candidate for causation of these health effects. In the United States, the EPA limits the total concentration of the four chief constituents (chloroform, bromoform, bromodichloromethane, and dibromochloromethane), referred to as total trihalomethanes (TTHM), to 80 parts per billion in treated water.

THM Treatment
THM levels tend to increase with pH, temperature, time, and the level of "precursors" present. Precursors are organic material which reacts with chlorine to form THM's. One way to decrease THM's is to eliminate or reduce chlorination before the filters and to reduce precursors. There are more precursors present before filtration, so we want to reduce or eliminate the time chlorine is in contact with this water. If some oxidation before filtration is required, an alternative disinfectant like potassium permanganate or peroxide could be considered. Note that this may not be an option if prechlorination is necessary to achieve required CT values.

The EPA has indicated that the best available technology for THM control at treatment plants is removal of precursors through "enhanced coagulation". Enhanced coagulation refers to the process of optimizing the filtration process to maximize removal of precursors. Removal is improved by decreasing pH (to levels as low as 4 or 5), increasing the feed rate of coagulants, and possibly using ferric coagulants instead of alum.

Understanding Cryptosporidiosis
Cryptosporidium is an emerging parasitic protozoan pathogen because its transmission has increased dramatically over the past two decades. Evidence suggests it is newly spread in increasingly popular day-care centers and possibly in widely distributed water supplies, public pools and institutions such as hospitals and extended-care facilities for the elderly. Recognized in humans largely since 1982 and the start of the AIDS epidemic, Cryptosporidium is able to cause potentially life-threatening disease in the growing number of immunocompromised patients. Cryptosporidium was the cause of the largest reported drinking water outbreak in U.S. history, affecting over 400,000 people in Milwaukee in April, 1993. More than 100 deaths are attributed to this outbreak. Cryptosporidium remains a major threat to the U.S. water supply (Ibid.).

The EPA is developing new drinking water regulations to reduce Cryptosporidium and other resistant parasitic pathogens. Key provisions of the Long Term 2 Enhanced Surface Water Treatment Rule include source water monitoring for Cryptosporidium; inactivation by all unfiltered systems; and additional treatment for filtered systems based on source water Cryptosporidium concentrations. EPA will provide a range of treatment options to achieve the inactivation requirements. Systems with high concentrations of Cryptosporidium in their source water may adopt alternative disinfection methods (e.g., ozone, UV, or chlorine dioxide). However, most water systems are expected to meet EPA requirements while continuing to use chlorination. Regardless of the primary disinfection method used, water systems must continue to maintain residual levels of chlorine-based disinfectants in their distribution systems.

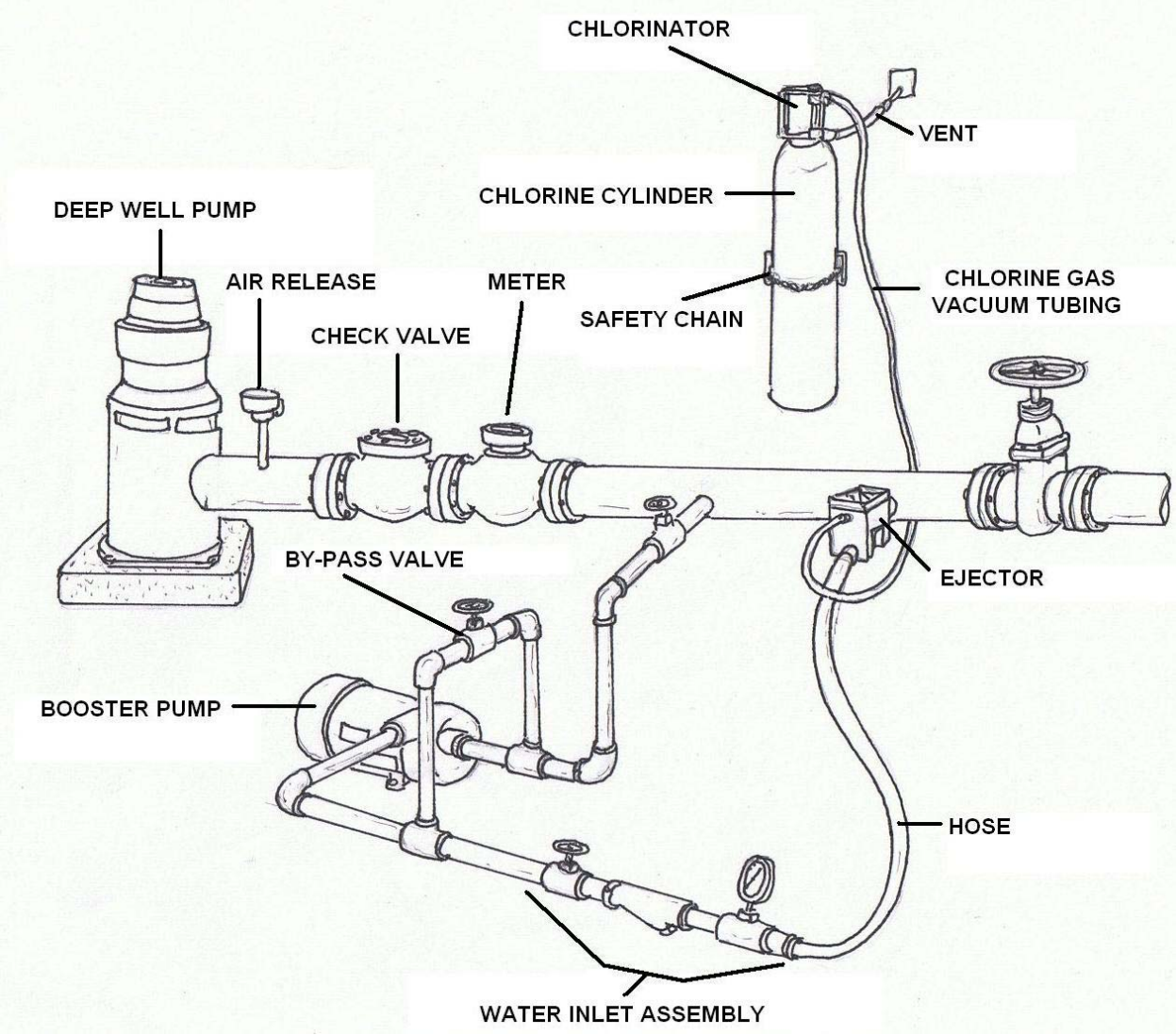
Understanding Giardia lamblia
Giardia lamblia, discovered approximately 20 years ago, is another emerging waterborne pathogen. This parasitic microorganism can be transmitted to humans through drinking water that might otherwise be considered pristine. In the past, remote water sources that were not affected by human activity were thought to be pure, warranting minimal treatment. However, it is known now that all warm-blooded animals may carry Giardia and that beaver are prime vectors for its transmission to water supplies.

There is a distinct pattern to the emergence of new pathogens. First, there is a general recognition of the effects of the pathogen in highly susceptible populations such as children, cancer patients and the immunocompromised. Next, practitioners begin to recognize the disease and its causative agent in their own patients, with varied accuracy. At this point, some may doubt the proposed agent is the causative agent, or insist that the disease is restricted to certain types of patients. Finally, a single or series of large outbreaks result in improved attention to preventive efforts. From the 1960's to the 1980's this sequence of events culminated in the recognition of Giardia lamblia as a cause of gastroenteritis (Lindquist, 1999).

Understanding Waterborne Diseases
Detection and investigation of waterborne disease outbreaks is the primary responsibility of local, state and territorial public health departments, with voluntary reporting to the CDC. The CDC and the U.S. Environmental Protection Agency (EPA) collaborate to track waterborne disease outbreaks of both microbial and chemical origins. Data on drinking water and recreational water outbreaks and contamination events have been collected and summarized since 1971.

While useful, statistics derived from surveillance systems do not reflect the true incidence of waterborne disease outbreaks because many people who fall ill from such diseases do not consult medical professionals. For those who do seek medical attention, attending physicians and laboratory and hospital personnel are required to report diagnosed cases of waterborne illness to state health departments. Further reporting of these illness cases by state health departments to the CDC is voluntary, and statistically more likely to occur for large outbreaks than small ones.

Despite these limitations, surveillance data may be used to evaluate the relative degrees of risk associated with different types of source water and systems, problems in current technologies and operating conditions, and the adequacy of current regulations. (Craun, Nwachuku, Calderon, and Craun, 2002).


CHLORINATOR
VENT
CHLORINE CYLINDER
DEEP WELL PUMP
AIR RELEASE
METER
CHLORINE GAS
VACUUM TUBING
SAFETY CHAIN
CHECK VALVE
BY-PASS VALVE
EJECTOR
BOOSTER PUMP
HOSE
WATER INLET ASSEMBLY

Understanding Bacteriological Monitoring

26 waterborne-disease outbreaks have been documented each year in the United States over the past 25 years (Kramer and others, 1996). The persistence of outbreaks over time indicates that more progress is needed to meet the “drinkable and swimmable” goals of Federal water-quality legislation. Although significant improvements in drinking water and wastewater treatment have been achieved, waterborne disease outbreaks indicate that certain types and sources of waterborne pathogens (disease-causing organisms) are still a threat to human health in the United States (Craun, 1992). In particular, waterborne disease outbreaks caused by Escherichia coli O157.:H7 were reported more frequently in 1995-96 than in previous years, and during that same period, Cryptosporidium and Giardia caused large outbreaks associated with recreational water quality (Levy and others, 1998).

Microbiological examination of water is used to determine the sanitary quality of water and the public health risk from waterborne disease. Although microbiological monitoring of finished waters is well established, microbiological monitoring of source waters and recreational waters is considered by some to be fragmented, incomplete, or virtually nonexistent in many parts of the Nation (Rose and others, 1999). Data to characterize the microbiological quality of source waters are usually collected for local purposes, most often to judge compliance with standards for protection of public health in swimmable or drinkable waters. For example, monitoring programs vary widely at the local level for recreational waters, and the result is the inconsistent use of indicator organisms across the United States (U.S. Environmental Protection Agency, 1999a).

There is a need to identify human and animal factors associated with contamination of different source and recreational waters and to understand the processes that affect microbiological water quality. Concepts about the relation between the occurrence and distribution of microbiological contaminants and a range of environmental factors such as climate, hydrology, land use, and human and animal population densities need to be tested in areas that represent the national water-use patterns for public and domestic supply and for recreational uses.

Understanding Bacteriological Monitoring
Understanding Bacteria Sampling

Waterborne bacterial pathogens in the United States include species in the genera Salmonella, Shigella, Vibrio, Campylobacter, Yersinia, and pathogenic strains of E. coli. Because bacterial pathogens generally appear intermittently in low concentrations in the environment and because methods of culturing are difficult, fecal-indicator bacteria are used to indicate the possible presence of pathogens. The most widely used bacterial indicators include total coliforms, fecal coliforms, E. coli, fecal streptococci, enterococci, and Clostridium perfringens (C. perfringens). A good indicator organism should be applicable in all types of water; unable to reproduce in ambient waters; be harmless to man and other animals; lend itself to easy, quantitative testing procedures; be of warm-blooded animal origin; correlate with fecal contamination; and be present in waters in greater numbers than and survive as long as or longer than pathogens.

The historical definition of the total-coliform group has been based on the method used for detection (lactose fermentation) rather than on systematic bacteriology (American Public Health Association and others, 1998). Total coliforms are defined as aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose with gas formation at $35^{O}C$ within 48 hours (Britton and Greeson,1989). Elevated temperature tests identify those genera of total coliform bacteria that belong in the more specific fecal-coliform group. Fecal coliforms are total coliforms capable of producing gas from lactose at $44.5^{O}C$.

Escherichia coli is a species of the fecal-coliform group. Total coliforms include several genera that are found in the human intestine; however, some genera are also found in soils, on vegetation, and in industrial wastes. This multiplicity of sources makes the sanitary significance of total coliforms difficult to establish (Palmer and others, 1984).

They are used as a rough measure of source-water quality and as a screen for fecal contamination. In addition, speciation of the total-coliform group may provide information on treatment effectiveness and the source of colonization of a distribution system or well (American Public Health Association, 1998, p. 9-1). The fecal-coliform indicator used to assess fecal contamination of water has been faulted because of nonfecal sources of at least one member of the fecal coliform group. For example, thermotolerant Klebsiella species have been observed in pulp- and papermill effluents, textile-processing-plant effluent, cotton-mill wastewaters, and sugar-beet wastes, in the absence of fecal contamination (U.S. Environmental Protection Agency, 1986a).

Alternatively, E. coli is a natural inhabitant of the gastrointestinal tract of warm-blooded animals and is direct evidence of fecal contamination from warm-blooded animals. The fecal streptococci are a group of fecal-indicator bacteria that include a variety of species and strains that are all gram positive cocci. Although the normal habitat of fecal streptococci is the gastrointestinal tract of warm-blooded animals, some species are not exclusive to animals (American Public Health Association, 1998, p. 9-74). In fact, studies on the distribution of fecal streptococci in water indicate that at least one strain commonly found in environmental samples is ubiquitous and can exist for extended periods in soil and water (Geldreich, 1976). Fecal streptococci, therefore, have limited value as an indicator of fecal contamination in environmental samples. The enterococci group is a subgroup of the fecal streptococci, and it is considered a more specific indicator of fecal contamination.

The enterococci are differentiated from other streptococci by their ability to grow in 6.5 percent chloride, at pH 9.6, and at elevated temperatures. The enterococci method is valuable for determining the extent of fecal contamination of recreational surface waters, especially marine waters (American Public Health Association, 1998, p. 9-75).

In addition, because enterococccci cells are a different shape and have different survival rates than members of the coliform group, enterococci may be useful in assessing transport of fecal contamination in ground water. Clostridium perfringens is present in large numbers in human and animals wastes, and its spores are more resistant to disinfection and environmental stresses than is E. coli. Clostridium perfringens has been suggested as a conservative tracer of past fecal contamination and as an indicator for chlorinated water in distribution systems (Bisson and Cabelli, 1980).

Clostridium perfringens, however, is probably not an appropriate indicator for most recreational waters because spores in the sediment are resuspended into the water column from swimmer or wave disturbances (Bisson and Cabelli, 1980). One exception is that C. perfringens may be a reliable indicator of streamwater quality in tropical climates, where warm water temperatures support the growth and reproduction of E. coli and aerobic conditions preclude the growth and sporulation of C. perfringens (Fujioka and Shizumura, 1985).

Clostridium perfringens has also been found to be a sensitive indicator of microorganisms entering streams from point sources but not a reliable indicator of nonpoint sources (Sorenson and others, 1989). Detection of C. perfringens in water has been proposed as an indicator of the presence and density of pathogenic viruses and possibly other stress resistant microorganisms (U.S. Environmental Protection Agency, 1996c).

Protozoan Pathogens

The principal protozoan pathogens that affect the public health acceptability of waters in the United States are Giardia lamblia (Giardia) and Cryptosporidium parvum (Cryptosporidium). These organisms are widely distributed in the aquatic environment and have been implicated in several recent outbreaks of waterborne disease, including a well-publicized outbreak of cryptosporidiosis in Milwaukee, Wisconsin (Rose and others, 1997). Both Giardia and Cryptosporidium produce environmentally resistant forms (called cysts and oocysts), which allow for the extended survival of the parasites in water and treated water.

Because cysts and oocysts are more resistant to disinfection and survive longer in the environment than bacterial indicators, fecal-indicator bacteria are not adequate indicators for Giardia and Cryptosporidium in source waters. The presence of protozoan pathogens in water, therefore, must be verified by identification of the pathogens themselves. The USEPA-required method for detection of Giardia and Cryptosporidium in source and drinking water under the ICR involves nominal porosity filtration and indirect fluorescent antibody procedures (U.S. Environmental Protection Agency, 1996c). The ICR method has been criticized for being difficult to implement, being characterized by poor recovery of target organisms, and yielding highly variable results (U.S. Environmental Protection Agency, 1996b). As a result, the USEPA supported the development of Method 1622 for Cryptosporidium (U.S. Environmental Protection Agency, 1998b), and Method 1623 for Giardia and Cryptosporidium (U.S. Environmental Protection Agency, 1999c). Method 1622 was validated through an interlaboratory study and revised as a final, valid method in January 1999.

Understanding Routine Coliform Sampling
Streamwater sample collection
When designing a sampling plan, consider that the spatial and temporal distribution of microorganisms in surface water can be as variable as the distribution of suspended sediment because microorganisms are commonly associated with solid particles. The standard samplers can be used to collect streamwater samples for bacterial and viral indicators, *Cryptosporidium*, and *Giardia* providing that the equipment coming in contact with the water is properly cleaned and sterilized. For streamwater samples, these include the US-D77TM, US-D95, US-DH81, and weighted- and open-bottle samplers with autoclavable Teflon, glass, or polypropylene components.
• Prepare a separate set of sterile equipment (bottles nozzles, and caps) for sampling at each site.
• Follow sampling techniques given in Shelton (1994) to ensure that a sample is representative of the flow in the cross section. Use equal-width increment (EWI) or equal-discharge-increment
(EDI) methods described in Edwards and Glysson (1988), unless site characteristics dictate otherwise.
• Because churn and cone splitters cannot be autoclaved, use a sterile 3-L bottle to composite subsamples for bacterial and viral indicators when using EDI and EWI methods. If possible, composite by collecting subsamples at vertical locations in the cross section without overfilling the bottle.
• Alternatively, if the stream depth and (or) velocity is not sufficient to use depth-width integrating techniques, collect a sample by a hand-dip method (Myers and Sylvester, 1997).
• Collect approximately 1 L of streamwater for bacterial and viral indicators. Process the sample for *E. coli* and enterococci; send the remainder (at least 500 mL) on ice to the laboratory for *C. perfringens* and coliphage analysis.

Method 1623
For *Cryptosporidium* and *Giardia* analysis by Method 1623 (U.S. Environmental Protection Agency, 1999c), collect 10 L of streamwater for each protozoan pathogen using standard sampling techniques described in Myers and Sylvester (1997). Special sterilization procedures are needed for equipment used in the collection of samples for *Cryptosporidium* and *Giardia*. Autoclaving is not effective in neutralizing the epitopes on the surfaces of the oocysts and cysts that will react with the antibodies used for detection.

• Wash and scrub the equipment with soap and warm tap water to remove larger particulates and rinse with deionized water. Submerge the equipment in a vessel containing 12 percent hypochlorite solution for 30 minutes. Wash the equipment free of residual sodium hypochlorite solution with three rinses of filter-sterilized water; do not de-chlorinate the equipment using sodium thiosulfate. This procedure is best done in the office with dedicated sampling equipment for each site; however, it may be done in the field as long as the hypochlorite solution is stored and disposed of properly.
• Composite the sample in a 10-L cubitainer that is pre-sterilized by the manufacturer. The cubitainer is sent in a cardboard box to laboratory for *Cryptosporidium* analysis. The sample does not have to be kept on ice during transport. At this time, two methods are recommended for analysis of water samples for enteric viruses: (1) the reverse-transcriptase, polymerase chain reaction (RTPCR) method (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997) and (2) the cell-culture method (U.S. Environmental Protection Agency, 1996c). Sampling and equipment cleaning procedures are more thoroughly described elsewhere (G. Shay Fout, U.S. Environmental Protection Agency, 1997; U.S. Environmental Protection Agency, 1996c). Briefly, 100 L of streamwater is pumped by means of a specially designed sampling apparatus and passed through a Virosorb1 1MDS filter (Cuno, Meriden, Conn.). The sampling equipment is obtained from the analyzing laboratory; for example, the USGS Ohio District Laboratory has modified the sampling apparatus (G. Shay Fout, U.S. Environmental Protection Agency, 1997) into a self-contained box with easy-to-use control valves. The 1MDS filters, which remove viruses present in the water by charge interactions, are kept on ice and sent to a central laboratory for virus elution, concentration, and detection.

Groundwater Sample Collection
Collecting ground-water samples by use of sterile techniques requires knowledge of the type of well, its use, its construction, and its condition.
• Swab the electronic tape used for water-level measurements with isopropyl or ethyl alcohol.
• In sampling subunit survey wells, once purging criteria have been met as described in Koterba and others (1995), collect the sample directly from the tap into a sterile container.
• Remove screens, filters, other devices from the tap before collecting the sample, and do not sample from leaking taps. Because we are interested in the microbial population in the ground water and not in the distribution system, it is best to sample directly from the wellhead using a pump with sterile tubing, if possible. Because this is operationally prohibitive for private domestic wells, a tap that yields water directly from the well and before entering the holding tank is preferred. Water collected after treatment is unsuitable for microbiological analysis.
• Document the stage of the distribution system from which water was collected and details about the distribution system, including the type of tank and condition of the tank and pipes. In addition, if the well can easily be opened for inspection, document the condition of the well, including the sanitary seal (if any) and the amount of debris in the well. Any information on the location of the well, including proximity to septic systems or feedlots, should also be documented in the field at the time of sampling.

For wells without in-place pumps, samples should be obtained by use of the following methods (in descending order from most to least desirable):
(1) a peristaltic or vacuum pump with autoclavable silicon tubing, (2) a sterile bailer, (3) a chlorine-disinfected pump and tubing, or (4) a detergent-cleaned pump and tubing. Pre-sampling activities, such as purging, must be carried out in such a way as to avoid contaminating the well. All equipment must be properly cleaned and sterilized between sites, using a Liquinox wash and a thorough tap water or deionized-water rinse. If using this last method, collect additional field blanks to evaluate the effectiveness of the cleaning procedure. Refer to Myers and Sylvester (1997) for a detailed discussion of ground-water sampling for microbiological analysis.

Because ground water is less prone to microbiological contamination than surface water, larger volumes of ground water are needed than of surface water.

- For regular sampling, collect 3 L of ground water for bacterial and viral indicators.
- Process the sample for total coliforms, *E. coli*, and enterococci using 200-mL sample volumes for each analysis; send the remainder (at least 2.5 L) to the laboratory for coliphage analysis. In the laboratory, coliphage analysis is done using 1 L for somatic and 1 L for F-specific coliphage.
- For enteric virus analysis by RT-PCR and cell culture, use the same sampler for ground-water samples as for streamwater samples; pump 2,000 L of ground water through the sampling apparatus and 1MDS filter.

Sample Preservation and Storage

Holding times for samples before processing are 6 hours for total coliforms, *E. coli*, and enterococci and 24 hours for *C. perfringens*, coliphage, *Cryptosporidium*, *Giardia*, and the 1MDS filters for enteric viruses by RTPCR and cell culture.

- After collection, immediately store the sample on ice.
- Be sure to keep the sample out of direct sunlight, because ultraviolet rays kill microorganisms.
- Add sodium thiosulfate to sample bottles for bacterial and viral indicators if the water collected contains residual chlorine. (Samples may have residual chlorine if the sampling site is downstream from a wastewater-treatment plant that chlorinates its effluents). Add ethylene diaminetetracetic acid to sample bottles when water is suspected to contain trace elements such as copper, nickel, and zinc at concentrations greater than 1 mg/L (Britton and Greeson, 1989, p. 5-6; U.S. Environmental Protection Agency, 1978, p. 6; American Public Health Association and others, 1998, p. 9-19). (Sodium thiosulfate or ethylene diaminetetracetic acid are not added to containers for *Cryptosporidium* and *Giardia)*.

Analytical Methods

Field Analysis

Analysis of water samples for total coliforms, *E. coli,* and enterococci, are done by use of membrane filtration (MF) or most-probable number (MPN) methods. Because membrane filtration is easier to use and provides a more precise quantification of bacteria than MPN, MF is recommended for most analyses. Refer to Myers and Sylvester (1997) for complete MF procedures.

Different MF methods are used for quantification of bacteria in ground-water and streamwater samples.

- For examining streamwater samples for *E. coli*, use the USEPA-recommended mTEC agar method (Environmental Protection Agency, 1986b).
- For examining ground-water samples for total coliforms and *E. coli*, use the MI method (Brenner and others, 1993).
- For enterococci, use the mEI method (U.S. Environmental Protection Agency, 1997).
- For streamwater, plate sufficient sample volumes in order to obtain at least one plate in the ideal count range. For ground water, a 200-mL sample volume is usually sufficient.

Testing of new microbiological monitoring methods and comparing the recoveries of new methods to the USEPA-approved method can be done by use of the NAWQA network. For ground-water samples, for example, one may include a commercially available MPN kit, Colilert (Idexx Laboratories, Westbrook, Maine), for simultaneous detection of total coliforms and *Escherichia coli*. For streamwater sampling, one may include a single-step modified Mtec medium with 5-bromo-6-chloro-3-indolyl'β-d-glucuronide (Bennett Smith, USEPA, Cincinnati, Ohio, oral commun., 1997); this method was developed to replace the mTEC method. Other new methods can be added to the monitoring program for field testing as they are developed.

Laboratory Analysis

Samples need to be kept on ice and shipped to a central laboratory for analysis of coliphage, *C. perfringens*, *Cryptosporidium, Giardia*, and enteric viruses by the current analytical methods. The single-agar layer (SAL), direct plating method with induction of β-galactosidase (Ijzerman and Hagedorn, 1992) is recommended for detection of somatic and F-specific coliphage in streamwater samples. In this method, 100-mL sample volumes are mixed with an agar medium, *E. coli* host culture, chemicals that induce the β-galactosidase enzyme, and appropriate antibiotics. The mixtures are poured into four 150- x 15-mm plates and incubated at 35°C.

Upon infection by coliphage in the water sample, the *E. coli* host cells are lysed and stable indolyl product that is dark blue is visible within each plaque. Viral plaques are easily identified and enumerated by the distinct blue circle. Because of contamination by naturally occurring bacteria in streamwater samples, antibiotic- resistant host-culture strains, *E. coli* CN-13 (resistant to nalidixic acid) and *E. coli* F-amp (resistant to streptomycin and ampicillin) are used as hosts for somatic and F-specific coliphage, respectively. Large sample volumes, such as 1-L volumes or greater, are recommended for detection of coliphage in ground water. Because the SAL method is impractical for sample volumes above 100 mL, an alternative method should be used for ground-water sample analysis.

One example, currently being tested by USEPA, is a two-step enrichment presence-absence method (U.S. Environmental Protection Agency, 1999e). Samples for enumeration of *C. perfringens* are analyzed by use of the mCP agar method (U.S. Environmental Protection Agency, 1996c). Standard MF techniques are used, and the plates are incubated anaerobically for 24 hours at 44.5°C. After incubation, the plates are exposed to ammonium hydroxide, and all straw-colored colonies that turn dark pink to magenta are counted as *C. perfringens*. In the laboratory, *C. perfringens* analyses are done on 100-, 30- and 10-mL volumes of streamwater. In the case of a high-flow or high-turbidity streamwater sample, lower sample volumes may be plated.

Method 1623 (U.S. Environmental Protection Agency, 1999c) is recommended for detection of *Cryptosporidium* oocysts and *Giardia* cysts in water. The oocysts are concentrated on a capsule filter from a 10-L water sample, eluted from the capsule filter with buffer, and concentrated by centrifugation. Immunomagnetic separation (IMS) is used to separate the oocysts from other particulates in the sample. In IMS, the oocysts are magnetized by attachment of magnetic beads conjugated to an antibody and then are separated from sediment and debris by means of a magnet.

Fluorescently labeled antibodies and vital dye are used to make the final microscopic identification of oocysts and cysts. The reverse-transcriptase, polymerase chain reaction (RT-PCR) and cell-culture methods are recommended for detection of enteric viruses in water samples (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997; U.S. Environmental Protection Agency, 1996c). To prepare samples for RT-PCR and cell culture, attached viruses are eluted from a 1MDS filter with beef extract (pH 9.5), concentrated using celite (pH 4.0), and eluted with sodium phosphate (pH 9.5).

For RT-PCR analysis, viruses are isolated from the eluate by ultracentrifugation through a sucrose gradient, and trace contaminants are removed by extraction with a solvent mixture. During these steps, the 10-L streamwater sample (or 2,000-L ground-water sample) is concentrated down to 40 µL. An aliquot of the concentrate is used for RT-PCR, wherein any target viral RNA is converted to DNA and amplified by use of an enzymatic process. The RT-PCR products are analyzed by agarose gel electrophoresis and confirmed by hybridization. The enteric viruses detected by use of this method include enterovirus, hepatitis-A, rotavirus, reovirus, and calicivirus.

For cell-culture analysis, the sample eluate is added to a monlayer of a continuous cell line derived from African green monkey kidney cells (U.S. Environmental Protection Agency, 1996c). Each cell culture is examined microscopically for the appearance of cytopathic effects (CPE) for a total of 14 days; if CPE is not observed in 14 days, a second passage is done. Results are reported as most probable number of infectious units per volume of water.

QA/QC Activities and Measures

QA/QC activities and measures to take to reduce contamination.

• Use a sterilization indicator, such as autoclave tape, in preparing sample bottles and other equipment for collection of microbiological samples to determine whether adequate temperatures and pressures have been attained during autoclaving.

• Prepare a separate set of sterile equipment for microbiological sampling at each site.

• Before processing samples in the field vehicle, wipe down the area with a disinfectant (such as isopropyl alcohol) to ensure a sterile working surface.

• Monitor the incubators daily to ensure temperatures are appropriate for the methods used.

For bacteria samples, membrane-filtration (MF) equipment and MF procedure blanks are used to estimate analytical bias.

Field personnel should do the following:

• Prepare an MF equipment blank, a 50- to 100-mL aliquot of sterile buffered water plated before the sample—for every sample by field personnel for total coliform, *E. coli*, and enterococci analyses to determine the sterility of equipment and supplies.

• Prepare a MF procedure blank, a 50- to 100-mL aliquot of sterile buffered water plated after the sample— for every fourth sample to measure the effectiveness of the analyst's rinsing technique or presence of incidental contamination of the buffered water.

If contamination from a MF equipment or procedure blank is found, results are suspect and are qualified or not reported. Proper and consistent procedures for counting and identifying target colonies will be followed, as described in Myers and Sylvester (1997).

• After counting, turn the plate 180° and ensure the second count is within 5 percent of the first count. Have a second analyst check calculations of bacterial concentrations in water for errors.

For coliphage, *Cryptosporidium, Giardia*, and enteric virus samples, equipment and field blanks are used to determine sampling and analytical bias. Equipment blanks for these analyses are different from the MF equipment blanks for bacterial analysis. An equipment blank is a blank solution (sterile buffered water) subjected to the same aspects of sample collection, processing, storage, transportation, and laboratory handling as an environmental sample, but it is processed in an office or laboratory. Field blanks are the same as equipment blanks except that they are generated under actual field conditions.

• For enteric virus analysis, collect one equipment blank after collection of the first sample to ensure that equipment cleaning and sterilization techniques are adequate.

• For coliphage, *Cryptosporidium, Giardia*, and enteric virus analyses, collect field blanks periodically. At a minimum, the number of field blanks should equal 5 percent of the total number of samples collected. Five percent of samples collected for bacterial and viral indicators (total coliforms, *E. coli*, enterococci, *C. perfringens*, and coliphage) should be nested replicate samples to estimate sampling and analytical variability. For streamwater samples, concurrent replicates to estimate sampling variability are collected by alternating subsamples in each vertical between two collection bottles. For ground-water samples, sequential replicates are collected one after another into separate sterile bottles. Concurrent and sequential replicates are then analyzed in duplicate (split replicates) to estimate analytical variability.

• Because of the expense associated with collection and analysis of samples for pathogens (*Cryptosporidium* and enteric viruses), collect only one replicate sample per year at a site wherein detection of pathogens was found in an earlier sample.

To assess analytical bias of the sampling and analytical method, 2 to 5 percent of the samples collected for enteric virus should be field matrix spikes.

• Run all but 10 L of ground water through the 1 MDS filter and collect the remaining 10 L in a carboy. In the laboratory, the poliovirus vaccine will be added to the 10 L and then passed through the same 1MDS filter. Analysis will be done by use of the cell-culture and RT-PCR methods. • All cell-culture positive samples are serotyped to identify or discount laboratory contamination. Because of the variability in the performance of Method 1623 for recovery of *Cryptosporidium* and *Giardia*, each sample will be collected in duplicate—one will be a regular sample and the other a matrix spike. The laboratory will add a known quantity of cysts and oocysts to the matrix spike to determine recovery efficiency, as described in USEPA (1999c).

Quality Assurance and Quality Control in the Laboratory

The following criteria may be used to evaluate each production analytical laboratory: (1) appropriate, approved, and published methods, (2) documented standard operating procedures, (3) approved quality-assurance plan, (4) types and amount of quality-control data fully documented and technical defensible, (5) participation in the standard reference sample project (6) scientific capability of personnel, and (7) appropriate laboratory equipment.

The microbiology laboratories must follow good laboratory practices—cleanliness, safety practices, procedures for media preparation, specifications for reagent water quality—as set forth by American Public Health Association (1998) and Britton and Greeson (1989). Some specific guidelines are listed in the following paragraphs.

Reference cultures are used by the central laboratory to evaluate the performance of the test procedures, including media and reagents. Pure cultures of *E. coli, Enterobacter aerogenes,* and *Streptococcus faecalis* (American Type Culture Collection, Rockville, Md.) are used to ensure that MF culture media and buffered water are performing adequately. A pure culture of *C. perfringens*, isolated from a sewage sample and verified by standard procedures, is used to evaluate the test procedure and each lot of media and reagents.

Because contamination of samples from coliphage during the analytical procedure is highly probable (Francy and others, 2000), a negative control of host and sterile buffered water is run concurrently with each batch of samples. In addition, to ensure that the method is being executed properly, a positive-control sewage sample is run with each batch of samples. A laminar flow safety hood is recommended for processing the samples for coliphage analysis. Alternatively, a separate coliphage room may be established to discourage laboratory contamination during the analytical process. An ultraviolet light is installed and operated for 8 hours every night in the safety hood or coliphage room to reduce contamination.

The laboratory should follow the QA/QC guidelines in Method 1623 (U.S. Environmental Protection Agency, 1999c) for *Cryptosporidium* and *Giardia* and in the cell-culture and RT-PCR analysis for enteric viruses (G. Shay Fout, U.S. Environmental Protection Agency, written commun., 1997; U.S. Environmental Protection Agency, 1996c).

Understanding Coliforms

Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. A fecal coliform (sometimes faecal coliform) is a facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacterium. Fecal coliforms are capable of growth in the presence of bile salts or similar surface agents, are oxidase negative, and produce acid and gas from lactose within 48 hours at 44 ± 0.5°C.

Coliform bacteria include genera that originate in feces (e.g. Escherichia) as well as genera not of fecal origin (e.g. Enterobacter, Klebsiella, Citrobacter). The assay is intended to be an indicator of fecal contamination; more specifically of E. coli which is an indicator microorganism for other pathogens that may be present in feces. Presence of fecal coliforms in water may not be directly harmful, and does not necessarily indicate the presence of feces.

"Indicator" Organisms
Water pollution caused by fecal contamination is a serious problem due to the potential for contracting diseases from pathogens (disease causing organisms). Frequently, concentrations of pathogens from fecal contamination are small, and the number of different possible pathogens is large. As a result, it is not practical to test for pathogens in every water sample collected. Instead, the presence of pathogens is determined with indirect evidence by testing for an "indicator" organism such as coliform bacteria. Coliforms come from the same sources as pathogenic organisms. Coliforms are relatively easy to identify, are usually present in larger numbers than more dangerous pathogens, and respond to the environment, wastewater treatment, and water treatment similarly to many pathogens. As a result, testing for coliform bacteria can be a reasonable indication of whether other pathogenic bacteria are present.

Total Coliforms, Fecal Coliforms, and E. Coli
The most basic test for bacterial contamination of a water supply is the test for total coliform bacteria. Total coliform counts give a general indication of the sanitary condition of a water supply.
A. Total coliforms include bacteria that are found in the soil, in water that has been influenced by surface water, and in human or animal waste.
B. Fecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.
C. Escherichia coli (E. coli) is the major species in the fecal coliform group. Of the five general groups of bacteria that comprise the total coliforms, only E. coli is generally not found growing and reproducing in the environment. Consequently, E. coli is considered to be the species of coliform bacteria that is the best indicator of fecal pollution and the possible presence of pathogens.

Are Coliform Bacteria Harmful?
Most coliform bacteria do not cause disease. However, some rare strains of E. coli, particularly the strain 0157:H7, can cause serious illness. Recent outbreaks of disease caused by E. coli 0157:H7 have generated much public concern about this organism. E. coli 0157:H7 has been found in cattle, chickens, pigs, and sheep. Most of the reported human cases have been due to eating under cooked hamburger. Cases of E. coli 0157:H7 caused by contaminated drinking water supplies are rare.

Coliform Testing
Testing for bacteria is the only reliable way to know if your water is safe. You cannot tell by the look, taste, or smell of the water if disease-causing organisms are in it. The New York State Department of Health recommends that well owners test their water for coliform bacteria at least once a year. If you have experienced bacteria problems in the past, it is recommended that you test your well more frequently.

When Should I Test?
Late spring or early summer are the best times to test your well, since coliform contamination is most likely to show up during wet weather. Whether your test results are positive or negative, understand that the sample you collected is just a "snapshot" of your well's water quality. The more samples you have tested, the more confident you can be about the quality of the water you are drinking.

What do the Results Mean?
If coliform bacteria are present in your drinking water, your risk of contracting a water-borne illness is increased. Although total coliforms can come from sources other than fecal matter, a positive total coliform sample should be considered an indication of pollution in your well. Positive fecal coliform results, especially positive E. Coli results, should be considered indication of fecal pollution in your well.

What Should be done if Coliform Bacteria are Detected in a Well?
When coliforms have been detected, repairs or modifications of the water system may be required. Boiling the water is advised until disinfection and retesting can confirm that contamination has been eliminated. A defective well is often the cause when coliform bacteria are found in well water.

What Kinds of Defects can Allow Contamination?
- a missing or defective well cap - seals around wires, pipes, and where the cap meets the casing may be cracked, letting in contaminants
- contaminant seepage through the well casing - cracks or holes in the well casing allow water that has not been filtered through the soil to enter the well. This seepage is common in the wells made of concrete, clay tile, or brick
- contaminant seeping along the outside of the well casing - many older wells were not sealed with grout when they were constructed
- well flooding - a common problem for wellheads located below the ground in frost pits that frequently flood during wet weather.

Long-Term Options for Dealing with Bacterial Contamination of a Well
- Connecting to the regional public water system, if possible
- Inspecting wells for defects and repairing them if possible
- Constructing a new well
- Installing continuous disinfection equipment
- Using bottled water for drinking and food preparation

Understanding Positive or Coliform Present Results
The Total Coliform Bacteria test is the standard microbiological test of the sanitary quality of drinking water. The EPA has stated that good drinking water should not contain any Coliform bacteria.
There are primarily 18 different bacteria which make up the group known as “Coliforms”. In most cases, Coliform bacteria are not harmful. However, if these bacteria are found in your water supply, this indicates that other disease causing bacteria may enter through the same pathway and be present in your drinking water.

If Coliform bacteria are found, the water supply is considered a potential health hazard and is classified as “UNSAFE” for human consumption. This test DOES NOT indicate if the water is chemically safe to drink.

E. COLI – One of the Coliform Bacteria

E. Coli is one of the approximate 18 members of Coliform group. The standard Coliform Bacteria test tells the difference between coliforms of fecal origin, specifically E. coli (from the intestines of warm-blooded

animals) and coliforms from other sources. Drinking water contaminated with E. coli is considered an "EXTREME HEALTH HAZARD".

The test results are reported as "PRESENT" or "ABSENT"

"ABSENT" – Good news, it means that Coliform bacteria were NOT in the test sample. In other words it "PASSED" the test.

"PRESENT" – Means that Coliform Bacteria were found in the sample and it "FAILED" the test. If Coliforms were found in the sample then E.coli (as a member of the Coliform Group) is also reported as "Present" or "Absent".

Coliforms "Present" and E. coli "Absent" – Very Unsafe – Potential Health Hazard.

Coliforms "Present" and E. coli "Present" – "EXTREME HEALTH HAZARD".

If your water system fails, the first step is usually to perform a "batch chlorination" on your drinking water supply. NRC will send written instructions for this procedure if your test results indicate a failure. After the chlorination procedure has been performed, use your water supply for a minimum of 5-7 days and retest. Until you have a test which shows that the bacteria are ABSENT, exercise caution with this system. It is recommended that you test for Coliform bacteria at least every six months.

Understanding Maximum Contaminant Levels (MCLs)
National Primary Drinking Water Regulations (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect public health by limiting the levels of contaminants in drinking water.

Emerging Pathogens
Although many of the established waterborne pathogens have been controlled by sanitation measures and water treatment processes, new diseases continue to be identified, and new discoveries present a better understanding of existing chronic diseases. Many of these discoveries raise questions about possible waterborne transmission. The bacteria that now need to be considered in this developing area are Helicobacter pylori, Mycobacterium species, Burkholderia pseudomallei and Francisella tularensis.

Helicobacter Pylori
Although spiral-shaped organisms have been observed in the stomachs of humans for many years, it was not until 1982 that a Campylobacter-like organism was isolated from patients with gastritis and a causative relationship between a new species, Helicobacter pylori, and gastric disease realized (Warren and Marshall 1983). H. pylori is a pathogen of global proportions and is generally accepted as the cause of most gastric and peptic ulcers. These diseases may lead to gastric adenocarcinoma.

H. pylori occurs worldwide in developing and developed countries. Where low degrees of hygiene and socioeconomic problems exist, infection rates may approach 100%. In developed countries, infection rates are probably between 30 and 60%. Transmission from person to person is not fully understood, mainly because of the difficulty in culturing the organism and identifying it outside the body. Epidemiological studies show the cluster phenomenon of H. pylori infection in families. It is suggested that infected mothers may play a key role in transmission within families (Rothenbacher et al. 1999).

H. pylori has been identified in faeces, and it is assumed that transmission is therefore oral–oral or faecal–oral. The organism has not been isolated from the environment or from drinking water, and waterborne transmission remains a possibility that should be investigated. The epidemiology, however, points to person-to-person transmission in early life.

Mycobacterium
The mycobacteria are a group of slow-growing organisms. The most important is Mycobacterium tuberculosis, the causative organism of tuberculosis, which takes about 4–6 weeks to grow in the diagnostic laboratory. M. tuberculosis is not a waterborne pathogen; there are, however, a number of Mycobacterium species that occur in the environment and can cause disease in humans. Mycobacterium avium and its related species cause an infection of cervical lymph nodes; it occurs in the environment and is most probably accompanied by ingestion or inhalation. M. avium can grow in water to which no additional nutrients have been added; although water treatment processes of coagulation and filtration appear to reduce the numbers, it is not affected by chlorine levels of 1 mg/ml. It is therefore not surprising that these organisms can regrow and colonize domestic water systems. Once ingested, M. avium can colonize the pharynx without causing any disease. The number of cases reported was very low, but patients with HIV/AIDS are very susceptible.

Another species, Mycobacterium xenopi, has been reported as the waterborne cause of spinal infections following a look-back exercise on over 3000 patients who had undergone discectomy operations some years beforehand (Astagneau et al. 2001).

Mycobacterium paratuberculosis causes Johne's disease in cattle. It is a chronic wasting disease with considerable economic consequences. The organism is extremely difficult to culture; when it does grow, it is very slow and dependent on an exogenous source of mycobactin, which is an iron chelating agent produced by all other mycobacteria. Transmission is by either direct or indirect contact with infected animals and occurs mainly through the faecal–oral route. Organisms are ingested in large numbers by young animals when they feed in troughs that have been contaminated by faeces of shedding animals (Chiodini et al. 1984).

M. paratuberculosis has recently been suggested as a cause of Crohn's disease, a non-specific chronic transmural inflammatory disease of humans that affects the intestinal tract, commonly the ileum. The disease is chronic, debilitating and of a relapsing nature; the symptoms experienced include diarrhea with blood in the stools and abdominal pain. Complications include obstruction, fistulation and abscesses. There have been many bacteria implicated over the years, but no definite etiological agent has been found. It is thought that immunological mechanisms may play an important role.

Molecular techniques have been developed for the diagnosis of M. paratuberculosis infections and applied to human surgically resected tissues. M. paratuberculosis was detected in approximately 30% of samples, but the sets of results from different laboratories have been conflicting. Some studies were unable to detect the organism; in other studies, the organism was detected in a smaller percentage of healthy subjects. In addition, a few Crohn's disease patients have shown clinical remission when treated with anti-tuberculosis drugs. There is therefore much more work to be done to acquire a better understanding. M. paratuberculosis may be present in surface water contaminated by cattle faeces. Routine testing for indicator organisms would detect faecal pollution, and normal water treatment processes of coagulation and filtration are likely to remove mycobacteria. It is unlikely that drinking-water is a major source of M. paratuberculosis, and its association with Crohn's disease is still under investigation.

Burkholderia Pseudomallei
Burkholderia pseudomallei is the cause of melioidosis, an acute pneumonia often followed by systemic infection with later presentations of abscesses. The organism is widespread in the environment and was originally described in Rangoon in patients compromised by severe poverty who had presumably inhaled the organism in dust when sleeping on the ground. It occurs commonly in southeast Asia and has been detected in service personnel repatriated from those areas in the past. It was also investigated as a biological weapon by several nations, to be released as an aerosol and cause pneumonia infection in those exposed. A recent study in Bologna, Italy, detected B. pseudomallei in 7% of 85 samples of drinking-water collected from public and private buildings. The mean count was 578 cfu/100 ml. The occurrence of the organism was found to correlate with the HPC at 22 and 36 °C (Zanetti et al. 2000).

Francisella Tularensis
Tularaemia is a zoonosis caused by a highly infective and virulent organism Francisella tularensis, which occurs throughout the northern hemisphere but has never been isolated within the United Kingdom. It occurs in a wide range of animal reservoir posts and can be isolated from the environment in water and mud. It is transmitted to humans who come in close contact with the animal reservoir, arthropods that feed on them or debris and dust associated with them. It can also be transmitted through the ingestion of contaminated water. Human epidemics sometimes occur and are associated with epizootics in the animal

Bacteria of potential health concern 75 populations, evidenced by die-offs. There are several presentations of tularaemia in humans, depending on the route of exposure. Ingestion usually results in oropharyngeal tularaemia, with fever, pharyngitis and cervical lymphadenitis. Other forms include ulcero-glandular, pleuropneumonic and typhoidal. Following the recent war in Kosovo, over 900 suspected cases of tularaemia were identified and 327 cases confirmed serologically. The epidemiological investigation pointed to rodent-contaminated wells, and rodent carcasses found in some wells tested positive for F. tularensis (Reintjes et al. 2002). In a waterborne outbreak reported from Spain, 19 cases who had contact with river-caught crayfish were identified (Anda et al. 2001). Attempts to isolate F. tularensis from water were unsuccessful. Drinking-water was not involved. F. tularensis is notoriously difficult to culture, requiring a source of cysteine. F. tularensis was investigated and developed as a biological weapon; the infectious dose was found to be extremely low — 10 organisms.

Examples of classical biological warfare agents

Agent	**Disease**
Bacillus anthracis	Anthrax
Brucella species	Brucellosis
Burkholderia mallei	Glanders
Burkholderia pseudomallei	Melioidosis
Francisella tularensis	Tularaemia
Yersinia pestis	Plague
Rickettsia species	Typhus
Coxiella burnetii	Q fever
Clostridium botulinum toxin	Botulism
Staphylococcus aureus enterotoxin B	Staphylococcal food poisoning
Smallpox virus	Smallpox

The remaining bacteria of concern are either heterotrophs that might have a role in disease or emerging pathogens that do have a role in disease and could possibly be waterborne. It is important that these organisms and diseases are kept under surveillance in order to confirm or refute the suggested associations. Many of the organisms are difficult to grow, and there is no validated trigger of when to look for them.

The HPC does not measure all organisms present, of which many will be non-culturable but viable, and indeed several of the organisms of concern described above would not grow on HPC media. The HPC, however, does give an indication of change in the flora of drinking-water, and the HPC should be evaluated as a trigger for further investigation.

Many new molecular techniques for the detection of pathogens and putative pathogens in water are being described (Waage et al. 1999a,b,c; Lightfoot et al. 2001). DNA chips that have the capacity to detect up to 44 pathogens on one single chip are being developed.

These tests are very expensive when compared with the routine monitoring tests carried out in the water industry and in public health monitoring. The HPC should be evaluated as the signal of changing events in a drinking-water supply to trigger the utilization of these new molecular tests to detect the new bacteria of concern and any associated virulence genes.

Understanding Heterotrophic Plate Count
The analytical methods promulgated under the authority of Section 304(h) of the Clean Water Act are sometimes referred to as the "304(h)" or "Part 136" methods. The methods measure chemical and biological pollutants in media, such as wastewater, ambient water, sediment, and biosolids (sewage sludge). These various CWA methods are tested in a variety of labs and matrices. In addition to Part 136 methods, some approved methods are published or incorporated by reference at 40 CFR Parts 401-503, approved industry-specific methods.

In addition to general purposes methods, EPA has approved special purpose analytical methods. These methods were developed to work in samples or for pollutants specific to certain industrial categories. For example, methods specific to the Pharmaceutical Manufacturing and Pesticide Chemicals industrial categories are listed in Tables IF and IG, respectively, at 40 CFR Part 136.

Methods specific to other industrial categories are listed or incorporated by reference into the regulations at 40 CFR Parts 401-503. These include methods specific to the Pulp, Paper, and Paperboard category (40 CFR Part 430), and specific to Use or Disposal of Sewage Sludge (biosolids) (at 40 CFR Part 503.) Industry-specific methods that are approved for compliance monitoring in the industry for which they are designated may be used for general use, if the same method is listed in Tables IA to IE, or IH at 40 CFR 136.3.

Understanding Total Coliforms
The Total Coliform Rule was published in 1989 and became effective in 1990. The rule set both health goals (MCLGs) and legal limits (MCLs) for the presence of total coliform in drinking water. The rule also detailed the type and frequency of testing that water systems must undertake. In 2003, EPA announced its intent to revise the Total Coliform Rule.

2010 Proposed Revisions to the Total Coliform Rule
The Environmental Protection Agency (EPA) is proposing revisions to the 1989 Total Coliform Rule (TCR), a national primary drinking water regulation (NPDWR). The purpose of the TCR is to protect public health by ensuring the integrity of the drinking water distribution system and monitoring for the presence of microbial contamination. EPA anticipates greater public health protection under the proposed revised requirements, which are based on recommendations by a federal advisory committee.

The proposed revisions to the TCR will:

- require public water systems that are vulnerable to microbial contamination to identify and fix problems, and

- establish criteria for systems to qualify for and stay on reduced monitoring, thereby providing incentives for improved water system operation.

The proposed RTCR maintains and strengthens the objectives of the current TCR and is consistent with the recommendations in the AIP. The objectives are: (1) To evaluate the effectiveness of treatment, (2) to determine the integrity of the distribution system, and (3) to signal the possible presence of fecal contamination. The proposed revision better addresses these objectives by requiring systems that may be vulnerable to fecal contamination (as indicated by their monitoring results) to do an assessment, to identify whether any sanitary defect(s) is (are) present, and to correct the defects.

Therefore, the Agency anticipates greater public health protection under the proposed RTCR compared to the current TCR because of its more preventive approach to identifying and fixing problems that affect or may affect public health.

The following is an overview of the key provisions of the proposed RTCR:

- MCLG and MCL for E. coli and coliform treatment technique for protection against potential fecal contamination. The proposed RTCR establishes a maximum contaminant level goal (MCLG) and maximum contaminant level (MCL) for E. coli. It takes a preventive approach to protecting public health by establishing a coliform treatment technique for protection against potential fecal contamination. The treatment technique uses both total coliforms and E. coli monitoring results to start an evaluation process that, where necessary, will require the PWS to conduct follow-up corrective action that could prevent future incidences of contamination and exposure to fecal contamination and/or waterborne pathogens.

- Monitoring. As with the current TCR, PWSs will continue to monitor for total coliforms and E. coli according to a sample siting plan and schedule specific to the system.

Sample siting plans under the proposed RTCR must continue to be representative of the water throughout the distribution system. Under the proposed RTCR, systems have the flexibility to propose repeat sample locations that best verify and determine the extent of potential contamination of the distribution system rather than having to sample within five connections upstream and downstream of the total coliform-positive sample location. In lieu of proposing new repeat sample locations, the systems may stay with the default used under the current TCR of five connections upstream and downstream of the total coliform-positive sample location.

As with the current TCR, the proposed RTCR allows reduced monitoring for some small ground water systems. The proposed RTCR is expected to improve public health protection compared to the current TCR by requiring small ground water systems that are on or wish to conduct reduced monitoring to meet certain eligibility criteria. Examples of the criteria include a sanitary survey showing that the system is free of sanitary defects, a clean TCR compliance history for 12 months, and a recurring annual site visit by the State and/or a voluntary Level 2 assessment for systems on annual monitoring.

For small ground water systems, the proposed RTCR requires increased monitoring for high-risk systems that meet certain criteria such as unacceptable compliance history under the RTCR. The proposed RTCR specifies conditions under which systems will no longer be eligible for reduced monitoring and be required to return to routine monitoring or to monitor at an increased frequency.

The proposed RTCR requires systems on a quarterly or annual monitoring frequency (applicable only to ground water systems serving 1,000 or fewer people) to conduct additional routine monitoring the month following one or more total coliform-positive samples. Under the proposed RTCR, systems must collect at least three routine samples during the next month, unless the State waives the additional routine monitoring. This is a reduction in the required number of additional routine samples from the current TCR, which requires at least five routine samples in the month following a total coliform-positive sample for all systems serving 4,100 or fewer people.

The current TCR requires all systems serving 1,000 or fewer people to collect at least four repeat samples while PWSs serving 1,000 people or greater to collect three repeat samples. The proposed rule requires three repeat samples after a routine total coliform-positive sample, regardless of the system type and size.

Seasonal Systems
The proposed RTCR establishes monitoring requirements for seasonal systems for the first time. Seasonal systems represent a special case in that the shutdown and start-up of these water systems present additional opportunities for contamination to enter or spread through the distribution system. Seasonal systems must demonstrate completion of a State-approved start-up procedure. In addition, they must designate the time period(s) for monitoring based on site-specific considerations (such as during periods of highest demand or highest vulnerability to contamination) in their State-approved sample siting plan. See section III.A.3 of this preamble for a detailed discussion of seasonal systems.

Assessment and Corrective Action
As part of a treatment technique, all PWSs are required to assess their systems when monitoring results show that the system may be vulnerable to contamination. Systems must conduct a simple self-assessment (Level 1) or a more detailed assessment (Level 2) depending on the severity and frequency of contamination. The system is responsible for correcting any sanitary defect(s) found through either a Level 1 or Level 2 assessment.

Violations and Public Notification
The proposed RTCR establishes an E. coli MCL violation, a treatment technique violation, a monitoring violation, and a reporting violation. Public notification is required for each type of violation, with the type of notification dependent on the degree of potential public health concern. This is consistent with EPA's current public notification requirements under 40 CFR part 141 subpart Q. The proposed RTCR also modifies the public notification and Consumer Confidence Report language to reflect the construct of the proposed rule. See sections III.A.6 and III.A.7 of this preamble for detailed discussions of violations and public notification under the proposed RTCR.

Transition to the RTCR
The proposed RTCR allows all systems to transition to the new rule at their current TCR monitoring frequency, including systems on reduced monitoring under the current TCR. States will then evaluate the monitoring frequency during each sanitary survey conducted after the compliance effective date of the RTCR. This process reduces State burden by not requiring the State to determine appropriate monitoring frequency at the same time as when the State is trying to adopt primacy, develop policies, and train their own staff and the PWSs in the State.

The provisions of the proposed RTCR are contained in the new 40 CFR part 141 subpart Y, superseding 40 CFR 141.21 beginning three years following the publication of the final revised rule.

A. Proposed Rule Provisions and Rationale
1. Terms used in the proposed RTCR
a. Provisions. i. Clean compliance history. For the purposes of the proposed RTCR, EPA is proposing to define “clean compliance history” as a record of no maximum contaminant level (MCL) violations under 40 CFR 141.63; no monitoring violations under 40 CFR 141.21 or subpart Y; and no coliform treatment technique trigger exceedances or coliform treatment technique violations under subpart Y.
ii. Sanitary defect. EPA is proposing to define “sanitary defect” as a “defect that could provide a pathway of entry for microbial contamination into the distribution system or that is indicative of a failure or imminent failure in a barrier that is already in place” (USEPA 2008c).
iii. Seasonal systems. EPA is proposing to define a seasonal system as a non-community water system that is operated in three or fewer calendar quarters per calendar year.
b. EPA's rationale. i. Clean compliance history. EPA is proposing a definition of “clean compliance history” because without a definition, the use of the phrase could result in multiple interpretations. Clean compliance history is one of the criteria a system must meet to be eligible for reduced monitoring. The advisory committee recommended this definition (USEPA 2008c, AIP p. 10).
ii. Sanitary defect. The advisory committee recommended the definition of sanitary defect. The proposed RTCR takes a more preventive approach to protect public health by establishing a framework for the assessment of public water systems to identify sanitary defects and to correct them as appropriate. The first part of the proposed definition of a “sanitary defect” focuses on problems in the distribution system that may provide a pathway for contaminants to enter the distribution system and its implication for potential exposure to both microbial and chemical contaminants. The second part of the definition also recognizes the importance of having barriers in place to prevent the entry of microbial contaminants into

the distribution system. Indications of failure or imminent failure of these barriers are defects that require corrective action.

Sanitary Defect
Sanitary defect is a term specific to the proposed RTCR assessment and corrective action provisions. Sanitary defects are not intended to be linked directly to "significant deficiencies" under the Interim Enhanced Surface Water Treatment Rule (IESWTR) (USEPA 1998b, 63 FR 69389, December 16, 1998) and Ground Water Rule (GWR) (USEPA 2006c, 71 FR 65574, November 8, 2006), although some problems could meet either definition. Nothing in this proposed rule is intended to limit the existing authorities of States under other regulations. The following is a list of examples of sanitary defects and defects in the distribution system coliform monitoring practices.

Examples of sanitary defects:

- ✓ Cross connection and backflow issues such as a required backflow prevention device not in place or not operating properly; or an unprotected cross connection found. Operator issues such as failure to follow standard operating procedures (SOPs) that protect distribution system integrity and sanitary conditions.

- ✓ Distribution system issues such as inadequate inspection and maintenance of the distribution system; loss of distribution system integrity such as main breaks; failure to maintain adequate pressure; improper flushing operations; improper construction of new, replaced, or renovated lines; inadequate disinfection during and after repair/replacement activities; or inability to maintain required residual throughout the distribution system.

- ✓ Storage issues such as overflow, vents, hatches, and other penetrations not properly configured, screened, or sealed; inadequate maintenance of storage facilities; or inadequate disinfection during and after repair/replacement activities

- ✓ Disinfection issues such as inability to maintain required residual throughout the distribution system.

iii. Seasonal systems. Seasonal systems fall under the broader category of non-community water systems (NCWS) and therefore are subject to provisions applicable to that category of systems. However, seasonal systems have unique characteristics and timetables that make them particularly susceptible to contamination. Seasonal systems represent a special case in that the shut down and start-up of the water system present opportunities for contamination to enter or spread through the distribution system. For example, loss of pressure after a system's shut down can lead to intrusion of contaminants. Microbial growth prior to start-up can result in biofilm formation, which can lead to the accumulation of contaminants. These systems are also more susceptible to contamination due to changes in the conditions of the source water (such as variable contaminant loading due to increased septic tank or septic field use), the seasonal nature of the demand, and the stress that the system experiences. As a result, the Agency is establishing a definition for seasonal systems and setting forth provisions that mitigate the risk associated with the unique characteristics of this type of system. The advisory committee recommended that such provisions pertain to seasonal systems.

c. Request for comment. EPA requests comment on the proposed definitions and whether they work within the construct of the proposed RTCR. Specifically, EPA requests comment on the proposed definition of seasonal systems. The advisory committee recommended that seasonal systems be identified and be subject to additional regulatory requirements because the shutdown and startup of the system presents opportunities for contaminants to enter or spread through the distribution system. These results are possible in any system that shuts down and does not maintain adequate pressure throughout the distribution system. The AIP describes a seasonal system as "one which operates less than four calendar quarters per year" (USEPA 2008c). EPA has interpreted this to mean that a seasonal system is one which is shut down for at least one full calendar quarter (i.e., it operates in three or fewer calendar quarters). EPA requests comment on whether this proposed definition of "seasonal system" is adequate to address the concern that motivated the advisory committee's recommendation and is consistent with its intent. For example, a system that operated from March to October would operate in all four calendar quarters and would not be considered a seasonal system, but would be subject to the same possibility of

distribution system intrusion as a seasonal system that operated April to November (i.e., in only three calendar quarters).

Should EPA modify the definition to address this issue? If so, how should the definition be modified? Should systems that close for some specified period (e.g., 30 days, 60 days, 90 days) be subject to seasonal system requirements? What should that specified period be?

Systems that operate intermittently (e.g., only on weekends or only when a camp is open) may also be subject to distribution system contamination due to lack of adequate pressure. Should this be addressed? If so, how should it be addressed—through regulation, guidance, or some other approach? Is there a specific shutdown time that should be considered for intermittent systems in developing the approach and determining which systems should be included?

In addition to the public health benefits associated with these requirements, EPA is aware of the burden that States will have in determining which systems must comply and in tracking compliance. Therefore, EPA requests comment on ways to reduce State burden and facilitate implementation of seasonal system provisions.

2. MCLG and MCL for E. coli, and Coliform Treatment Technique

a. Provisions. The current TCR established a maximum contaminant level goal (MCLG) of zero for total coliforms (including fecal coliforms and E. coli) and an MCL for total coliforms. EPA is proposing in the RTCR to eliminate the MCLG for total coliforms (including fecal coliforms) and the MCL for total coliforms. Under the proposed RTCR, EPA establishes an MCLG of zero and an MCL for E. coli and a treatment technique for coliform. The proposed MCL for E. coli is based on the monitoring results for total coliforms and E. coli.

A system is in compliance with the E. coli MCL unless any of the following conditions occur:

- A system has an E. coli positive repeat sample following a total coliform-positive routine sample; or
- A routine sample is E. coli-positive and one of its associated repeat samples is total coliform-positive; or
- A system fails to test for E. coli when any repeat sample tests positive for total coliforms; or
- A system fails to take all required repeat samples following a routine sample that is positive for E. coli.

The proposed MCL is similar to the criteria that define the conditions (if exceeded) when a Tier 1 acute MCL violation occurs under the current TCR but with two modifications. First, the proposed MCL excludes fecal coliforms. Second, the proposed MCL also includes an additional condition by which a system violates the MCL, namely failing to collect all repeat samples following an initial E. coli-positive sample. Although not explicitly stated, as a logical consequence of the second condition, a system also violates the MCL when an E. coli- positive routine sample is followed by an E. coli-positive repeat sample because E. coli are a subset of total coliforms. EPA is also proposing a coliform treatment technique, which uses total coliforms and E. coli as indicators of a possible breach in the distribution system that could lead to fecal contamination.

b. EPA's rationale. i. Inclusion of MCLG for E. coli and removal of MCLG for total coliforms (including fecal coliforms). EPA is proposing in the RTCR to include an MCLG of zero for E. coli and to remove the current MCLG of zero for total coliforms (including fecal coliforms). This is because E. coli is a more specific indicator of fecal contamination and potential harmful pathogens in drinking water than are total coliforms (including fecal coliforms). Many of the organisms detected by total coliform and fecal coliform methods are not of fecal origin and do not have any direct public health implication. See also the discussion of fecal coliforms in section III.A.9 of this preamble. New information has become available since promulgation of the current TCR in 1989 that indicates that measurement of fecal coliforms sometimes detects organisms that may not have any connection to fecal contamination (Edberg et al. 2000). An MCLG of zero for E. coli is more appropriate than an MCLG of zero for total coliforms (including fecal coliforms) since E. coli is a more specific indicator of the presence of fecal contamination.

Total coliforms (including fecal coliforms) do not in and of themselves pose a public health risk, but they may indicate the presence of a pathway by which fecal contamination can occur. Therefore, the removal of the MCLG for total coliforms (including fecal coliforms) would prevent possible public confusion as a result of attributing greater public health significance to the presence of total coliforms than is warranted. EPA believes that the removal of the MCLG for total coliforms, along with the other proposed changes discussed in the succeeding paragraphs, leads to a rule that is more protective of public health, and is less confusing to the public. The proposed MCLG of zero for E. coli and the removal of the MCLG for total coliforms (including fecal coliforms) are also consistent with the recommendation made by the advisory committee in the AIP.

ii. Inclusion of MCL for E. coli and removal of MCLs for total coliforms and fecal coliforms. EPA is proposing to include in the RTCR an MCL for E. coli because approved analytical methods continue to be available to measure the presence of E. coli in water samples, i.e., the presence of E. coli is technologically feasible to ascertain. Violation of the proposed MCL for E. coli signifies fecal contamination occurrence and a possible high risk of exposure to pathogens. EPA is proposing to eliminate the MCLs for total coliforms and fecal coliforms because under the proposal there is no longer an MCLG for either total coliforms or fecal coliforms, for the reasons explained earlier. The proposed MCL for E. coli is consistent with the recommendation made by the advisory committee in the AIP.

iii. Coliform treatment technique. The 1996 SDWA amendments authorize EPA to promulgate a treatment technique in lieu of an MCL if EPA determines that "it is not economically or technologically feasible to ascertain the level of the contaminant" (SDWA 1412(b)(7)(A)). While it is technologically feasible to ascertain levels of E. coli (i.e., analytical methods continue to be available to measure the presence of E. coli in water samples), because of the intermittent nature of fecal contamination, it is not economically feasible to ascertain the level of E. coli occurrence below which the water may be deemed safe. This is because it is not economically feasible to monitor E. coli with sufficient frequency to ensure such safety.

Because total coliform bacteria are part of the soil ecosystem, positive samples are indicators of fecal contaminant entry into drinking water via a pathway from the soil. EPA is proposing a coliform treatment technique, supplemental to directly measuring E. coli, to provide additional protection against fecal contamination. Under the proposed coliform treatment technique, as specified in the AIP, total coliform-positive samples, in the absence of E. coli, are still indicators of an E. coli or other fecal contaminant pathway.

A PWS that exceeds a specified frequency of total coliform occurrence must conduct a Level 1 or Level 2 assessment to determine if any sanitary defect(s) exist(s) and, if found, to correct the defect(s). In addition, under the proposed treatment technique requirements, a PWS that incurs an E. coli MCL violation must conduct a Level 2 assessment and take remedial action if any sanitary defects are found.

The treatment technique requirements as proposed enhance public health protection beyond the E. coli MCL for the following reasons:

- ✓ The assessment and corrective action provisions of the treatment technique when the MCL for E. coli is exceeded require PWSs to investigate the potential causes of the fecal contamination and require timely remedial action if any sanitary defects are found. Under the current TCR, there are no requirements for investigation and corrective action after an MCL exceedance. Without such a find-and-fix provision, the pathway for contamination may not be identified and eliminated as sampling alone may not be adequate to identify intermittent sources of fecal contamination. The assessment and corrective action provisions of the proposed rule increase the likelihood of finding and correcting any sanitary defect and reduce the chance of recurrence of fecal contamination in the future.

- ✓ Using total coliforms in addition to E. coli as an indicator to prompt assessment and corrective action increases the sensitivity for identifying potential pathways for contamination. As discussed in section II.D.2 of this preamble, the presence of total coliforms indicates the potential existence of a pathway through which fecal contamination could follow. The absence (versus the presence) of total coliforms in the distribution system indicates a reduced likelihood that fecal contamination and/or waterborne pathogens are occurring in the distribution system. Analyses from EPA's 2005 Six-Year Review 2 data (USEPA 2006b; USEPA 2010e) (see section VI.B of this preamble for details on the Six-Year Review 2 data) and from the proposed RTCR Economic Analysis (EA) occurrence modeling show that total coliform presence in drinking water is approximately 20 to 40 times higher than E. coli occurrence in drinking water (see chapter 4 of the Proposed RTCR EA (USEPA 2010a)). Similarly, under the current TCR, non-acute MCL (also referred to as monthly MCL) violations (informed by total coliform occurrence) occur roughly 10 times more often than acute MCL violations (informed by total coliform and E. coli occurrence, essentially equivalent to the occurrence that triggers an E. coli MCL violation under this proposed rule). Thus, including monitoring of total coliforms, as well as E. coli, as part of a treatment technique to indicate when systems must find and fix any sanitary defects, substantially increases the likelihood of identifying such defects.

- ✓ The proposed treatment technique was supported by the advisory committee and is consistent with the recommendations in the AIP.

c. Request for comment. EPA requests comment on its proposal to eliminate the MCLG and MCL provisions for total coliforms and fecal coliforms and to include an MCLG and MCL for E. coli and coliform treatment technique provisions based on monitoring for total coliforms and E. coli. EPA also requests comment on its proposed definition of the E. coli MCL.

3. Monitoring

a. Provisions. As with the current TCR, the proposed RTCR requires all PWSs to collect and test samples for total coliforms and E. coli according to a sample siting plan and schedule specific to the system. Under the proposed RTCR, all PWSs are still required to take repeat samples within 24 hours of learning of any routine monitoring sample that is total coliform-positive. PWSs must comply with the repeat monitoring requirements and E. coli analytical requirement, discussed in detail in section III.A.4 of this preamble. All samples taken for proposed RTCR compliance (routine and repeat) may occur at a customer's premises, dedicated sampling station, or other designated compliance sampling location.

Under the proposed RTCR, system sample siting plans must include routine and repeat sample sites and any sampling points necessary to meet the Ground Water Rule (GWR) requirements. The sample siting plan is subject to State review and revision. The PWS may propose repeat monitoring locations that are expected to be representative of a pathway for contamination into the distribution system (for example, near a storage tank). Instead of identifying set repeat sampling locations (i.e., within five service connections upstream and downstream of the original sampling location that tested total coliform-positive), systems may elect to specify criteria for selecting their repeat sampling locations on a situational basis in a standard operating procedure (SOP), which is part of the sample siting plan.

Upon State review, the PWS must demonstrate to the State's satisfaction that the sample siting plan remains representative of the water quality in the distribution system. The State may modify the SOP as needed. To address access issues, small systems must specify in their sampling plans where the two additional samples will be taken. The State may determine that monitoring at the entry point to the distribution system (especially for undisinfected ground water systems) is effective to differentiate between potential source water and distribution problems.

Under the proposed RTCR, PWSs may take more than the minimum required number of routine samples and include the results in calculating whether the total coliform treatment technique trigger for conducting an assessment has been exceeded only if the samples are taken in accordance with the sample siting plan and are representative of water throughout the distribution system.

EPA is not proposing to make substantive changes to the current TCR requirements for (1) special purpose samples, and (2) invalidation of total coliform samples. EPA is proposing a minor modification to the provision for special purpose samples by changing “total coliform MCL” to “coliform treatment technique trigger.”

The following are the proposed monitoring requirements for different categories of systems.
i. Ground water NCWSs serving ? 1,000 people. (a). Routine monitoring. The proposed RTCR requires ground water NCWS serving 1,000 or fewer people to routinely monitor each quarter for total coliforms and E. coli. Seasonal systems under this category must routinely monitor every month (seasonal systems are discussed later in this section).
(b). Transition to the RTCR. The proposed RTCR requires all ground water NCWSs serving 1,000 or fewer people, including seasonal systems, to continue with their TCR monitoring schedules as of the compliance date of the RTCR, unless or until any of the conditions for increased monitoring discussed later on in this section are triggered on or after the compliance date or unless otherwise directed by the State, including through the special monitoring evaluation conducted under a sanitary survey. In addition, systems on annual monitoring, including seasonal systems, must have an initial annual site visit by the State within one year of the compliance date (or an annual voluntary Level 2 assessment by a party approved by the State) and an annual site visit each year thereafter to remain on annual monitoring.

This rule proposes that after the compliance date of the final RTCR, during each sanitary survey the State (which would be either EPA or a State that has received primacy for this rule) must perform a special monitoring evaluation to review the status of the water system, including the distribution system, to determine whether the system is on an appropriate monitoring schedule and modify the monitoring schedule as necessary. States must evaluate system factors such as the pertinent water quality and compliance history, the establishment and maintenance of contamination barriers, and other appropriate protections and validate the appropriateness of the water system's existing monitoring schedule and modify as necessary. For seasonal systems on quarterly or annual monitoring, this evaluation must also include review of the approved sample siting plan which designates the time period(s) for monitoring based on site-specific considerations (such as during periods of highest demand or highest vulnerability to contamination). The system must collect compliance samples during these time periods.
(c). Reduced monitoring. The State has the discretion to reduce the monitoring frequency for well-operated ground water NCWSs from the quarterly routine monitoring to no less than annual monitoring, if the water system can demonstrate that it meets the criteria for reduced monitoring provided in this section.

To be eligible to qualify for and remain on annual monitoring after the compliance date, a ground water NCWS serving 1,000 or fewer people must meet all of the following criteria:

- The most recent sanitary survey shows the system is free of sanitary defects, has a protected water source and meets approved construction standards;

- The system must have a clean compliance history (no MCL violations or monitoring violations under the current TCR and/or proposed RTCR, no Level 1 or Level 2 trigger exceedances or treatment technique violations under the proposed RTCR) for a minimum of 12 months. (For a more detailed discussion on Level 1 and Level 2 triggers, see section III.A.5 of this preamble); and

- An initial site visit by the State within the last 12 months to qualify for reduced annual monitoring, and recurring annually to stay on reduced annual monitoring; and correction of all identified sanitary defects. A voluntary Level 2 assessment by a party approved by the State may be substituted for the State annual site visit in any given year.

(d). Increased monitoring. Ground water NCWS serving 1,000 or fewer people on quarterly or annual monitoring that experience any of the following events must begin monthly monitoring the month following the event:

- ✓ The system triggers a Level 2 assessment or two Level 1 assessments in a rolling 12 month period;

- ✓ The system has an E. coli MCL violation;

- ✓ The system has a coliform treatment technique violation (for example, if the system fails to conduct a Level 1 assessment or correct for sanitary defects if required to do so); or

- ✓ The system on quarterly monitoring has two monitoring violations in a rolling 12-month period or system on annual monitoring has one monitoring violation.

The system must continue monthly monitoring until the requirements in this section for returning to quarterly or annual monitoring are met.

(e). Requirements for returning to quarterly monitoring. To be eligible to return to quarterly monitoring, ground water NCWSs serving 1,000 or fewer people must meet all of the following criteria:

* Within the last 12 months, the system must have a completed sanitary survey or a site visit by the State or a voluntary Level 2 assessment by a party approved by the State. The system is free of sanitary defects, and has a protected water source; and

* The system has a clean compliance history (no E. coli MCL violations, Level 1 or 2 triggers, coliform treatment technique violations or monitoring violations) for a minimum of 12 months.

(f). Requirements for returning to reduced annual monitoring. To be eligible to return to reduced annual monitoring after being placed on increased monitoring, the system must meet the criteria to return to routine quarterly monitoring plus the following criteria:

- ✓ An annual site visit (recurring) by the State and correction of all identified sanitary defects. An annual voluntary Level 2 assessment may be substituted for the State annual site visit in any given year; and

- ✓ The system must have in place or adopt one or more additional enhancements to the water system barriers to contamination as approved by the State. These measures could include but are not limited to the following:

—Cross connection control, as approved by the State;
—An operator certified by an appropriate State certification program, which may include regular visits by a circuit rider;
—Continuous disinfection entering the distribution system and a residual in the distribution system in accordance with criteria specified by the State; and
—Maintenance of at least a 4-log inactivation or removal of viruses each day of the month based on daily monitoring as specified in the GWR (with allowance for a 4-hour exception).
—Other equivalent enhancements to water system barriers as approved by the State.

(g). Seasonal systems. The proposed rule requires all seasonal systems to demonstrate completion of a State-approved start-up procedure on and after the compliance date of the final RTCR. Seasonal systems may continue with their TCR monitoring frequency after the compliance date of the final RTCR unless or until any of the conditions for increased monitoring discussed previously are triggered on or after the compliance date or as directed by the State. Under the proposed RTCR, seasonal systems are required to take routine samples monthly.

To be eligible for reduced monitoring after the compliance date, seasonal systems must meet the following criteria:

- ✓ The system must have an approved sample siting plan that designates the time period for monitoring based on site-specific considerations (e.g., during periods of highest demand or highest vulnerability to contamination). The system must collect compliance samples during this time period; and

- ✓ To be eligible for reduced quarterly monitoring, the system must also meet all the reduced monitoring criteria discussed in section III.A.3.a.i.(e) of this preamble, Requirements for returning to quarterly monitoring.

- ✓ To be eligible for reduced annual monitoring, the system must also meet all the reduced monitoring criteria discussed in section III.A.3.a.i.(f) of this preamble, Requirements for returning to reduced annual monitoring.

(h). Additional routine monitoring. All systems collecting samples on a quarterly or annual frequency must conduct additional routine monitoring following a single total coliform-positive sample (with or without a Level 1 trigger event). The additional routine monitoring consists of three samples in the month following the total coliform-positive sample at routine monitoring locations identified in the sample siting plan. This is a change from the current TCR additional routine monitoring requirement of taking a total of five samples the month following a total coliform-positive sample for systems that take four or fewer samples per month.

In this proposal, consistent with the current TCR, the State may waive the additional routine monitoring requirement if:

- ➢ The State, or an agent approved by the State, performs a site visit before the end of the next month the system provides water to the public. Although a sanitary survey need not be performed, the site visit must be sufficiently detailed to allow the State to determine whether additional monitoring and/or any corrective action is needed. The State cannot approve an employee of the system to perform this site visit, even if the employee is an agent approved by the State to perform sanitary surveys.

- ➢ The State has determined why the sample was total coliform-positive and establishes that the system has corrected the problem or will correct the problem before the end of the next month the system serves water to the public. In this case, the State must document this decision to waive the following month's additional monitoring requirement in writing, have it approved and signed by the supervisor of the State official who recommends such a decision, and make this document available to the EPA and public. The written documentation must describe the specific cause of the total coliform-positive sample and what action the system has taken and/or will take to correct this problem.

The State may not waive the requirement to collect three additional routine samples the next month in which the system provides water to the public solely on the grounds that all repeat samples are total coliform-negative. If the State determines that the system has corrected the contamination problem before the system takes the set of repeat samples required in § 141.858, and all repeat samples were total coliform-negative, the State may waive the requirement for additional routine monitoring the next month.

All additional routine samples are included in determining compliance with the MCL and coliform treatment technique requirements.

ii. Ground water CWSs serving 1,000 people. (a). Routine monitoring. The proposed RTCR requires ground water CWSs serving 1,000 or fewer people to routinely monitor each month for total coliforms and E. coli.

The State may reduce the monitoring frequency for ground water CWS from the monthly routine monitoring to quarterly reduced monitoring if the water system can demonstrate that it meets the criteria for reduced monitoring provided later in this section
(b). Transition to the RTCR. All ground water CWSs serving 1,000 or fewer people continue with their current TCR monitoring schedules unless or until any of the increased monitoring requirements in this section occur or as directed by the State.

After the compliance date of the final RTCR, the State must determine whether the system is on an appropriate monitoring schedule by performing a special monitoring evaluation during each sanitary survey to review the status of the PWS, including the distribution system. The State must evaluate system factors such as the pertinent water quality and compliance history, the establishment and maintenance of barriers to contamination, and other appropriate protections to validate the water system's existing monitoring schedule or require more frequent monitoring.
(c). Reduced monitoring. The State has the flexibility to reduce the monitoring frequency for well-operated ground water CWS from the monthly routine monitoring to no less than quarterly monitoring if the water system can demonstrate that it meets the criteria for reduced monitoring provided in this section.

To be eligible for quarterly reduced monitoring, ground water CWSs serving 1,000 or fewer people on monthly monitoring after the compliance date must be in compliance with State-certified operator provisions and meet each of the following criteria:

- The most recent sanitary survey shows the system is free of sanitary defects (or has an approved plan and schedule to correct them), has a protected water source, and meets approved construction standards;

- The system must have a clean compliance history (no MCL violations or monitoring violations under the current TCR and/or proposed RTCR, no Level 1 or Level 2 trigger exceedances or treatment technique violations under the proposed RTCR) for a minimum of 12 months; and

- The system must meet at least one of the following criteria:

—An annual site visit by the State or a voluntary Level 2 assessment by a party approved by the State or meeting criteria established by the State and correction of all identified sanitary defects (or an approved plan and schedule to correct them), or
—A cross connection control program, as approved by the State,
—The system must maintain continuous disinfection entering the distribution system and a residual in the distribution system in accordance with criteria specified by the State,—The system must maintain at least a 4-log inactivation or removal of viruses each day of the month based on daily monitoring as specified in the GWR (with allowance for a 4-hour exception) (USEPA 2006c, 71 FR 65574, November 8, 2006); or
—Other equivalent enhancements to water systems as approved by the State.

(d). Return to routine monitoring requirements. When a system on quarterly monitoring experiences any of the following events the system must begin monthly monitoring:

- System triggers a Level 2 assessment or two Level 1 assessments in a rolling 12 month period;
- System has an E. coli MCL violation;
- System has a coliform treatment technique violation (e.g., fails to conduct a Level 1 or Level 2 assessment or to correct for a sanitary defect if required to do so); or
- System has two routine monitoring violations in a rolling 12-month period.

The system must continue monthly monitoring until all the reduced monitoring requirements discussed previously in this section are met. A system that loses its certified operator must also return to monthly monitoring the month following the loss.

(e). Additional routine monitoring. All systems collecting samples on a quarterly frequency must conduct additional routine monitoring following a single total coliform-positive sample (with or without a Level 1 trigger event). The additional routine monitoring consists of three samples in the month following the total coliform-positive sample at routine monitoring locations identified in the sample siting plan. The current TCR additional routine monitoring requirements consist of taking a total of five samples the month following a total coliform-positive sample for systems that take four or fewer samples per month.

In this proposal, consistent with the current TCR, the State may waive the additional routine monitoring requirement if:

- The State, or an agent approved by the State, performs a site visit before the end of the next month the system provides water to the public. Although a sanitary survey need not be performed, the site visit must be sufficiently detailed to allow the State to determine whether additional monitoring and/or any corrective action is needed. The State cannot approve an employee of the system to perform this site visit, even if the employee is an agent approved by the State to perform sanitary surveys.
- The State has determined why the sample was total coliform-positive and establishes that the system has corrected the problem or will correct the problem before the end of the next month the system serves water to the public. In this case, the State must document this decision to waive the following month's additional monitoring requirement in writing, have it approved and signed by the supervisor of the State official who recommends such a decision, and make this document available to the EPA and public. The written documentation must describe the specific cause of the total coliform-positive sample and what action the system has taken and/or will take to correct this problem.

The State may not waive the requirement to collect three additional routine samples the next month in which the system provides water to the public solely on the grounds that all repeat samples are total coliform-negative. If the State determines that the system has corrected the contamination problem before the system takes the set of repeat samples required in § 141.858, and all repeat samples were total coliform-negative, the State may waive the requirement for additional routine monitoring the next month.

All additional routine samples are included in determining compliance with the MCL and the coliform treatment technique requirements.

iii. Subpart H systems of this part serving 1,000 people. The monitoring requirements for subpart H systems of this part (PWSs supplied by surface water source or ground water source under the direct influence of surface water (GWUDI)) serving 1,000 or fewer people remain the same as under the current rule (see§ 141.856). These systems are not eligible for reduced monitoring. In addition, the proposed rule requires all seasonal systems, on and after the compliance date of the final RTCR, to demonstrate completion of a State-approved start-up procedure.

iv. PWSs serving 1,000 people. The monitoring requirements for PWSs serving more than 1,000 people remain the same as under the current TCR (see§ 141.857), with the exception of the applicable revisions to the repeat sampling locations provided in § 141.858 and additional routine monitoring provisions. Systems on monthly monitoring are not required to take additional routine samples the month following a total coliform-positive sample. These systems are not eligible for reduced monitoring. In addition, the proposed rule requires all seasonal systems, on and after the compliance date of the final RTCR, to demonstrate completion of a State-approved start-up procedure.

b. EPA's rationale. i. Sampling sites and monitoring plans. Consistent with current practice, the proposed RTCR requires systems to develop a sample siting plan that is representative of the water throughout the distribution system. EPA is proposing to maintain the provision from the current TCR that indicates that sample siting plans are subject to State review and revision. The advisory committee recommended that States review and revise sample siting plans consistent with current practice and that the State develops and implements a process to ensure the adequacy of sample siting plans including a periodic review. The advisory committee also recommended that specific elements be included in the sampling plans such as the routine and repeat sample sites and sampling locations necessary to meet the requirements of the GWR. Alternative repeat monitoring locations (e.g., at storage tanks and entry points to the distribution system) are subject to State approval. The system must demonstrate to the State's satisfaction that these alternative monitoring locations are representative of the water quality in the distribution system.

By allowing systems to specify criteria for selecting their repeat sampling locations in their SOP instead of setting fixed repeat sampling locations, systems can provide a more flexible and more protective response. The system can focus the repeat samples at locations that will best verify and determine the extent of potential contamination of the distribution system based on specific situations. In addition, EPA is proposing to require State approval if a ground water system serving 1,000 or fewer people wants to use a single sample to meet both the repeat monitoring requirements of the RTCR and the source water monitoring requirements of the GWR. EPA is proposing to allow the use of dedicated sampling locations for the following reasons:

To reduce potential contamination of the taps. Utilities will have more control to prevent contamination of the tap by preventing its use by unauthorized persons and allowing no routine use of the tap except for sampling;

- To facilitate access to sampling taps. Currently systems may be constrained by where they sample, e.g., only at public buildings or in certain individual customer's houses.

- To improve sampling representation of the distribution system. Allowing dedicated sample taps in areas where systems have not been able to gain access will facilitate better sampling representation of the distribution system.

- ii. Ground water PWSs serving 1,000 people. (a). Routine monitoring. The advisory committee recommended that ground water NCWSs serving 1,000 or fewer people remain under a routine quarterly monitoring as provided in the current TCR. They believed that in conjunction with the assessment and corrective action requirements, public health protection would be maintained or improved without increasing sampling costs over current TCR requirements. The advisory committee also recognized that current sampling costs are not insignificant for small systems, and wanted to recognize the good performance of systems by allowing them to be able to continue to qualify for reduced monitoring, but under the more specific and rigorous criteria described previously. To continue to provide adequate health protection, systems on reduced monitoring must adhere to criteria that ensure that barriers are in place and are effective. Furthermore, systems with problems that may indicate poor system integrity, maintenance, or operations, or systems that fail to monitor, are triggered into monthly monitoring. This approach leverages the limited resources of these small ground water NCWSs and of States, so that systems with minimal problems can minimize their costs and States can focus their resources on systems needing the greatest attention, such as systems with problems or vulnerabilities.

The advisory committee thought it best to continue with existing routine monthly monitoring requirements for ground water CWSs serving 1,000 or fewer people in order to maintain the current levels of effort to identify potential problems. Since sanitary surveys are required under the GWR and these surveys provide substantial diagnostic value and corrective action response for problems identified, specifying higher routine monitoring frequency for these systems was not deemed necessary.

These systems may also qualify for reduced monitoring if they meet certain criteria.
(b). Transition to the RTCR. The advisory committee was concerned about the ability of the States and systems to adopt the new regulations and to make all the determinations that may be necessary to determine the appropriate monitoring frequency within three years of rule promulgation. Requiring significant changes in monitoring frequencies in a short period (i.e., without a transition period) could overwhelm State resources. The advisory committee recommended phasing in the requirements and using the sanitary survey process to facilitate a successful transition and implementation. The advisory committee, therefore, recommended that these systems continue with their current monitoring frequency during a transition period and that the State review the monitoring frequency to determine whether it is appropriate during each sanitary survey (USEPA 2008c, AIP p.9). This gives the systems the opportunity to address operation and maintenance issues to maintain existing monitoring frequency or qualify for reduced monitoring. Systems on reduced TCR monitoring stay on reduced monitoring during the transition period if they continue to meet the reduced monitoring criteria. During the special monitoring evaluation conducted as part of the periodic sanitary survey, the State will determine whether the individual systems are on the proper monitoring schedule.

(c) Reduced monitoring. The reduced monitoring requirements are intended to recognize that well-operated systems may be less vulnerable to contamination. Therefore, certain conditions are specified under which reduced monitoring could be allowed. These include a clean compliance history for a minimum of 12 months, and an annual visit from the State for systems taking one sample per year and correction of all identified sanitary defects. Ground water NCWSs serving 1,000 or fewer people, with a routine quarterly monitoring frequency, could qualify for reduced annual monitoring, while ground water CWSs serving 1,000 or fewer people, with a routine monthly monitoring frequency, could qualify for reduced quarterly monitoring.

For NCWSs on annual monitoring, the advisory committee believed that requiring a system to have an annual site visit or a Level 2 assessment provides at least an equivalent level of diagnosis of problems and vulnerabilities that might exist as compared to quarterly monitoring without an annual site visit. Several States have elected to conduct annual site visits while also doing annual monitoring for some NCWSs.

(d) Increased monitoring requirements for NCWSs. The advisory committee wanted to recognize that if certain vulnerabilities are identified in a system, the system should be required to conduct more frequent monitoring to identify and correct its problems and better protect public health. Other than sanitary surveys or other site visits, monitoring is the primary means to identify pathways for potential contamination. If the system is deemed more vulnerable to such pathways, as indicated by the increased monitoring criteria, it must conduct more monitoring.

(e) Requirements for returning to routine monitoring and reduced monitoring. The advisory committee believed that systems that address or correct vulnerabilities as indicated by a clean compliance history should be allowed to return to routine monitoring, and subsequently to reduced monitoring (for NCWS). This provision allows for reduced monitoring costs.

(f) Seasonal systems. The advisory committee recognized that seasonal systems have unique characteristics that make them more susceptible to contamination. These systems do not maintain pressure while not in operation, which can result in the intrusion of contaminants. During the time when a seasonal system is not in operation, septic tank drain fields or other pollution sources may accumulate that could affect the conditions or quality of the source water (especially for intermittent contaminants) that infrequent monitoring may not be able to capture. If monitoring is done only at the start-up, there may not be enough time for the system to reach equilibrium (i.e., there might not be enough time to recognize if microorganisms from a septic tank moved to the wellhead in seasonally operated systems). Therefore, the proposed rule requires seasonal systems to monitor routinely at a monthly frequency. Seasonal systems can qualify for reduced monitoring if they meet certain criteria. For a seasonal system to be

allowed to monitor at a reduced frequency, the proposed rule requires the system to have an approved sample siting plan that designates the time period for monitoring and takes into consideration site-specific conditions. A system on a reduced monitoring schedule (less than monthly) must collect samples when there is the greatest chance that contamination could be identified and, due to the variability in water demands, when systems could be most challenged.

(g) Additional routine monitoring. EPA is proposing to retain the requirement of taking additional routine samples the month following a total coliform-positive sample for systems on quarterly or annual monitoring. The advisory committee recognized both the benefits and the limitations of additional routine monitoring. Additional routine samples are meant to enhance the diagnostic ability and supplement the infrequent routine monitoring of systems on quarterly or annual monitoring. Without the provision of additional monitoring, systems on annual or quarterly monitoring with a total coliform-positive sample would not take any samples the following month. The advisory committee believed that additional samples collected the following month are appropriate to help recognize the problem if it still persists.
For systems required to take the additional routine samples the following month (i.e., systems on quarterly or annual monitoring), the proposed RTCR changes the requirement from taking a total of five routine samples to a requirement of just three routine samples. The advisory committee recognized that it is appropriate to drop from five to three samples the following month to reduce monitoring costs while still maintaining a substantial likelihood of identifying a problem if a problem persists. EPA recognizes that a reduction in the number of samples taken could also mean a reduction in the number of positive samples found. However, the reduction in the number of additional routine samples in conjunction with the new assessment and corrective action provisions of the proposed RTCR.

For systems taking at least one sample monthly, the advisory committee recommended no additional routine samples for these systems for the following reason. Taking no additional routine samples the following month substantially reduces monitoring costs. The assessment and corrective action provisions will give systems the ability to identify and prevent the occurrence of problems. EA modeling results show that although there is a decrease in the number of E. coli MCL violations found with the decrease in the number of additional routine samples taken (i.e., going from five samples to one during the month following a total coliform-positive), the assessment and corrective action provisions lead to more E. coli MCL violations being prevented compared to the current TCR.

In addition, whenever a total coliform-positive occurs during routine sampling, there is also a requirement to conduct repeat sampling to determine the extent of contamination or if potential pathways to contamination persist. For small systems serving 1,000 or fewer people on monthly monitoring, if a repeat sample is total coliform-positive, at least a Level 1 assessment will be triggered. If a sanitary defect(s) is (are) found, the system is required to correct the sanitary defect(s).

For systems on monthly monitoring, the assessment and corrective action provisions and the repeat sampling provisions mitigate the need for additional routine sampling for the following month.

iii. Subpart H systems of this part serving ? 1,000 people. EPA is not proposing to change the routine monitoring requirements for systems using surface water or GWUDI serving 1,000 or fewer people, which include not allowing reduced monitoring for these systems. Since systems using surface water or ground water under the influence of surface water tend to have much higher levels of contaminants in their source water, and in general have more complex operations than ground water systems, it is appropriate to allow reduced routine monitoring for ground water systems but not for subpart H systems of this part. The advisory committee recommended that no reduced routine monitoring provisions be allowed for subpart H systems of this part serving 1,000 or fewer people.
iv. Public water systems serving 1,000 people. EPA is proposing to eliminate the additional routine samples the month following a total coliform-positive sample for PWSs serving between 1,000 and 4,100 people for the same reasons discussed previously for small ground water systems monitoring monthly. PWSs serving more than 1,000 people are currently required to routinely monitor monthly (one to four samples per month depending on size) and continue to do so under the proposed RTCR.

c. Request for comment. EPA requests comment on the proposed monitoring requirements for PWSs. Specifically, EPA requests comment on the following questions: Are there other issues that EPA should consider in its approach to help systems transition to the RTCR? Should EPA develop guidance that would help States identify seasonal systems and implement the RTCR requirements (e.g., suggestions for startup procedures and identifying vulnerable time periods)? What start-up procedures or other provisions regarding seasonal systems would be appropriate for inclusion in such guidance? EPA also requests comment on whether seasonal systems should be required to comply with State-directed shut down procedures (in addition to start-up procedures).

EPA requests comment on the following additional questions: Should daily measurement of chlorine residual count toward the maximum residual disinfectant level (MRDL) monitoring and be one of the criteria for reduced monitoring? Should NTNCWSs be required to comply with the CWS requirements (as they are in other rules such as DBP rules) since NTNCWSs serve the same people over time and include populations that may be at greater risk (e.g., schools, hospitals, nursing homes)? Will the reduced, routine, and increased monitoring requirements for NCWSs shift the fixed State resources from CWS oversight to NCWS oversight in those States with large numbers of NCWSs? If so, what might be done to limit the impact? Should EPA develop guidance on how to develop a sample siting plan? Should sample siting plans require State approval.

EPA and the advisory committee did not identify any specific issues regarding consecutive systems in the proposed RTCR. EPA requests comment on whether there are such issues and how they should be addressed in the RTCR.

4. Repeat Samples

a. Provisions. Under the proposed RTCR, all systems must take at least three repeat samples for each routine total coliform-positive sample. This is a change from the current TCR requirements where systems serving 1,000 or fewer people must collect at least four repeat samples while the rest of the systems must collect three repeat samples. EPA is not changing the following provisions: The 24-hour limit within which the system must collect the repeat samples; the authority of the State to extend this limit on a case-by-case basis; and the non-waiver by the State of the requirement for a system to collect repeat samples.

In addition to taking repeat samples, systems must test each routine total coliform-positive sample for E. coli. They must also test any repeat total coliform-positive sample for E. coli. As with the current TCR, if E. coli is present, the system must notify the State the same day it learns of the positive result or by the end of the next business day at the latest. The proposed rule is not changing the provision that a State has the discretion to allow the system to forgo E. coli testing in cases where the system assumes that the total coliform-positive sample is E. coli-positive. If the State allows a system to forgo E. coli testing, the system must still notify the State and comply with the E. coli MCL requirements specified in § 141.858.

As with the current TCR, the system must collect at least one repeat sample from the sampling tap where the original total coliform-positive sample was taken. Unless different locations are specified in its sample siting plan, the system must also collect at least one repeat sample at a tap within five service connections upstream, and at least one repeat sample at a tap within five service connections downstream of the original sampling site. The State may waive the requirement to collect at least one repeat sample upstream or downstream of the original sampling site if the total coliform-positive sample is at the end of the distribution system, or one service connection away from the end of the distribution system.

Under the proposed rule, ground water systems (GWSs) required to conduct triggered source monitoring under the GWR must take ground water source samples in addition to the repeat samples. However, a ground water system serving 1,000 or fewer people may use a repeat sample collected from a ground water source to meet both the repeat monitoring requirements of the proposed RTCR and the source water monitoring requirements of the GWR, but only if the State approves the use of a single sample to meet both rule requirements (i.e., a dual purpose sample) and the use of E. coli as a fecal indicator for source water monitoring. If the sample is E. coli-positive, the system violates the E. coli MCL under the proposed RTCR and must also comply with the GWR requirements following a fecal indictor-positive sample. These provisions are consistent with the GWR.

If a system with a limited number of monitoring locations (such as a system with only one service connection or a campground with only one tap) takes more than one repeat sample at the triggered source water monitoring location, the system may reduce the number of additional source water samples by the number of repeat samples taken at that location that were not E. coli-positive. For example, if a system takes two dual purpose samples and one is E. coli- positive and the other is E. coli-negative, the system has an E. coli MCL violation under the proposed RTCR and is required to take four additional source water samples, rather than five, under the GWR (see 40 CFR 141.402(a)(3)). If the system takes more than one of these repeat samples at the triggered source water monitoring location and has more than one repeat sample that is E. coli-positive, then the system would have both an E. coli MCL violation under the proposed RTCR and a second fecal indicator-positive source sample under the GWR. The system would then need to also comply with the treatment technique requirements under 40 CFR 141.403.

Under the proposed rule, the system must collect all repeat samples on the same day consistent with current TCR requirements. The State may allow systems with a single service connection to collect the required set of repeat samples over a three-day period or to collect a larger volume repeat sample(s) in one or more sample containers of any size, as long as the total volume collected is at least 300 ml.
The proposed RTCR is not changing the requirement that systems collect an additional set of repeat samples for each total coliform-positive repeat sample. As with the original set of repeat samples, the system must collect the additional repeat samples within 24 hours of being notified of the positive result, unless the State extends the time limit. The system must repeat this process until either total coliforms are not detected in one complete set of repeat samples or the system determines that the coliform treatment technique trigger has been exceeded and notifies the State. After a trigger (see section III.A.5 of this preamble) is reached, the system is required to conduct only one round of repeat monitoring after each total coliform-positive or E. coli- positive routine sample. If a trigger is reached as a result of a repeat sample being total coliform- or E. coli-positive, no further repeat monitoring related to that sample is necessary.

The proposed RTCR is also not changing the current TCR provision that a subsequent routine sample, which is within five service connections of the initial routine sample and is collected after an initial routine sample but before the system learns the initial routine sample is total coliform-positive, may count as a repeat sample instead.

Results of all routine and repeat samples not invalidated by the State must be used to determine whether the coliform treatment technique trigger has been exceeded (see section III.A.5 of this preamble for a discussion of the coliform treatment technique triggers).

b. EPA's rationale. i. Why EPA is maintaining a provision for repeat sampling. As with the current TCR, the proposed RTCR requires systems to take repeat samples after a total coliform-positive sample. EPA believes that sampling immediately after an initial positive sample (i.e., conducting repeat sampling) increases the likelihood of identifying the source and/or nature of the possible contamination. Analysis conducted by EPA indicated that once a total coliform-positive is found, there is a much greater likelihood of finding another total coliform-positive within a short period of time of the initial finding. Repeat sampling (when total coliform-positive) can indicate a current pathway for potential external contamination into the distribution system.

EPA used the Six-Year Review 2 (USEPA 2010e) data to support statistical modeling which produced estimates of average occurrence of routine total coliform-positive samples and repeat total coliform-positive samples and to characterize how occurrence varies from system to system. EPA's occurrence model assumes that, among similar systems, the positive rate for total coliforms in routine samples varies as a beta random variable. EPA used the Six-Year Review 2 data (USEPA 2010e) to estimate the parameters for the distribution of occurrences of routine and repeat total coliform-positive samples.

ii. Frequency of repeat samples. The advisory committee recommended that the current TCR requirement for systems serving more than 1,000 people to take three repeat samples subsequent to a routine total coliform-positive be retained. The advisory committee recommended that systems serving 1,000 or fewer people also be required to take three repeat samples rather than the four required under the current TCR. This view is supported by analysis of repeat sample records from the Six-Year Review 2 data (USEPA 2010e).

Repeat sampling helps utility operators to better understand the extent and duration of potential pathways of contamination into the distribution system. The Six-Year Review 2 data (USEPA 2010e) show that the average percentage of samples that are positive among repeat samples is much higher than that of routine samples, demonstrating that when operators are required to take a second look at their systems following the positive routine sample, they find, on average, a higher rate of coliform presence than during routine sampling. In other words, the high repeat total coliform-positive rate indicates the persistence of total coliforms at such locations in the distribution system.

Further analysis of the data shows that for all PWSs serving 1,000 or fewer people, two or more of the repeat samples are positive in 75 percent of those instances in which there are any positive repeat samples. For those 75 percent of instances, reducing the number of repeat samples from four to three would have no effect on the number of systems that would be triggered to conduct an assessment of the system under the proposed RTCR. In these cases, at least one of the remaining repeat samples would still be total coliform-positive, and only one positive repeat sample is required to trigger an assessment.

The data show that one repeat sample is positive in 25 percent of the instances in which any of the four repeat samples is positive. For these instances, EPA estimates that if only three repeat samples had been taken instead of four, three out of four (or 75 percent) of these positive samples would still have been encountered.

Although dropping the required number of repeat samples from four to three means that some fraction of triggers may be missed, the other provisions of the proposed RTCR compensate for that change and, taken as a whole, the provisions of the proposed RTCR provide for greater protection of public health. One such provision includes enhanced consequences for monitoring violations. For example, systems that do not take all of their repeat samples under the proposed RTCR are triggered to conduct a Level 1 assessment. This permits an increase in public health protection over the current TCR because PWSs are required to assess their systems when monitoring results show that the PWS may be vulnerable to contamination (indicated by exceeding the trigger). Moreover, because of the substantial cost of this potential consequence, systems would be more likely to take all of their required repeat samples in the first place.

It is important to point out that the majority of systems in this category are ground water systems treating to less than 4-log inactivation for viruses (see Exhibit 4.1 of the Proposed RTCR EA (USEPA 2010a)). Because of the triggered source monitoring provision under the GWR, these systems are required to collect a fecal indicator sample from the source water following a total coliform-positive sample in the distribution system in addition to the repeat samples. Under the existing GWR and TCR, systems taking four repeat samples are permitted to take the fourth repeat sample at the source water if they measure for E. coli as the fecal indicator and if they have State approval. Under the proposed RTCR, systems would continue to take this source water sample to comply with the GWR in addition to the required repeat samples in the distribution system to comply with the TCR.

A positive sample at the source that is not also considered a repeat sample would not trigger an assessment under the proposed RTCR, but it would provide diagnostic value to the system in addition to triggering additional requirements under the GWR (i.e., corrective action or five additional source water fecal indicator samples).

As under the existing GWR and current TCR, with State approval, ground water systems serving 1,000 or fewer people may use the sample taken at the location required for triggered source monitoring to also count toward the repeat monitoring requirements of the proposed RTCR. In this case, the State must also approve the use of E. coli as the fecal indicator under the GWR, and the system would comply with both GWR and the proposed RTCR when a total coliform-positive or E. coli-positive sample occurs. The advisory committee recommended this flexibility to reduce the burden on small ground water systems that in most cases will have a very limited distribution system and only one source, consistent with the GWR.

iii. Location of repeat samples. The advisory committee believed that requiring repeat samples to be taken within five service connections up and downstream of the original total coliform-positive location can be difficult for systems to implement within the required 24 hours for a repeat sample because of issues such as access to the site. Therefore, the advisory committee recommended that systems be

allowed to develop standard operating procedures (SOPs) as part of their sample siting plan to identify alternative monitoring sites and facilitate the identification of the source and extent of any problem. EPA is not requiring prior State approval for this provision since there is no reduction in monitoring and the SOP is expected to be used only by larger systems with the technical resources to justify alternative monitoring sites.

The advisory committee also recommended that ground water systems have the flexibility to propose repeat sampling locations that differentiate potential source water and distribution system contamination (e.g., by sampling at entry points to the distribution system). See section III.A.3 of this preamble for additional discussion on this topic. Consistent with its understanding of the intent of the TCRDSAC, EPA has proposed that systems be allowed to exercise this flexibility only with prior State approval. State approval is required because this constitutes a reduction in monitoring (no separate triggered source water samples). EPA believes that this reduction in monitoring is appropriate only if the State determines that the dual purpose sample provides public health protection equivalent to that provided by separate repeat and source water samples. EPA believes that many ground water systems serving 1,000 or fewer people, such as systems with extensive distribution systems, will not be able to show that this reduction in monitoring (i.e., a loss of repeat sample that is near the total coliform-positive routine sample site, but not near the source water sample site) will provide public health protection equivalent to separate samples. EPA believes that systems with limited or no distribution systems are the best candidate for approval.

c. Request for comment. EPA requests comment on the foregoing proposed repeat sampling requirements. Specifically, EPA requests comment on the proposal to allow samples taken at the ground water source to serve both as a triggered source sample under the GWR and as one of the repeat samples under the proposed RTCR. EPA is also requesting comment on whether systems should be allowed to use a dual purpose sample simply by including that in the sample siting plan, without prior State approval. Also, should systems using repeat monitoring sites more than five connections upstream or downstream from the routine total coliform-positive site be required to get prior State approval?

5. Treatment Technique Requirements

a. Provisions. i. Coliform treatment technique triggers. The non-acute MCL violation for total coliforms under the current TCR is effectively replaced by a coliform treatment technique involving monitoring for total coliforms under the proposed RTCR. Under the proposed treatment technique framework, the presence of total coliforms is used as an indicator of a potential pathway of contamination into the distribution system. As discussed in section III.A.2 of this preamble, the proposed RTCR eliminates the associated MCLG and MCL for total coliforms. The proposed revision specifies two levels of treatment technique triggers, Level 1 and Level 2, and their corresponding levels of response. Whether systems are required to conduct either a Level 1 or Level 2 assessment is based on the degree of potential pathway for contamination. The proposed rule further lays out an additional trigger for a Level 1 assessment and defines Level 2 triggers that require a more in-depth examination of the system and its monitoring and operational practices.

The system has exceeded the trigger immediately once any of the following conditions have been met:

Level 1 treatment technique triggers:

- ✓ For systems taking 40 or more samples per month, the PWS exceeds 5.0 percent total coliform-positive samples for the month; or
- ✓ For systems taking fewer than 40 samples per month, the PWS has two or more total coliform-positive samples in the same month; or
- ✓ The PWS fails to take every required repeat sample after any single routine total coliform-positive sample.

Level 2 treatment technique triggers:

- The PWS has an E. coli MCL violation (see section III.A.6 of this preamble for description of what constitutes an E. coli MCL violation); or

- The PWS has a second Level 1 treatment technique trigger within a rolling 12-month period, unless the first Level 1 treatment technique trigger was based on exceeding the allowable number of total coliform-positive samples, the State has determined a likely reason for the total coliform-positive samples that caused the initial Level 1 treatment technique trigger, and the State establishes that the system has fully corrected the problem.

- For PWSs with approved reduced annual monitoring, a Level 1 treatment technique trigger in two consecutive years.

ii. Assessment. EPA is proposing an assessment process in the RTCR to strengthen public health protection. Under the current TCR, a system is not required to perform an assessment following a monthly/non-acute MCL violation or an acute MCL violation. In contrast, the proposed RTCR requires systems to conduct assessments following the triggers specified above.
EPA is proposing two levels of assessment based on the associated treatment technique trigger: Level 1 assessment for a Level 1 treatment technique trigger and Level 2 assessment for a Level 2 treatment technique trigger.

At a minimum, both Level 1 and 2 assessments must include review and identification of the following elements:

- Inadequacies in sample sites, sampling protocol, and sample processing,

- Atypical events that may affect distributed water quality or indicate that distributed water quality was impaired,

- Changes in distribution system maintenance and operation that may affect distributed water quality, including water storage,

- Source and treatment considerations that bear on distributed water quality, where appropriate, and

- Existing water quality monitoring data.

EPA expects that States will tailor specific assessment elements to the size and type of the system and that each public water system in turn will tailor its assessment activities based on the characteristics of its distribution system.

Level 1 assessment:
A Level 1 assessment must be conducted when a PWS exceeds one or more of the Level 1 treatment technique triggers specified above. Under the proposed rule, this self-assessment shall consist of a basic examination of the source water, treatment, distribution system and relevant operational practices. The PWS might look at conditions that could have occurred prior to and caused the total coliform-positive sample. Example conditions include treatment process interruptions, loss of pressure, maintenance and operation activities, recent operational changes, etc. In addition, the PWS might check the conditions of the following elements: sample sites, distribution system, storage tanks, source water, etc.

The PWS must complete the Level 1 assessment as soon as practical after notification of its monitoring results or failure to take repeat samples. The PWS must submit the completed assessment form to the State for review within 30 days after determination that the PWS has exceeded the trigger. Failure to submit the completed assessment form within 30 days is a reporting violation. If the State determines that the assessment is insufficient, the State will consult with the PWS. If necessary after consultation, the PWS must submit a revised assessment to the State on an agreed upon schedule not to exceed 30 days from the date of the initial consultation.

The completed assessment form must include assessments conducted, all sanitary defects identified (or a statement that no sanitary defects were identified), corrective actions completed, and a timetable for any corrective actions not already completed. Upon completion and submission of the assessment form by the PWS to the State, the State shall determine if the system has identified the likely cause(s) for the Level 1 treatment technique trigger and establish whether the system has corrected the problem(s).

Level 2 assessment:
A Level 2 assessment must be conducted when a PWS exceeds one or more of the Level 2 treatment technique triggers specified previously.

A Level 2 assessment is a more comprehensive examination of the system, its monitoring and operational practices than the Level 1 assessment. The level of effort and resources committed to undertaking a Level 2 assessment will be commensurate with the more comprehensive investigation and review of available information, and engage additional parties and expertise relative to the Level 1 assessment. Level 2 assessments must be conducted by a party approved by the State: The State itself, a third party, or the PWS where the system has staff or management with the required certification or qualifications specified by the State. If the PWS or a third party conducts the Level 2 assessment, the PWS or third party must follow the State requirements for conducting the Level 2 assessment.

The PWS must complete the Level 2 assessment as soon as practical after notification that the PWS has exceeded a Level 2 treatment technique trigger. The PWS must submit the completed assessment form to the State for review within 30 days after determination that the PWS has exceeded the trigger. Failure to submit the completed assessment form after the PWS properly conducts the assessment is a reporting violation. The State may direct expedited action or additional actions such as in the case of an E. coli MCL violation. If the State determines that the assessment is insufficient, the State will consult with the PWS. If necessary after consultation, the PWS must submit a revised assessment to the State on an agreed upon schedule not to exceed 30 days from the date of the initial consultation.

The completed assessment form must include assessments conducted, all sanitary defects (or a statement that no sanitary defects were identified), corrective actions completed, and a timetable for any corrective actions not already completed. Upon completion and submission of the assessment form by the PWS to the State, the State shall determine if the system has identified the likely cause(s) for the Level 2 treatment technique trigger and, if so, establish that the system has corrected the problem(s).

iii. Corrective action. The current TCR does not require systems that have MCL violations to perform corrective actions. Under this proposal, EPA is requiring PWSs to correct sanitary defects found through either a Level 1 or Level 2 assessment. Ideally, systems will be able to correct any sanitary defects found in the assessment within 30 days and report that correction on the assessment form. When the correction of sanitary defects is not completed by the time the PWS submits the completed assessment form to the State, the PWS must complete the corrective action(s) on a schedule determined by the State. This schedule may be developed in consultation with the PWS. The schedule must include when the corrective action will be completed and any necessary milestones and temporary public health protection measures. The PWS must notify the State when each scheduled corrective action is completed.

At any time during the assessment or corrective action phase, either the PWS or the State may request a consultation with the other entity to discuss and determine the appropriate actions to be taken. The system may consult with the State on all relevant steps that the system is considering to complete the corrective action, including the method of accomplishment, an appropriate timeframe, and other relevant information.

E. coli detection in the distribution system indicates a public health hazard and can result in an E. coli MCL violation. Under the proposed rule, when an E. coli MCL violation has occurred, the system must complete a Level 2 assessment and corrective action must be implemented as soon as practical. The Agency encourages systems to promptly find the source of E. coli and fix the problem before the completed assessment form is due to the State.

b. EPA's rationale. i. Coliform treatment technique. The advisory committee indicated that the conditions leading to a monthly/non-acute MCL under the current TCR should trigger an assessment under the RTCR for several reasons. First, the advisory committee recognized that presence of total coliform indicates the potential presence of a pathway for contamination from external sources such as source water or through a loss of distribution system integrity. The change to a coliform treatment technique construct that uses total coliforms as an indicator of distribution system integrity places the emphasis on systems to take more preventive actions to address problems. These actions would better protect public health than the additional monitoring with no corrective action that is required under the current TCR. To address the high and constant number of PWSs with violations over the years under the current TCR, the proposed changes would be more protective by requiring systems to correct deficiencies associated with the non-acute MCL (see Exhibit VI.1 in section VI.C.1 of this preamble).

Second, the advisory committee indicated that the public notice associated with non-acute violations is confusing because the presence of total coliforms is not necessarily an indication of a potential public health threat; however, it is an indicator of a potential pathway for fecal contamination to enter into the distribution system. Under the treatment technique requirement, the presence of total coliforms (at the level equivalent to a non-acute violation) indicates a need to assess whether a problem exists. When a system fails to conduct the assessment, the system will then incur a violation and be required to issue public notification. If the system does conduct the assessment and satisfies the requirements of the treatment technique (including corrective action when a sanitary defect is identified), no public notification is required. Third, the occurrence of total coliforms in the context of the coliform treatment technique requirement continues to inform and further the original objectives of the TCR: to evaluate the effectiveness of treatment, determine the integrity of the distribution system, and signal the possible presence of fecal contamination. Finally, total coliform presence indicates the potential presence of a pathway for contaminants from external sources such as source water or through a loss of distribution system integrity.

ii. Assessment. The proposed rule requires assessments to ensure that specific action is taken to identify whether potential pathways of contamination into the distribution system exist. The advisory committee indicated that assessments are significant actions that protect public health. Under the current rule, when a system has a non-acute MCL violation and if any subsequent sampling did not detect total coliform, the problem may persist due to the intermittent nature of total coliform and remain unaddressed. However, the absence of total coliform-positive samples subsequent to an initial positive finding is not a reliable indicator that a contamination pathway no longer exists. In contrast, the proposed revisions would ensure that systems examine and assess the cause of the total coliform occurrence (that is equivalent to the current non-acute MCL level) and take any corrective action if necessary.

Under the proposed rule, the system will also be required to conduct an assessment if it fails to conduct repeat monitoring following an initial total coliform-positive sample result. As discussed in section III.A.4 of this preamble, repeat monitoring is critical in identifying the extent, source, and characteristics of fecal contamination in a timely manner. Since the revised rule proposes to eliminate additional routine monitoring for systems that monitor at least monthly and decrease the number of additional routine monitoring and repeat monitoring samples for the smallest systems, the need to conduct repeat monitoring is more crucial than ever in providing immediate and useful information needed to protect public health. The cost for collecting and analyzing a repeat sample would be considerably less than the cost for conducting a Level 1 assessment. EPA expects that systems will want to ensure that assessments are conducted only when potential problems may exist rather than for failure to take repeat samples.

The proposed rule specifies two different levels of assessments—Level 1 and Level 2—to recognize that a higher level of effort to diagnose a problem applies to situations of greater potential of public health concern such as repeated Level 1 triggers or an E. coli MCL violation. Level 2 assessments are conducted by a party approved by the State, which may be the PWS where it has staff or management with the certification or qualifications as determined by the State. The Level 2 assessments may also be conducted by the State or a third party approved by the State.

To make more transparent what the Level 1 and Level 2 assessments entail and to facilitate consistent implementation among States, the proposed rule specifies minimum elements for these assessments. The advisory committee recommended that the minimum elements identified previously in this preamble be included in the Level 1 and Level 2 assessments to identify potential flaws in monitoring or specific pathways of contamination. Although the proposed RTCR specifies the same minimum elements for both the Level 1 and Level 2 assessments, the Level 2 assessment involves a more in-depth examination of these elements compared to a Level 1 assessment. Specific examples of how the Level 2 assessments are more in-depth than Level 1 assessments may be found in Appendix X of the AIP (USEPA 2008c).

EPA recognizes that not every assessment will identify a sanitary defect or find a reason or cause for the presence of total coliforms. If no sanitary defect is identified, the system must document that fact in the completed assessment form and provide supporting evidence for this conclusion. EPA expects that only systems that adhere to proper procedures and standards set by the State are eligible to arrive at this determination, and only after providing sufficient supporting evidence.

The advisory committee recommended that the Level 1 and Level 2 assessments be conducted as soon as practical after the PWS receives notice that the system has exceeded the treatment technique trigger. The advisory committee also recommended that systems submit the completed assessment forms to the State within 30 days after determination that the PWS has exceeded the trigger. The rationale for the 30-day interval is to allow sufficient time for problem identification and potential remediation of the problem in conjunction with the follow-up assessment, in most cases.

To help States and PWSs conduct assessments, EPA intends to develop a draft assessment and corrective action guidance manual and to make it available for public comment prior to promulgation of the final rule and to finalize the guidance manual after the rule is finalized.

iii. Corrective action. The advisory committee recognized that not every assessment will identify a sanitary defect. However, the advisory committee recommended that the RTCR require all sanitary defects be corrected by the system in a timely manner. The system, in consultation with the State as needed, identifies and determines the specific corrective action.

Under the proposed rule, the State may allow the PWS additional time to conduct the corrective action if needed. EPA recognizes that some systems may not be able to fix sanitary defects before submitting the completed assessment form within the 30-day interval due to the extent and cost of the corrective action.

In such situations, EPA encourages the State and PWS to work together to determine the appropriate schedule for corrective actions (which may include additional or more detailed assessment or engineering studies) to be completed as soon as possible. The system must comply with the agreed upon schedule and notify the State when each scheduled corrective action is completed.

Either the PWS or the State may request consultation with the other party to determine the appropriate actions to be taken. EPA is not requiring this to be a mandatory consultation to provide ease of implementation for States. In many cases, consultation may not be necessary because the type of corrective action for the sanitary defect will be clear and can be fixed right away (for example, replacement of a missing screen).

c. Request for comment. EPA requests comment on the: (1) Proposed change from the non-acute MCL for total coliforms to a coliform treatment technique requirement that uses total coliforms as an indicator of a pathway of contamination; (2) proposed requirement for systems to conduct an assessment following a trigger condition; (3) proposed levels of assessment required; and (4) proposed requirement for systems to correct all sanitary defects found during an assessment. In addition, EPA requests comment on how to ensure that a Level 2 assessment is more comprehensive than a Level 1 assessment (e.g., should a Level 2 assessment include additional elements such as asset management and capacity development?). Should EPA provide more detail, either in guidance or rule language, on the elements and differences between a Level 1 and Level 2 assessments? If in rule language, how should the rule language distinguish the two levels of assessments? Please provide examples. Additionally, should EPA provide additional guidance on how systems might address the situation where a Level 1 or Level 2 assessment fails to identify any sanitary defects (i.e., the trigger event remains unexplained). If so, what should such guidance say?

6. Violations

a. Provisions. EPA is proposing to modify the definition of the existing MCL violation, establish a treatment technique violation, and revise the monitoring and reporting violations. EPA is proposing that public notice be required for each type of violation (see section III.A.7 of this preamble for detail information on public notification).

i. E. coli MCL violation. A violation of the E. coli MCL occurs when:

- ✓ A routine sample is total coliform-positive and one of its associated repeat samples is E. coli-positive; or
- ✓ A routine sample is E. coli-positive and one of its associated repeat samples is total coliform-positive; or
- ✓ A system fails to take all required repeat samples following a routine sample that is positive for E. coli; or
- ✓ A system fails to test for E. coli when any repeat sample tests positive for total coliforms.

ii. Coliform treatment technique violation. A coliform treatment technique violation occurs when:

- ✓ A system fails to conduct a required assessment within 30 days of notification of the system exceeding the trigger (see section III.A.5 of this preamble for conditions under which monitoring results trigger a required assessment); or
- ✓ A system fails to correct any sanitary defect found through either a Level 1 or 2 assessment within 30 days (see also section III.A.6 of this preamble) or in accordance with State-derived schedule.

There would be no treatment technique violation associated solely with a system exceeding one or more action triggers (Level 1 or Level 2 triggers).

iii. Monitoring violation. Under the current TCR, a monitoring violation occurs when a system fails to comply with the total coliform monitoring requirements, including the sanitary survey requirement. Under the proposed RTCR, a monitoring violation occurs when a system fails to take every required routine or additional routine sample in a compliance period, or when it fails to test for E. coli following a routine sample that is total coliform-positive.

In addition, if a system on quarterly monitoring has a monitoring violation in two or more quarters, or if a system on annual monitoring misses its annual monitoring, it must begin monthly monitoring until it meets criteria for less frequent monitoring. See section III.A.3 of this preamble for a detailed discussion on monitoring frequency.

iv. Reporting violation. A reporting violation occurs when a system that properly conducts monitoring or an assessment fails to submit a monitoring report or a correctly completed assessment form by the required deadline. The PWS is responsible for reporting this information to the State regardless of any arrangement with a laboratory. A reporting violation also occurs when a system fails to notify the State following an E. coli-positive sample.

b. EPA's rationale. To define violations, the advisory committee built upon the principles underlying the current TCR violations and current TCR public notification and suggested changes to improve public health protection where they saw a specific need. This proposal specifies responses to different degrees of potential public health concern. As described in the next section on providing information and notification to the public, Tier 1, Tier 2, and Tier 3 public notices are required following violations corresponding to the severity of each violation type.

i. E. coli MCL violation. An E. coli MCL violation (which includes failure to take all required repeat samples following an E. coli-positive sample) creates concern of an immediate potential public health threat. For this reason, an E. coli MCL violation is considered an acute violation requiring immediate response by the system. Including an E. coli MCL violation condition for systems failing to collect all repeat samples following an initial E. coli- positive sample enhances public health protection by preventing a system from incurring only a monitoring violation when there is an indication of fecal contamination. As discussed previously in section II.D of this preamble, the presence of E. coli indicates a pathway of fecal contamination and should be taken seriously. Systems need to follow up with repeat samples to characterize the extent and source of such contamination. Failure to take the required repeat samples following an initial E. coli- positive sample is not protective of public health and is a serious violation.

ii. Coliform treatment technique violation. A coliform treatment technique violation occurs when a potential pathway of contamination in the distribution system is unexplored and/or uncorrected. Performing the Level 1 and 2 assessments and taking corrective action are essential aspects of compliance with the treatment technique. A system which neglects to perform the prescribed assessment or corrective action is in violation of the proposed RTCR's treatment technique requirements.

iii. Monitoring violation and reporting violation. Monitoring and reporting violations occur when a system fails to comply with the routine monitoring requirements or when a system fails to submit monitoring reports or completed assessment forms. EPA believes that monitoring violations and reporting violations need to be addressed so that a system is held accountable to take actions to reduce public health risk, including regular monitoring of water quality.
c. Request for comment. EPA requests comment on the proposed violation determinations.

7. Providing Notification and Information to the Public
a. Provisions. To correspond to the changes in the proposed revised rule, EPA is proposing some modifications to the public notice (PN) requirements contained in 40 CFR part 141 subpart Q. Tier 1 PN is required for an E. coli MCL violation. Tier 2 PN is required for a treatment technique violation for failure to conduct assessments or corrective actions. Tier 3 PN is required for a monitoring violation or a reporting violation.

In the current TCR, if a system has an acute MCL violation which is based on the presence of fecal coliforms or E. coli, or which is based on the system's failure to test for fecal coliforms or E. coli following a total coliform-positive repeat sample, the system is required to publish Tier 1 PN. Under the proposed RTCR, a system is required to publish Tier 1 PN when it has an E. coli MCL violation (see section III.A.6 of this preamble for what constitutes an E. coli MCL violation). In addition, the system will continue to be required to notify the State after learning of an E. coli-positive sample, as currently is required under the TCR. As mentioned earlier in section III.A.2 of this preamble, EPA is proposing to eliminate the MCL for fecal coliforms. Under the proposed rule, the standard health effects language, which is required to be included in all public notification actions, is modified to delete the reference to the fecal coliform MCL and fecal coliforms. The language for a non-acute violation under the current TCR is modified to apply to a violation of the assessments and corrective action requirements of the coliform treatment technique.

In the current TCR, a system is required to publish a Tier 2 PN when the system has a non-acute MCL violation, which is based on total coliform presence. Under the proposed rule, a system is required to publish a Tier 2 PN if the system violates the coliform treatment technique requirements. Also, EPA is proposing to modify the standard health effects language for coliform to emphasize the assessment and corrective action requirements of the proposed rule.

In the current TCR, a system is required to publish a Tier 3 PN when the system has a monitoring or reporting violation. In the proposed rule, the Tier 3 PN requirements are changed to incorporate the recommendation in the AIP that monitoring violations be considered distinct from reporting violations under the proposed RTCR. Both types of violations require Tier 3 PN.

Consumer confidence report (CCR) requirements are also modified. Health effects language for the CCR, which is identical to the health effects language required for PN, is updated in the same way as described for PN. In addition, the proposed RTCR removes the CCR requirements that require the inclusion of total numbers of positive samples, or highest monthly percentage of positive samples for total coliforms as well as total number of positive samples for fecal coliforms. These provisions are replaced by requirements to include the number of Level 1 and Level 2 assessments required and completed, the corrective actions required and completed, and the total number of positive samples for E. coli. Unchanged and consistent with existing provisions under the current TCR, a CWS may provide Tier 3 PN using the annual CCR.

b. EPA's rationale. The proposed public notification requirements are consistent with the AIP language as well as with the tier system described in 40 CFR part 141 subpart Q. These changes are appropriate because some of the types of violations in the proposed RTCR are different from the current TCR. The standard health effects language for the public notification is also revised as appropriate given the changes to what constitutes a violation under the proposed RTCR.

The proposed Tier 1 PN requirement for an E. coli MCL violation is consistent with the current TCR. Tier 1 PN is required for NPDWR violations and situations with significant potential to have serious adverse effects on human health as a result of short term exposure. The existing Tier 1 PN requires public notice as soon as possible but no later than 24 hours after the system learns of the violation. Exposure to E. coli in drinking water can possibly result in serious, acute health effects, such as diarrhea, cramps, nausea, headaches, or other symptoms and possible greater health risks for infants, young children, some of the elderly, and people with severely compromised immune systems.

Tier 2 PN is required for all NPDWR violations and situations with potential to have serious adverse effects on human health not requiring Tier 1 PN.

The system must provide public notice as soon as practical, but no later than 30 days after the system learns of the violation. A treatment technique violation under the proposed RTCR meets these criteria because it is an indication that the public water system failed to conduct an assessment or complete corrective action following identification of sanitary defects. Identification of a sanitary defect indicates that a problem may exist in the distribution system that has potential to cause public health concern.

Tier 3 PN is required for all other NPDWR violations and situations not included in Tier 1 or Tier 2. The existing Tier 3 PN requires a system to provide public notice no later than one year after the system learns of the violation or situation or begins operating under a variance or exemption. Monitoring violations and reporting violations meet these criteria because, while they do represent a violation of the proposed RTCR, the risk to public health is not as clearly linked as those that are Tier 1 or 2. Therefore, EPA believes that a public notice given at least annually fulfills the public's right-to-know about these violations.

Consumer confidence report requirements are updated to reflect the advisory committee's recommendations that total coliforms be used as an indicator to start an evaluation process that, where necessary, will require the PWS to correct sanitary defects. EPA believes it is most appropriate to inform the public about actions taken, in the form of assessments and corrective actions, since failure to conduct these activities lead to treatment technique violations under the proposed RTCR. Because the proposed RTCR no longer includes the total coliform MCL but now includes a trigger, EPA believes that systems no longer need to report the number of total coliform-positive samples via the CCR, since that could cause confusion or inappropriate changes in behavior among consumers. In addition, the CCR requirements will also reflect the removal of fecal coliform provisions under the proposed RTCR.

c. Request for comment. EPA requests comment on whether the PN and CCR language revisions are consistent with the provisions of the proposed RTCR that reflect the use of total coliforms as an indicator within a coliform treatment technique. Since EPA is not aware of health effects resulting solely from exposure to total coliforms, the proposed RTCR eliminates the public notification requirement for detection of total coliforms, but provides for public notification upon detection of E. coli, and for violation of the coliform treatment technique.

The Agency does request comment, however, on the loss of information to consumers resulting from elimination of public notification requirements following positive sample results for total coliforms.

EPA also requests comment on whether the proposed RTCR should require special notice to the public of sanitary defects, in addition to the PN requirements, similar to the GWR special notice requirements. This would be consistent with current requirements for other regulations that limit pathogens in ground water systems. Under 40 CFR 141.403(a)(7)(i), a CWS must inform the public of the significant deficiency and/or fecal indicator-positive sample. The CWS must continue to inform the public annually until the significant deficiency is corrected or the fecal contamination in the ground water source has been determined by the State to be corrected. Under 40 CFR 141.403(a)(7)(ii), an NCWS that receives notice from the State of a significant deficiency must inform the public of any significant deficiency that has not been corrected within 12 months of being notified by the State, or earlier if directed by the State. The NCWS must continue to inform the public annually until the significant deficiency is corrected.

8. Reporting and Recordkeeping Requirements for Systems

a. Provisions. i. Reporting. In addition to the existing general reporting requirements provided in 40 CFR 141.31, the proposed RTCR requires a PWS to:

- ✓ Notify the State no later than the end of the next business day after it learns of an E. coli-positive sample.

- ✓ Report to the State an E. coli MCL violation no later than the end of the next business day after learning of the violation. The PWS is also required to notify the public according to the provisions laid out in 40 CFR part 141 subpart Q.

- ✓ Report to the State a treatment technique violation no later than the end of the next business day after it learns of the violation. The PWS must also notify the public in accordance with 40 CFR part 141 subpart Q.

- ✓ Report to the State monitoring violations within ten days after the system discovers the violation, and notify the public in accordance with 40 CFR part 141 subpart Q.

- ✓ Notify the State when each scheduled corrective action is completed for corrections not completed by the time of the submission of the assessment form.

In addition, systems triggered into conducting an assessment are required to submit the completed assessment form within 30 days after determination that the coliform treatment technique trigger has been exceeded (see section III.A.3 of this preamble for additional discussion).

ii. Recordkeeping. EPA is proposing to maintain the current TCR requirements regarding retention of sample results and records of decisions related to monitoring schedules found in 40 CFR 141.33, including provisions that address the new requirements of the proposed RTCR pertaining to reduced and increased monitoring, treatment technique, etc. In addition, systems are required to maintain on file for State review the assessment form or other available summary documentation of the sanitary defects and corrective actions taken. Systems are required to maintain these documents for a period not less than five years after completion of the assessment or corrective action.

b. EPA's rationale. In the case of an E. coli-positive sample, the proposed RTCR maintains the current TCR requirement that systems must notify the State by the end of the day when they are notified of the E. coli-positive result or by the end of the next business day if the State office is already closed. The advisory committee believed that this requirement is important to maintain because of the potential for immediate public health risk associated with E. coli presence and the desire for States to consider quickly whether additional actions might be appropriate. The same rationale applies to E. coli MCL violations.

Since there are new requirements for conducting assessments and corrective actions, and new conditions for obtaining increased or reduced monitoring provisions, the proposed rule includes reporting and recordkeeping requirements to facilitate tracking of Level 1 and Level 2 triggers and compliance with treatment technique requirements. Systems are required to maintain these files no less than five years.

Since systems have to maintain these files no shorter than the maximum period allowed between sanitary surveys (i.e., five years; see 40 CFR 142.16(b)(3) and 40 CFR 142.16(o)(2)), States have the opportunity to look at and review these files during sanitary surveys and/or annual visits. The five year period is also consistent with the recordkeeping requirements for microbiological analyses under 40 CFR 141.33(a).

The timeframe by which reporting and recordkeeping are required under the proposed rule is consistent with EPA's practice regarding reporting and recordkeeping requirements in other regulations under SDWA.

c. Request for comment. EPA requests comment on whether the timeframe required for reporting and recordkeeping requirements are appropriate.

9. Analytical Methods

a. AIP-related method issues. i. Evaluation of currently-approved methods. The AIP contains several recommendations by the advisory committee regarding the analytical methods approved under the proposed RTCR. The advisory committee noted that the methods currently approved under the current TCR have varying sensitivities and specificities, and recommended that " * * * the Agency evaluate all currently approved coliform analytical methods to determine whether these methods continue to be appropriate for use in drinking water compliance monitoring" (USEPA 2008c, AIP p. 7).

In the twenty years since the current TCR was promulgated, many methods have been developed and approved for use. Most of the approved methods that are used to support the current TCR were evaluated under EPA's Alternate Test Procedure (ATP) process. Under this process, a proposed method is evaluated in comparison to a reference method. A favorable comparison serves as the basis for subsequent approval of the method for use in regulatory compliance monitoring.

The ATP evaluations are designed based on the ATP Microbiology Protocol (USEPA 2004), an EPA guidance document that outlines how the evaluation study should be conducted. In the years the ATP program has been in place, the ATP guidance document has been revised several times. As a result of different protocols being used over time, the current set of approved methods have not all been evaluated under identical conditions.

In addition to the concerns expressed by the advisory committee that the approved methods may not be equivalent to each other, EPA notes that there have been additional concerns with some of the methods currently approved. This includes allegations that some of the approved methods may have been modified since approval without EPA's knowledge. EPA is also aware of reports of varying performance of some enzyme-based methods (Oldstadt et al. 2007; Fricker et al. 2003). Lastly, EPA is aware of at least one circumstance where the manufacturer of an approved method placed a "product hold" and recall on the medium after the product was reported to be experiencing reduced recovery of E. coli.

For these reasons, EPA believes that additional information may be needed regarding the performance of the currently approved methods in order to justify their continued approval. Among the options, EPA is considering a complete, side-by-side method evaluation study, whereby all the methods are compared to each other under identical conditions, according to the same protocol.

EPA is considering an approach under which vendors of all currently approved methods would have the option of voluntarily participating in an independent, third-party laboratory evaluation through EPA's Environmental Technology Verification (ETV) Program. The goal of the ETV Program is to provide independent, objective, and credible performance data for commercial-ready environmental technologies. More information on this program is available on EPA's Web site at www.epa.gov/etv/index.

Under the ETV approach, EPA anticipates that participating vendors would generally fund the majority of the cost of their method evaluation. Based on the results of the ETV study, as documented in the verification report, EPA would judge the appropriateness of each analytical method and would determine which should continue to be approved for future monitoring. EPA would then make any changes to the analytical methods approved under the RTCR through later rulemaking.

If a vendor chooses not to participate in the ETV study, EPA would allow the vendor to propose, for EPA's consideration, an equivalent alternative approach for method evaluation. EPA will determine whether the proposed approach will provide an independent, effective, and credible evaluation. EPA emphasizes that any alternative approach would need to be equivalent in scope and rigor to the ETV program. As with the ETV study, EPA would use the results from an alternative study to judge the appropriateness of each analytical method and would determine which methods warrant approval for future monitoring under this regulation.

iii. Approval of "24-hour" methods. The AIP also recommends that EPA "consider approving methods that allow the timely (e.g. on the order of 24 hours) analytical results for E. coli and TC and that provide relatively concurrent analyses, without significantly sacrificing accuracy, precision and specificity" (USEPA 2008c, AIP p. 7). EPA notes that many of the approved methods that may be used in compliance with the proposed rule can be completed in approximately 24 hours. However, the methods that detect lactose fermentation include a confirmation step that involves transfer of a presumptively positive culture into a more inhibitory confirmation medium which serves to ensure the initial positive was correct. As a result of this confirmatory step, lactose fermentation methods can take up to 96 hours to obtain a result. The enzyme based methods do not require this confirmation step, and their results can be obtained in a 24 to 48 hour time period.

EPA is aware of some concerns that methods with a 24 hour incubation time may not be able to detect as many coliform bacteria as methods with a 48 hour incubation period. Since many of the coliform bacteria found in a distribution system are injured or stressed due to disinfection practices, and since injured/stressed organisms may take longer to detect than 24 hours, this concern is of interest to EPA.

As part of, or in addition to, the method evaluation previously described, EPA may therefore further investigate the impact of incubation time on the recovery of stressed/injured organisms in drinking water using approved media. At this time, EPA believes that it is premature to conclude that either enzyme-based or lactose-based methods are inherently preferable.

As discussed during the advisory committee meetings, the analysis time of the analytical methods is just one aspect in the overall amount of time it takes before a PWS obtains sample results from the laboratory and subsequently collects repeat samples. Factors that can impact how quickly the PWS receives notification of a positive result include whether the PWS uses an in-house laboratory or must ship the sample to a distant contract laboratory, and whether the sample results are reported via an electronic means or via traditional mail. In addition, the turnaround time for repeat sampling can be affected by such factors as the laboratory daily hours of operation. The current TCR specifies that repeat samples be collected within 24 hours, but States currently have the flexibility to extend this timeline. The current TCR does not contain provisions for how quickly the laboratory must notify the PWS when a positive result is obtained. This proposal does not change these provisions.

iv. Elimination of fecal coliforms under the proposed RTCR. The AIP also contains a recommendation that EPA remove all provisions related to fecal coliforms under the proposed RTCR. Consistent with this recommendation, and for the following reasons, EPA is proposing to eliminate all fecal coliform provisions in the RTCR.

First, the fecal coliform group can contain bacteria not associated with fecal contamination. E. coli is the most prominent member of the fecal coliform group. However, other coliform bacteria, such as thermotolerant strains of Klebsiella spp., have been shown to occur in the fecal coliform group (Warren et al. 1978). These non-E. coli bacteria are often found in environmental sources (for example, soil, vegetation, water) and, therefore, are not exclusively associated with feces. Due to the presence of these non-fecal bacteria, the fecal coliform group may not always provide the public water system with meaningful data regarding the vulnerability of their distribution system to fecal contamination.

Secondly, when the current TCR was developed, there were few E. coli methods available. Many public water systems were familiar with and preferred to use the fecal coliform methods. However, since the current TCR was promulgated, many E. coli methods have been developed and approved for use. EPA believes that most systems nationwide currently test for E. coli, while few test for fecal coliform bacteria. Since the methods used to test for E. coli have approximately the same cost as those used to test for fecal coliform bacteria, this proposed change is not expected to create an additional burden on PWSs.

EPA is proposing to eliminate all analytical method provisions for fecal coliforms that are included in the current TCR. EPA proposes instead to allow testing only for E. coli following a total coliform-positive sample. This change will provide the water system with more meaningful information regarding potential fecal contamination of the distribution system.

The current TCR specifies a number of analytical methods that can be used for compliance sample analysis (in 40 CFR 141.21(f)). Since fecal coliform bacteria are not regulated contaminants under this proposed rule, the analytical methods for fecal coliforms are no longer applicable and are removed from the list of analytical methods. All other methods used for compliance with the current TCR are maintained for compliance sample analysis under the proposed RTCR.

v. Request for comment on AIP-related method issues. EPA is requesting comment on the following RTCR analytical method issues related to recommendations from the TCRDSAC in its AIP:

- The use of an ETV approach for a reevaluation of analytical methods.
- Whether the RTCR should include provisions to ensure a more expedited results notification process. The RTCR could, for example, include language requiring that PWSs arrange to be notified of a positive result by their laboratory within 24 hours.
- Whether the RTCR should require repeat samples be taken within 24 hours of a total coliform-positive with no (or limited) exceptions.

b. Other method issues. In addition to addressing the recommendations of the advisory committee, EPA is proposing some minor technical changes related to analytical methods.

Many of these changes document practices that are already followed by PWSs and laboratories, and are consistent with the Manual for the Certification of Laboratories Analyzing Drinking Water (referred to as the "Laboratory Certification Manual") (USEPA 2005), an EPA document that outlines method requirements and good laboratory practices for certified laboratories conducting drinking water compliance sample analyses.

Some of these changes were brought to the attention of EPA by EPA Regions and States involved in the implementation of the drinking water certification program. Other minor changes have been proposed to make the analytical methods section of this regulation easier to understand and implement. Each proposed change is described as follows with a discussion of the rationale for the change.

i. Holding time. The proposed RTCR continues to provide a 30-hour holding time limit for the samples collected in compliance with this regulation (40 CFR 141.21(f)(3)). However, EPA is proposing to change the definition for holding time from "the time from sample collection to initiation of analysis may not exceed 30 hours" to "the time from sample collection to initiation of test medium incubation may not exceed 30 hours."

ii. Dechlorinating agent for sample preservation of chlorinated water supplies. The proposed RTCR establishes the following provision: "If chlorinated water is to be analyzed, sufficient sodium thiosulfate (Na 2 S 2 O 3) must be added to the sample bottle before sterilization to neutralize any residual chlorine in the water sample." Dechlorination procedures are addressed in section 9060A.2 of Standard Methods for the Examination of Water and Wastewater (20th and 21st editions) (Clesceri et al. 1998; Eaton et al. 2005).

iii. Filtration funnels. EPA is proposing to add the following footnote to the analytical methods table (§ 141.852) under the revised rule:

All filtration series must begin with membrane filtration equipment that has been sterilized by autoclaving. Exposure of membrane filtration equipment to UV light is not adequate to ensure sterilization. Subsequent to the initial autoclaving, exposure of the filtration equipment to UV light may be used to sanitize the funnels between filtrations within a filtration series.
iv. Analytical methods table changes. EPA is proposing the following changes to the analytical methods table:

- ✓ The table is organized by methodology (e.g., lactose-fermentation methods vs. enzyme-substrate methods).
- ✓ E. coli methods are included in the table.
- ✓ 18th and 19th editions of Standard Methods for the Examination of Water and Wastewater are no longer approved and have been removed.
- ✓ The references to Standard Methods 9221A and 9222A are removed.
- ✓ The reference to Standard Methods 9221B is changed to 9221B.1, B.2.
- ✓ The reference to Standard Methods 9221D is changed to 9221D.1, D.2.
- ✓ The table proposes to allow Standard Methods 9221D in the multiple tube format as described in Standard Methods 9221B.
- ✓ The citation for MI agar is changed to EPA Method 1604 for clarity and consistency.
- ✓ The table clarifies that Standard Methods 9221 F.1 and 9222 G.1 a (1), (2) may be used for E. coli analysis.
- ✓ The table clarifies the correct formulation for EC-MUG broth, when used in conjunction with Standard Methods 9222G.1 a (2), through the addition of the following footnote:

The following changes must be made to the EC broth with MUG (EC-MUG) formulation: Potassium dihydrogen phosphate, KH_2PO_4 must be 1.5g and 4-methylumbelliferyl-Beta-D-glucuronide must be 0.05 g.

- ➢ The table reflects the approval of a modified Colitag method for the simultaneous detection of E. coli and other total coliforms.

v. EPA's rationale for proposed changes related to other method issues. (a). Holding time.
The current rule states “The time from sample collection to initiation of analysis may not exceed 30 hours” (40 CFR 141.21 (f)(3)). Since promulgation of the current TCR, some States and EPA Regions have commented that “initiation of analysis” may be interpreted several different ways, which can lead to the sample being held longer than the 30 hours intended by the rule. The proposed language more clearly defines the amount of time that the sample may be held and is consistent with section 6.4.1 of the Manual for the Certification of Laboratories Analyzing Drinking Water which states: “For the analysis of total coliform in drinking water, the time between sample collection and the placement of sample in the incubator must not exceed 30 hours.”

EPA believes that changing the definition of holding time from “the time from sample collection to initiation of analysis” to “the time from sample collection to initiation of test medium incubation” may slightly decrease the amount of time a PWS has to get the sample to a laboratory. EPA does not believe that this change will significantly reduce the amount of time a water system has to get a sample to the laboratory, as most of the methods approved under this rule require 30 minutes or less to process and prepare the sample for the incubation step. Thus, the initial analytical steps should not constitute a large portion of the holding time as a whole. EPA recommends that PWSs that have difficulty meeting the holding time notify the laboratory that the samples are in transit and need to be given priority. The laboratory could begin analysis immediately upon sample arrival so that the samples could be placed in the incubator in time to meet the 30 hour holding time. EPA notes that a laboratory may have to make specific accommodations in their processes in order to properly analyze a sample received close to the end of the holding time. EPA believes that this is feasible with proper planning.

(b). Dechlorinating agent for sample preservation of chlorinated water supplies. Under this proposal, EPA would require that chlorinated water samples be collected in bottles that contain the dechlorinating agent sodium thiosulfate. This is consistent with section 3.15.4 of the Laboratory Certification Manual, which states “If chlorinated water is to be analyzed, sufficient sodium thiosulfate (Na 2 S 2 O 3) must be added to the sample bottle before sterilization to neutralize any residual chlorine in the water sample.” Neutralization ceases the bactericidal action of the chlorine during sample transit, thus allowing a more accurate assessment of what the true microbial content of the water sample was at the time of sample collection. Implementation of this new requirement should be straightforward since PWSs need only ask the laboratory for pre-treated sample containers. EPA does not believe this provision will cause an increase in cost to PWSs, as the cost of the bottles with the sodium thiosulfate is essentially the same as the cost of the bottles without the sodium thiosulfate.

(c). Filtration funnels. Under this proposal, EPA is requiring that membrane filtration equipment be autoclaved before beginning a filtration series. This requirement is consistent with section 4.1.3 of the Laboratory Certification Manual, which states: “Membrane filter equipment must be autoclaved before the beginning of a filtration series.”

Under the current TCR, not all of the approved membrane filtration methods require that a filtration series begin with membrane filtration units that have been sterilized by autoclave. Some of the approved methods allow the laboratory to use ultraviolet (UV) radiation exposure in lieu of autoclaving to sterilize filtration units between filtration series. EPA does not believe that ultraviolet radiation is sufficient to properly sterilize the membrane filtration equipment. Additionally, EPA believes that when ultraviolet radiation is used, not all areas of the membrane filtration equipment are exposed, and therefore microorganisms may persist and contaminate other water samples and the laboratory. For these reasons, EPA is proposing to include a footnote to the analytical methods table in order to ensure proper sterilization.

EPA does, however, believe that ultraviolet light can be used to sanitize the filtration equipment between filtrations within a filtration series, as stated in section 4.1.4 of the Laboratory Certification Manual: “Ultraviolet light (254 nm) may be used to sanitize equipment (after initial autoclaving for sterilization), if all supplies are pre-sterilized. Ultraviolet light may be used to reduce bacterial carry-over between samples during a filtration series.”

(d). Analytical methods table. In this proposal, EPA is identifying a number of changes to the analytical methods table for clarity and accuracy.

In the current TCR, the methods are listed by date approved and the E. coli methods are listed in a text format. In this proposal, the analytical methods table is organized by methodology (e.g., lactose-fermentation methods vs. enzyme-substrate methods), and the E. coli methods are included in the table. Standard Methods for the Examination of Water and Wastewater is a reference document designed to represent "the best current practice of American water analysts." Periodically, new editions are published in order to incorporate improvements in the methods contained within this manual. Thus, new editions of this publication contain more current and improved versions of the methods. Under the current TCR, four editions of this publication are approved, resulting in different, oftentimes outdated, versions of the same method being approved.

Having multiple editions of this manual approved under this regulation also creates a burden for the laboratory certification officers who must understand the differences between the versions of the method for which the laboratory may be seeking certification. For these reasons, EPA is proposing to remove the 18th and 19th editions of Standard Methods for the Examination of Water and Wastewater for use in compliance sample analysis under the RTCR. EPA expects that the burden associated with this change will be minimal as most laboratories have already procured the newer editions or have arranged for access to the online publication.

In this proposed regulation, the reference to Standard Methods 9221A and 9222A are removed. These sections of the methods contain only introductory information, not any actual methodology. They do not represent methods approved for use under this regulation.

The references to Standard Methods 9221B and 9221D are modified in this proposed regulation. In the current TCR, the methods are referenced as 9221B and 9221D with footnote 5 denoting that the "completed phase" called for in the methods is not required. By more specifically citing Standard Methods 9221 B.1, B.2, and 9221 D.1, D.2 (which contain the applicable, required steps of these methods) EPA is able to eliminate the original footnote and improve clarity.

EPA is proposing to allow Standard Methods 9221D (Presence-Absence broth) to be used in a multiple tube format. This method has traditionally been used in a single bottle, allowing only the qualitative detection of total coliforms. However, there are published reports showing this method can be used in a multiple tube format for the quantitative detection of total coliforms (Rice et al. 1987; Rice et al. 1993). This medium would be used in the same manner that Lauryl Tryptose Broth (LTB) is described as being used in Standard Methods 9221B. Allowing the use of this method in a multiple tube format would allow PWSs that use this method to quantitate any total coliforms that may occur in the water sample.

EPA is proposing to change the citation for MI Agar. Under the current TCR, this method is cited as Standard Methods 9222, with a footnote citing the Applied and Environmental Microbiology article where the method was initially described. In this proposal, the method is now cited as EPA Method 1604, consistent with section 5.4.2.1.3 of the Laboratory Certification Manual. EPA Method 1604 is identical to the citation in the TCR and does not require the use of the original footnote. This change is also consistent with the citation of this method as listed in the Ground Water Rule (see 40 CFR 141.402).

The current TCR describes the use of "EC medium supplemented with 50 µg/mL of 4-methylumbelliferyl-Beta-D-glucuronide (MUG)" (see 40 CFR 141.21(f)(6)(i)). This proposal clarifies that this medium, included in both Standard Methods 9221F and Standard Methods 9222G.1 a (2), is approved for use under this regulation. This is consistent with the Laboratory Certification Manual, particularly section 5.1.8, which describes both of these methods as approved for use in the detection of E. coli under this regulation.

Lastly, EPA is clarifying the formulation for EC broth with MUG (EC-MUG) given in Standard Methods 9222G.1 a (2) to correct an error in the publication. The Standard Methods 9222G.1 a (2) formulation calls for 0.1 g of 4-methylumbelliferyl-Beta-D-glucuronide, and 1.4g KH 2 PO 4. This formulation differs from that given in Standard Methods 9221F.1, which calls for 0.05 g and 1.5 g, respectively. EPA believes that the correct formulation is given in Standard Methods 9221F and has confirmed this with Standard Methods committee members (Rice 2009). Accordingly, EPA has added a footnote to the 9222G.1 a (2) stating the proper formulation.

EPA anticipates that these changes to the analytical methods table will not cause any additional burden to the PWSs.

vi. Request for comment regarding holding temperature. The current TCR states the following regarding sample shipment: "Systems are encouraged but not required to hold samples below 10 deg. C during transit." Other national primary drinking water regulations requiring microbial sampling require that the samples be shipped in cold conditions, and require the sample be maintained at a temperature of 10 degrees Celsius (C) or less. Maintaining the sample temperature below 10 degrees C serves to preserve the bacterial population by minimizing both bacterial cell death and cell multiplication, thus allowing for a more accurate representation of the microbial population in the sample at the time of sample collection. Also, Standard Methods for Examination of Water and Wastewater, 21st edition (Eaton et al. 2005) recommends that samples be shipped at less than 8 degrees C but not frozen.

In the years since the promulgation of the current TCR, EPA has heard concern that at times, samples collected under the TCR may reach high temperatures during transit to the laboratory due to the lack of a requirement to ship samples on ice. High temperatures that may be reached during transit could have a deleterious or prolific effect on the bacterial cells present in the samples such that the samples may no longer represent the microbial content of the water at the time of sample collection.

EPA recognizes that requiring the samples under the proposed RTCR to be held at 10 degrees C or less, but above freezing, would result in an increased cost to the water systems (for shipping, supplies, etc.), but believes the extra burden may be warranted. EPA is seeking public comment on whether this passage should remain as is in the current TCR or whether the RTCR should require that the samples collected for compliance with this regulation be shipped in cold conditions, i.e., requiring a temperature of 10 degrees C or less, but above freezing to be maintained for better sample preservation. EPA also welcomes comments and supporting data on what the acceptable temperature range should be when samples are in transit.

B. Proposed Compliance Date

Consistent with SDWA section 1412(b)(10), EPA proposes that the compliance date of the final RTCR be three years from the date on which the regulation is promulgated (i.e., the publication date of the final rule in the Federal Register). PWSs must comply with the requirements of the rule by the compliance date.

EPA believes that capital improvements generally are not necessary to ensure compliance with the proposed RTCR. However, a State may allow individual systems up to two additional years to comply with the RTCR if the State determines that additional time is necessary for capital improvements, in accordance with SDWA section 1412(b)(10).

EPA requests comment on the proposed compliance date of the proposed RTCR.

C. Links to Other Drinking Water Rule Requirements

The proposed RTCR recognizes that existing NPDWRs contain linkages among monitoring requirements in different rules. The current residual disinfectant monitoring must be conducted at the same time and location at which TCR samples are taken, as provided for in the Surface Water Treatment Rule (SWTR) (USEPA 1989b, 54 FR 27486, June 29, 1989) and the Stage 1 Disinfectants and Disinfection Byproducts Rule (Stage 1 DBPR) (USEPA 1998a, 63 FR 69389, December 16, 1998). Under the GWR, TCR distribution system monitoring results determine whether a system is required to conduct source water monitoring. Under the SWTR, high measurements of turbidity in an unfiltered subpart H system of this part trigger additional total coliform samples. Sanitary survey provisions exist in surface water and ground water drinking water regulations. The proposed RTCR does not change the existing sanitary survey requirements except to add the special monitoring evaluation that States must conduct at systems serving 4,100 or fewer people. These evaluations do not increase the burden to conduct sanitary surveys because of the relatively simple nature of these systems and their monitoring requirements.

1. SWTR, Stage 1 and Stage 2 DBPRs, ADWR

After considering the possible linkages among the proposed RTCR and the SWTR, Stage 1 DBPR, Stage 2 DBPR (USEPA 2006e, 71 FR 388, January 4, 2006), and Airline Drinking Water Rule (ADWR) (USEPA 2009), EPA has concluded that the only necessary revision is to update the reference to the current TCR at 40 CFR 141.21, which is superseded by 40 CFR part 141 subpart Y beginning three years following publication of the final rule. EPA is also proposing several revisions to other NPDWRs, discussed below, that are not necessary but would facilitate implementation of all applicable NPDWRs.

2. GWR

As with the other drinking water rules mentioned above, EPA is proposing to update the references in the GWR to the current TCR at 40 CFR 141.21, which will be superseded by 40 CFR part 141 subpart Y.

3. Sanitary Surveys

Sanitary survey requirements are not included in the proposed RTCR. Under the current TCR, community water systems and non-community water systems that serve 4,100 or fewer people are required to conduct periodic sanitary surveys. Since the promulgation of the TCR in 1989, new sanitary survey requirements for surface water systems and ground water systems have been established for all system sizes and types under the Interim Enhanced Surface Water Treatment Rule (IESWTR) (USEPA 1998b, 63 FR 69477, December 16, 1998) (40 CFR 142.16(b)(3)), and the Ground Water Rule (GWR) (40 CFR 142.16(o)(2)(i)). Public water systems began implementing the IESWTR sanitary survey requirements in 2001. Therefore, for surface water systems, the current TCR sanitary survey requirements have phased out since that time. Implementation of the GWR sanitary survey requirements began in December 2009 for ground water systems. Therefore, for ground water systems, the GWR sanitary survey requirements will be in effect by the time the RTCR is finalized.

D. Best Available Technology (BAT)

1. Provisions

The proposed RTCR would maintain the provisions set forth in 40 CFR 141.63(d) (proposed to be in § 141.63(e)), regarding the best technology, treatment techniques, or other means available for achieving compliance with the MCL of either total coliforms or E. coli. EPA is proposing the following modifications:

- ✓ 40 CFR 141.63(d)(1) (proposed § 141.63(e)(1)) would be modified by replacing “coliforms” with “fecal contaminants.”

- ✓ 40 CFR 141.63(d)(3) (proposed § 141.63(e)(3)) would be modified by including “cross connection control” in the list of proper maintenance practices for the distribution system.

- ✓ 40 CFR 141.63(d)(4) (proposed § 141.63(e)(4)) would be modified by including the subparts P, T, and W that describe filtration and/or disinfection of surface water, and subpart S for disinfection of ground water.

2. EPA's Rationale

a. Change “coliform” to “fecal contaminants.” This change reflects the approach of the proposed RTCR that the presence of total coliforms does not necessarily have a direct public health implication. Instead, total coliform is used as an indicator of a potential pathway of contamination within a treatment technique requirement. For additional discussion on this topic, see section III.A.2 of this preamble.

b. Inclusion of cross connection control. EPA believes that adding cross connection control to the list of proper maintenance practices for distribution systems is appropriate because of the significant contribution of cross connections and backflow to waterborne disease outbreaks. From 1981 to 1998, the CDC documented 9, 734 detected and reported illnesses from 57 waterborne outbreaks related to cross connections (NRC 2006). From 1970 to 2001, approximately 12,000 illnesses resulted from 459 incidents of waterborne outbreaks from backflow events (NRC 2006).

c. Addition of other relevant subparts of 141. This change adds references to subparts that contain provisions for the other drinking water rules promulgated since 1989 when the TCR was promulgated (in particular, subpart P for the IESWTR, subpart S for the GWR, subpart T for the Long Term Enhanced Surface Water Treatment Rule (USEPA 2002, 67 FR 1812, January 14, 2002, and subpart W for the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA 2006d, 71 FR 654, January 5, 2006)). These drinking water rules contain updated filtration and disinfection standards that were not part of the current TCR when it was promulgated in 1989.

3. Request for Comment

EPA requests comment on the modifications to the existing BATs and whether there is a need to add or otherwise update the list of BATs.

E. Variances and Exemptions

1. Provisions

EPA is proposing to not allow variances or exemptions to the E. coli MCL. EPA is also proposing to eliminate the variance provisions in 40 CFR 141.4(b) that allow systems to demonstrate to the State that the violation of the monthly/non-acute total coliform MCL is due to biofilm and not fecal or pathogenic contamination. This change will also result in a parallel change in 40 CFR 142.63(b).

2. EPA's Rationale

Under the proposed RTCR, E. coli is used as an indicator of fecal contamination that may contain waterborne pathogens. To the extent a variance or exemption would permit the continued presence of E. coli, the potential for pathogens to be present also would remain. EPA believes that water which exceeds the MCL for E. coli poses an unreasonable risk to public health. Therefore, EPA is not allowing any variances or exemptions to the E. coli MCL. This provision is consistent with the existing requirement, since the provision that allows variances applies only to the monthly/non-acute total coliform MCL violation and not to the acute violation associated with the presence of E. coli.

Under the current TCR, EPA allows variances to the MCL for total coliforms when a system has demonstrated to the State that the violation of the total coliform MCL is due to a persistent growth of total coliforms in the distribution system (i.e., biofilm) rather than fecal or pathogenic contamination, a treatment lapse or deficiency, or a problem in the operation or maintenance of the distribution system.

EPA is proposing to eliminate the variance in 40 CFR 141.4(b) because under the proposed RTCR, there would no longer be an MCL for total coliforms (see section III.A.2 of this preamble). The current TCR MCL for total coliforms was based on the presence or absence of total coliforms in a sample (see 40 CFR 141.63 for details). In the proposed RTCR, the presence of total coliforms at a certain level requires the system to comply with the coliform treatment technique requirements (see section III.A.5 of this preamble). The assessment and corrective action requirements under this proposed rule include the possibility of recognizing that the total coliform presence is associated with biofilm. EPA plans to include this information in a new assessment and corrective action guidance manual related to the RTCR.

3. Request for Comment
EPA requests comment on its proposal to allow no variance or exemption to the E. coli MCL and to eliminate the variance provisions associated with the monthly/non-acute total coliform MCL.
F. Request for Comment on Other Issues Related to the Proposed RTCR

1. Consistency Between the Proposed RTCR and the GWR
EPA requests comment on the need for general consistency between the proposed RTCR and the GWR. Please provide specific examples. For example, under the current TCR, States are required to keep records of their decision to either waive or extend the 24-hour limit for collecting samples (that is, for repeat samples following a total coliform-positive sample, or for follow-up samples after high levels of turbidity) (see 40 CFR 142.14(a)(5)(i)(A) and 142.14(a)(5)(ii)(D)). The proposed RTCR also requires States to keep records of decisions to either waive or extend the 24-hour limit for repeat samples following a total coliform-positive sample, for samples following invalidation, or for follow-up samples after high levels of turbidity (see§§ 142.14(a)(10)(i)(A) and 142.14(a)(10)(ii)(D) of the proposed RTCR). Under the GWR, there are no recordkeeping requirements for the decision to waive or extend the 24-hour limit. Instead, the GWR includes special primacy requirements to describe criteria the State will use to extend the 24-hour limit (see 40 CFR 142.16(o)(3)(i)). EPA requests comment on whether it is appropriate to have States describe their criteria for waiving or extending the 24-hour limit as a primacy condition, or instead have States keep records of decisions to waive and/or extend the 24-hour limit.

2. Storage Tank Inspection and Cleaning
EPA requests comment on the value and cost of periodic storage tank inspection and cleaning. There are instances of storage tanks being the source of waterborne disease outbreaks at PWSs. In December 1993, a Salmonella typhimurium outbreak in Gideon, Missouri resulted in over 600 people affected by diarrhea, 31 cases of laboratory-confirmed salmonellosis and seven deaths of nursing home residents who had exhibited diarrheal illness (four deaths were confirmed by culture). The larger of the two storage tanks had a breach in the roof hatch that allowed pigeon droppings to be carried into the tank and likely accumulated in the several inches of sediment. This contaminated sediment, more than likely, was pulled into the distribution system by a flushing program that drained the tank (Clark et al. 1996). Salmonella typhimurium was isolated from the sediment of one of the towers, and tap water tested positive for fecal coliforms (CDC 1996).

In March 2008, Alamosa, Colorado (with a population of about 9,000 people) experienced a waterborne disease outbreak associated with Salmonella. The report released by the Colorado Department of Public Health and Environment (Falco and Williams 2009) indicated that the outbreak resulted in 442 reported cases of illnesses, 122 of which were laboratory confirmed, and one fatality. The State epidemiologist estimated that a total of 1,300 people may have been ill. Two storage tanks in Alamosa had several inches of sediment and breaches; one tank had breaches large enough for birds and animals to enter. Some of the key factors that contributed to these two outbreaks include significant levels of sediment (several inches to feet) and the presence of breaches of the integrity of the storage tank.

Sediment accumulation occurs within storage facilities due to quiescent conditions which promote particle setting. Over time sediment continues to accumulate in a tank, even if the finished water is consistently treated to below 0.1 nephelometric turbidity unit (NTU). For surface water systems, it is not uncommon to have1/4to1/2inch or more of sediment accumulate after two to three years (Kirmeyer et al. 1999). While there are no turbidity regulations for ground water systems (except for ground water under the direct influence of surface water (GWUDI)), the levels of turbidity can be significant in the water pumped from an aquifer. Sand particles, if allowed to accumulate, provide pore spaces that house diverse populations of biota (which may include pathogenic microorganisms) (Kirmeyer et al. 1999; van der Kooij 2003). Periodic high flows in the storage tank may scour, stir up, and suspend the sediment (along with entrapped bacteria and pathogens) and carry it into the distribution system, with greater accumulation of sediment being a more significant concern. Other water quality problems associated with sediment accumulation include increased disinfectant demand and disinfection byproduct formation.

The storage tank's vulnerability to contamination increases when breaches of the storage tank allow insects, animals, and birds and their associated diseases to enter. Contamination from bird and other animal excrement can potentially transmit disease-causing organisms to the finished water. Waterfowl, for example, are known carriers of many different waterborne pathogens including Vibrio cholerae (Ogg et al. 1989).

Based on the potential public health implications associated with poorly maintained storage tanks (e.g., as indicated by significant sediment accumulation and breaches), EPA is interested in receiving comments and supporting information regarding the state and condition of tanks that have been cleaned and inspected, costs of storage tank inspection and cleaning, and how public health can be better protected. EPA requests information on whether there are States that recommend or require periodic inspection and cleaning of storage tanks. If so, what are the requirements, the frequency of inspection and cleaning, and how successful are they? Are inspections and cleaning done by individual PWSs or by contractors?

3. States Under EPA Direct Implementation

EPA does not have the authorities provided to other primacy agencies under 40 CFR part 142 to use in implementing rules in direct implementation entities (e.g., Tribal systems and Wyoming). To provide EPA the flexibility of other primacy agencies to modify monitoring requirements as necessary to protect public health (e.g., to require more stringent monitoring or to develop criteria such as those that primacy States develop under the special primacy conditions requirement in 40 CFR 142.16) and facilitate implementation of this rule. EPA is requesting comment on whether the Agency should have the same authorities specified in subpart Y, as States have in 40 CFR 142.16, for PWSs for which the Agency has direct implementation responsibilities. EPA is requesting comment on whether this authority should be added to subpart Y specifically.

G. Limitations to the Public Comment on the Proposed RTCR

The proposed revisions to other drinking water regulations (SWTR, Stage 1 DBPR, Stage 2 DBPR, and ADWR) are made solely to update the reference to the current TCR at 40 CFR 141.21, which will be superseded by 40 CFR part 141 subpart Y beginning three years following publication of the final rule. This proposed rule would not change any substantive requirements of those rules and EPA is not soliciting public comments on those rules other than their proposed revised references to the current TCR or any other references to the current TCR that EPA may need to revise. IV.

The proposed RTCR provides States with flexibility to implement the requirements of the rule in a manner that maximizes the efficiency of the rule for the States and water systems while increasing the effectiveness of the rule to protect public health. While the proposed rule provides some reduction in monitoring relative to the current TCR, overall, the proposed rule is more stringent and better protects public health. As a result, States must adopt these revisions, when final, or adopt or maintain more stringent requirements, in order to maintain primacy. This section describes the regulations and other procedures and policies States must adopt in order to obtain primacy to implement the RTCR, if finalized as proposed today.

SDWA section 1413 establishes requirements that States or eligible Indian Tribes must meet to assume and maintain primary enforcement responsibility (primacy) for its PWSs. These requirements include:

- ✓ Adopting drinking water regulations that are no less stringent than Federal drinking water regulations;
- ✓ Adopting and implementing adequate procedures for enforcement;
- ✓ Keeping records and making reports available on activities that EPA requires by regulation;
- ✓ Issuing variances and exemptions (if allowed by the State), under conditions no less stringent than allowed under SDWA; and
- ✓ Adopting and being capable of implementing an adequate plan for the provisions of safe drinking water under emergency situations.

States may adopt more stringent requirements (e.g., requiring all systems to conduct routine monthly monitoring). Many States have used this authority in the past to improve public health protection and/or simplify implementation.

Section 1413(a)(1) of SDWA provides two years (plus up to two more years if the Administrator approves) after promulgation of the final RTCR for the State to adopt corresponding drinking water regulations in order to obtain primacy for the final RTCR. To implement the final RTCR, States would be required to adopt or maintain requirements that are at least as stringent as the following revisions to 41 CFR part 141:

- Section 141.4—Variances and exemptions (if allowed by the State).
- Section 141.21—Coliform sampling.
- Section 141.52—Maximum contaminant level goals for microbiological contaminants.
- Section 141.63—Maximum contaminant levels (MCLs) for microbiological contaminants.
- Section 141.74—Analytical and monitoring requirements.
- Section 141.132—Monitoring requirements.
- Subpart 141.153—Content of the reports.
- Subpart 141.202—Tier 1 Public Notice—Form, manner, and frequency of notice.
- Subpart 141.203—Tier 2 Public Notice—Form, manner, and frequency of notice.
- Subpart 141.204—Tier 3 Public Notice—Form, manner, and frequency of notice.
- Subpart O—Consumer Confidence Reports, Appendix A, Regulated Contaminants.
- Subpart Q—Public Notification of Drinking Water Violations, Appendix A, NPDWR Violations and Other Situations.
- Subpart Q—Public Notification of Drinking Water Violations, Appendix B, NPDWR Violations and Other Situations.
- Subpart Y—Revised Total Coliform Rule.

EPA's regulation at 40 CFR part 142 sets out the specific program implementation requirements for States to obtain primacy for the public water supply supervision program as authorized under SDWA section 1413. In addition to adopting basic primacy requirements specified in 40 CFR part 142, States may be required to adopt special primacy provisions pertaining to specific regulations where implementation of the rule involves activities beyond general primacy provisions. States must include these regulation-specific provisions in their application for approval of their program revision. States must continue to meet all other conditions of primacy for all other rules in 40 CFR part 142. Primacy requirements for the proposed RTCR are described below.

The advisory committee recognized that this rule will require more tracking to ensure effective implementation. Therefore, EPA plans to release an upgrade to SDWIS/State and SDWIS/FED (the State and Federal versions of the Safe Drinking Water Information System, respectively) within 18 months of final rule promulgation to accommodate monitoring data, tracking, compliance determinations and reporting of all rule related requirements, as appropriate.

A. State Special Primacy Requirements

To ensure that a State program includes all the elements necessary for an effective and enforceable program under the proposed RTCR, a State primacy application must include a description of how the State will perform the following:

- ✓ Sample Siting Plans—States must describe the frequency and process used to review and revise sample siting plans in accordance with 40 CFR 141, subpart Y to determine adequacy.

- ✓ Reduced Monitoring Criteria—The primacy application must indicate whether the State will adopt the reduced monitoring provisions of subpart Y. If the State adopts the reduced monitoring provisions, it must describe the specific types or categories of water systems that will be covered by reduced monitoring and whether the State will use all or a reduced set of the optional criteria. For each of the reduced monitoring criteria, both mandatory and optional, the State must describe how the criteria will be evaluated to determine when systems qualify.

- ✓ Assessments and Corrective Actions—States must describe their process to implement the new assessment and corrective action phase of the rule. The description must include examples of sanitary defects, examples of assessment forms or formats, and methods that systems may use to consult with the State on appropriate corrective actions.

- ✓ Invalidation of routine and repeat samples collected under subpart Y—States must describe their criteria and process to invalidate total coliform-positive and E. coli- positive samples under subpart Y. This includes criteria to determine if a sample was improperly processed by the laboratory, reflects a domestic or other non-distribution system plumbing problem or reflects circumstances or condition that does not reflect water quality in the distribution system.

- ✓ Approval of individuals allowed to conduct subpart Y Level 2 assessments—States must describe their criteria and process for approval of individuals allowed to conduct subpart Y Level 2 assessments.

- ✓ Special monitoring evaluation—States must describe how they will perform special monitoring evaluations during sanitary surveys for ground water systems serving 1,000 or fewer people to determine whether systems are on an appropriate monitoring schedule.

- ✓ Seasonal systems—States must describe how they will identify seasonal systems, how they will determine when systems on less than monthly monitoring must monitor, and what will be the seasonal system start-up provisions.

- ✓ Additional criteria for reduced monitoring—States must describe how they will require systems on reduced monitoring to demonstrate:

  —Continuous disinfection entering the distribution system and a residual in the distribution system;
  —Cross connection control;
  —Other enhancements to water system barriers; and
  —Procedures for seasonal systems to start up operations at the beginning of each season.

B. State Recordkeeping Requirements

The current regulations in 40 CFR 142.14 require States with primacy to keep records, including: Analytical results to determine compliance with MCLs, MRDLs, and treatment technique requirements; PWS inventories; State approvals; enforcement actions; and the issuance of variances and exemptions. The proposed RTCR requires States to keep additional records, including all supporting information and an explanation of the technical basis for each decision as follows. Records of the following decisions or activities must be retained for five years, consistent with recordkeeping requirements for existing regulations:

- ✓ Any decision to waive the 24-hour time limit for collecting repeat samples after a total coliform-positive routine sample, or to extend the 24-hour limit for collection of samples following invalidation, or for an unfiltered subpart H system of this part to collect a total coliform sample following a turbidity measurement exceeding 1 NTU.

- ✓ Any decision to allow a system to waive the requirement for three routine samples the month following a total coliform-positive sample. The record of the waiver decision must contain all the items listed in §§ 141.854(j) and 141.855(f) of the proposed RTCR.

- ✓ Any decision to invalidate a total coliform-positive sample. If the State decides to invalidate a total coliform-positive sample as provided in § 141.853(c)(1) of the proposed RTCR, the record of the decision must contain all the items listed in that paragraph.

- ✓ Completed and approved 40 CFR part 141 subpart Y assessments, including reports from the system that corrective action has been completed.

States must retain records of each of the following decisions in such a manner so that each system's current status may be determined at any time:

- ➢ Any decision to reduce the total coliform monitoring frequency for a community water system serving 1,000 or fewer people to less than once per month, as provided in § 141.855(d) of the proposed RTCR; and what the reduced monitoring frequency is. A copy of the reduced monitoring frequency must be provided to the system.

- ➢ Any decision to reduce the total coliform monitoring frequency for a non-community water system using only ground water and serving 1,000 or fewer people to less than once per quarter, as provided in § 141.854(e) of the proposed RTCR, and what the reduced monitoring frequency is. A copy of the reduced monitoring frequency must be provided to the system.

- ➢ Any decision to reduce the total coliform monitoring frequency for a non-community water system using only ground water and serving more than 1,000 persons during any month the system serves 1,000 or fewer people, as provided in § 141.857(d) of the proposed RTCR. A copy of the reduced monitoring frequency must be provided to the system.

- ➢ Any decision to waive the 24-hour limit for taking a total coliform sample for a public water system that uses surface water, or ground water under the direct influence of surface water, and that does not practice filtration in accordance with part 141, subparts H, P, T, and W, and that measures a source water turbidity level exceeding 1 NTU near the first service connection.

- ➢ Any decision to allow a public water system to forgo E. coli testing on a total coliform-positive sample if that system assumes that the total coliform-positive sample is E. coli- positive.

C. State Reporting Requirements
EPA currently requires at 40 CFR 142.15 that States report to EPA information such as violations, variance and exemption status, and enforcement actions. The proposed RTCR requires States to develop and maintain a list of public water systems that the State is allowing to monitor less frequently than once per month for community water systems or less frequently than once per quarter for non-community water systems, including the compliance date (the date that reduced monitoring was approved) of the reduced monitoring requirement for each system.

D. Interim Primacy
On April 28, 1998, EPA amended its State primacy regulations at 40 CFR 142.12 to incorporate the new process identified in the 1996 SDWA Amendments for granting primary enforcement authority to States while their applications to modify their primacy programs are under review (USEPA 1998c, 63 FR 23361, April 28, 1998). The new process grants interim primary enforcement authority for a new or revised regulation during the period in which EPA is making a determination with regard to primacy for that new or revised regulation. This interim enforcement authority begins on the date of the primacy application submission or the effective date of the new or revised State regulation, whichever is later, and ends when EPA makes a final determination. However, this interim primacy authority is only available to a State that has primacy (including interim primacy) for every existing NPDWR in effect when the new regulation is promulgated.

As a result, States that have primacy (including interim primacy) for every existing NPDWR already in effect may obtain interim primacy for the RTCR, beginning on the date that the State submits the application for this rule to EPA, or the effective date of its revised regulations, whichever is later. A State that wishes to obtain interim primacy for future NPDWRs must obtain primacy for this rule.

E. Request for Comment
EPA requests comment on the adequacy of the proposed RTCR requirements for State implementation, including but not limited to State special primacy requirements and State reporting and recordkeeping requirements. Specifically, EPA requests comment on whether there are any requirements that should be added to assure proper State oversight, or any that can be removed without detriment to implementation of the rule.

V. Distribution System Research and Information Collection Activities
A. Research and Information Collection Partnership
The advisory committee recommended that a Research and Information Collection Partnership (RICP) be formed to inform and support the drinking water community in developing future national risk management decisions pertaining to drinking water distribution systems. The advisory committee recommended seven priority areas for research and information collection. These seven priority areas are: (1) Cross-connection and backflow of contaminated water; (2) contamination due to storage facility design, operation, or maintenance; (3) contamination due to main installation, repair, or rehabilitation practices; (4) contaminant intrusion due to pressure conditions and physical gaps in distribution system infrastructure; (5) significance and control of biofilm and microbial growth; (6) nitrification issues that lead to public health effects; and (7) accumulation and release of contaminants from distribution system scales and sediments (USEPA 2008c, AIP p. 30).

In January 2009, EPA and the Water Research Foundation (WRF or the Foundation) signed a memorandum of understanding (MOU) to form the RICP in response to recommendations from the advisory committee contained in the AIP (USEPA and WRF 2009). The MOU conveys the partners' agreement to collaborate and identify, define, prioritize, coordinate, and communicate critical decision-relevant distribution system research and information collection needs of the drinking water community. The RICP is directed by a steering committee comprised of nine members: Three members from EPA, three members from water utilities, and three additional members representing the public health, environmental advocate, and State regulator perspectives.

B. Distribution System Optimization Activities

As part of the AIP, the advisory committee encouraged "the development of national and regional distribution system optimization partnerships that focus on protecting the integrity of drinking water quality once it is delivered to the distribution system. The purpose of the partnerships should be to inform and inspire proactive systems to implement best management practices that emphasize protection of public health. These partnerships, comprised, for example, of representatives from utilities, communities, academia, and regulatory organizations could develop continuous improvement programs that encompass water distribution optimization principles and practices for system design, operations, and maintenance. These partnerships should foster continuous review of distribution system issues and should define excellence in distribution system operation in terms of processes, systems, procedures, as well as measures. The optimization partnerships should encourage voluntary program participation of all drinking water utilities regardless of system size" (USEPA 2008c, AIP p. 25).

EPA is aware of two distribution system optimization programs that are currently being developed. EPA and the Foundation are concurrently developing distribution system optimization programs that focus on protecting public health in the distribution system. Developmental activities to support these efforts are occurring through the EPA's National Area Wide Optimization Program (AWOP) and the Foundation's project #4109. While these programs are being developed independently with differing measures of performance, both are founded on the optimization principles of improving water systems, and go beyond the regulatory requirements, while using existing staff and facilities. These principles and practices are currently being used through the in-plant treatment optimization programs operated through AWOP and the American Water Works Association's (AWWA) Partnership for Safe Water (the Partnership).

The goal of EPA's optimization program is to protect public health by addressing both the technical and management issues that limit the water system's ability to meet water quality performance goals. EPA has started developing a distribution system optimization program, which is currently focused on improving water treatment plant finished water quality while maintaining disinfectant residual and minimizing disinfection byproduct formation in the distribution system. Future work may focus on other water quality parameters or issues of concern. An outcome of this effort will be the identification of the key technical and management skills, practices, and tools that a water system should implement to achieve long-term distribution system optimization. Ultimately, participating AWOP States will be introduced to distribution system optimization methods developed by EPA. At this time, additional development activities are needed before a distribution system optimization program will be available for State implementation.

In 2007, the Foundation initiated project #4109 to identify a limited number of straightforward criteria that can be used by water utilities to measure distribution system optimization performance and to develop a self-assessment approach using standards of excellence. The results from this project will also be used to expand the Partnership for Safe Water Program treatment plant optimization program into distribution system optimization. The Foundation anticipates project #4109 to be completed by early 2010. With the results of project #4109, the Partnership anticipates finalizing a preliminary set of optimization goals and a model assessment process in calendar year 2010. Prior to finalizing the goals and assessment process, the Partnership will conduct trials at several volunteer utilities. The optimization goals and assessment process will be evaluated and refined based on those trials prior to consideration by the Partnership for adoption and implementation.

C. Request for Comment

EPA requests comment about these distribution system optimization projects and information about or suggestions for other possible approaches to distribution system optimization.

VI. Economic Analysis (Health Risk Reduction and Cost Analysis)

This section summarizes the Health Risk Reduction and Cost Analysis (HRRCA) in support of the proposed RTCR as required by section 1412(b)(3)(C) of the SDWA. EPA has prepared the RTCR Economic Analysis (EA) (USEPA 2010a) to comply with this requirement. The EA document for the proposed RTCR is available in the docket and is also published on the government's Web site at http://www.regulations.gov.

The HRRCA consists of seven elements:
(1) quantifiable and nonquantifiable health risk reduction benefits;
(2) quantifiable and nonquantifiable health risk reduction benefits from reductions in co-occurring contaminants;
(3) quantifiable and nonquantifiable costs that are likely to occur solely as a result of compliance;
(4) incremental costs and benefits of rule options;
(5) effects of the contaminant on the general population and sensitive subpopulations including infants, children, pregnant women, elderly, and individuals with a history of serious illness;
(6) any increased health risks that may occur as a result of compliance, including risks associated with co-occurring contaminants; and
(7) other relevant factors such as uncertainties in the analysis and factors with respect to the degree and nature of risk. See SDWA section 1412(b)(3)(C). A summary of these elements is provided in this section of the preamble, and a complete discussion can be found in the Proposed RTCR EA (USEPA 2010a).

The benefits described in this section are discussed qualitatively, and reductions in detection of total coliforms and E. coli and in Level 2 assessments are used to describe the benefits, as described later in this section. The costs discussed in this section are presented as annualized present values in 2007 dollars. Both benefit and cost measures are adjusted using social discounting. In social discounting, future values of a rule's or policy's effects are multiplied by discount factors. The discount factors reflect both the amount of time between the present and the point at which these events occur and the degree to which current consumption is more highly valued than future consumption (USEPA 2000c). This process allows comparison of cost and benefit streams that are variable over a given time period. EPA uses social discount rates of both three percent and seven percent to calculate present values from the stream of benefits and costs and also to annualize the present value estimates. Historically, the use of three percent is based on rates of return on relatively risk-free financial instruments, while seven percent is generally an estimate of before-tax rate of return to incremental private investment. For further information, see USEPA 2000c and OMB 1996.

In the Proposed RTCR EA (USEPA 2010a), EPA also presents the undiscounted stream of benefits and costs over the 25-year time frame (i.e., the year-to-year realization of benefits and costs presented in constant terms). The time frame used for both benefit and cost comparisons in this rule is 25 years. This time interval accounts for rule implementation activities occurring soon after promulgation (e.g., States adopting the criteria of the regulation) and the time for different types of compliance actions (e.g., assessments and corrective actions) to be realized up through the 25th year following rule promulgation.

EPA was unable to quantify health benefits for the proposed RTCR because there are insufficient data reporting the co-occurrence in a single sample of fecal indicator E. coli and pathogenic organisms. In addition, the available fecal indicator E. coli data from the Six-Year Review 2 dataset (USEPA 2010e) described in this preamble were limited to presence-absence data because the current TCR requires only the reporting of presence or absence of fecal indicator E. coli using EPA-approved standard methods.

However, as discussed in chapter 6 of the Proposed RTCR EA (USEPA 2010a), even though health benefits could not be directly quantified, the potential benefits from the proposed RTCR include avoidance of a full range of health effects from the consumption of fecally contaminated drinking water, including the following: acute and chronic illness, endemic and epidemic disease, waterborne disease outbreaks, and death. Also, since fecal contamination may contain waterborne pathogens including bacteria, viruses, and parasitic protozoa, in general, a reduction in fecal contamination should reduce the risk from these other contaminants.

The net costs of the rule stem mostly from the new assessment and corrective action requirements as well as the revised monitoring provisions described earlier in this preamble. This section of the preamble includes elements as follows: (A) Regulatory Options Considered, (B) Major Sources of Data and Information used in Supporting Analyses, (C) Occurrence and Predictive Modeling, (D) Baseline Profiles, (E) Anticipated Benefits of the Proposed RTCR, (F) Anticipated Costs of the Proposed RTCR, (G) Potential Impact of the Proposed RTCR on Households, (H) Incremental Costs and Benefits, (I) Benefits from Simultaneous Reduction of Co-occurring Contaminants, (J) Change in Risk from Other Contaminants, (K) Effects of Fecal Contamination and/or Waterborne Pathogens on the General Population and Sensitive Subpopulations, (L) Uncertainties in the Benefit and Cost Estimates for the Proposed RTCR, (M) Benefit Cost Determination for the Proposed RTCR, and (N) Request for Comment.

A. Regulatory Options Considered

EPA evaluated the following three regulatory options as part of this revised rule proposal: (1) The current TCR option, (2) the AIP option, and (3) an Alternative option. EPA discusses the three regulatory options briefly in this preamble and in greater detail in the Proposed RTCR EA (USEPA 2010a).

First, the current TCR option reflects EPA's understanding of how the current TCR (USEPA 1989a, 54 FR 27544, June 29, 1989) is currently being implemented. That is, the current TCR option is assumed to include "status quo" PWS and State implementation practices. Next, the AIP option is a revised TCR based on the recommendations of the advisory committee. The provisions of this proposed rule are based on the AIP option and are described in detail in section III of this preamble. Third, the Alternative option parallels the AIP in most ways but includes variations of some of the provisions that were discussed by the advisory committee before consensus was reached on the AIP.

The Alternative option differs from the AIP option in two ways. First, under the Alternative option, at the compliance date all PWSs are required to sample monthly for an initial period until they meet the eligibility criteria for reduced monitoring. EPA assumes that eligibility for reduced monitoring is determined during the next sanitary survey following the RTCR compliance date.

This more stringent approach differs from the AIP option that allows PWSs to continue to monitor at their current frequencies (with an additional annual site visit or voluntary Level 2 assessment requirement for PWSs wishing to remain on annual monitoring) until they are triggered into an increased sampling frequency. Second, under the Alternative option, no PWSs are allowed to reduce monitoring to an annual basis. EPA defined the Alternative option this way and included it in the Proposed RTCR EA (USEPA 2010a) to assess the relative impacts of a more stringent rule and to better understand the balance between costs and public health protection.

To understand the relative impacts of the options, EPA gathered available data and information to develop and provide input into an occurrence and predictive model. EPA estimated both baseline conditions and changes to these conditions anticipated to occur over time as a result of these revised rule options. The analysis is described in more detail in the Proposed RTCR EA (USEPA 2010a).

B. Major Sources of Data and Information Used in Supporting Analyses

This section of the preamble briefly discusses the data sources that EPA used in its supporting analyses for the proposed RTCR. For a more detailed discussion, see chapter 4 of the Proposed RTCR EA (USEPA 2010a).

1. Safe Drinking Water Information System Federal Version Data

Safe Drinking Water Information System Federal Version (SDWIS/FED) is EPA's national regulatory compliance database for the drinking water program and is the main source of PWS inventory and violation data for the proposed RTCR baseline. SDWIS/FED contains information on each of the approximately 155,000 active PWSs as reported by primacy agencies, EPA Regions, and EPA headquarters personnel. SDWIS/FED includes records of MCL violations and monitoring and reporting (MR) violations (both routine and repeat and minor and major). It does not include sample results. It also contains information to characterize the US inventory of PWSs including system name and location, retail population served, source water type (ground water (GW), surface water (SW), or ground water under the direct influence of surface water (GWUDI)), disinfection status, and PWS type (community water system (CWS), transient non-community water system (TNCWS), and non-transient non-community water system (NTNCWS)).

To create the PWS and population baseline, EPA used the fourth quarter of SDWIS/FED 2007 (USEPA 2007b), which was the most current PWS inventory data available when EPA began developing the Proposed RTCR EA. These data represent all current, active PWSs and the population served by these systems.

EPA also used the MCL violation data from SDWIS/FED to validate model predictions for systems serving 4,100 or fewer people and to predict E. coli (acute)_-MCL violations (current TCR, AIP, and Alternative option), total coliform (non-acute or monthly) MCL violations (current TCR), and Level 1 and Level 2 assessment triggers (AIP and Alternative option) for systems serving more than 4,100 people.

2. Six-Year Review 2 Data

Through an Information Collection Request (USEPA 2006b), States voluntarily submitted electronically available TCR monitoring data (sample results) that were collected between January 1998 and December 2005. EPA requested the TCR monitoring results with the intent of conducting analyses and developing models to assess the potential impacts of changes to the current TCR. EPA received data from 46 States, Tribes, and territories. A Data Quality Report (USEPA 2010c) describes how TCR monitoring data were obtained, evaluated, and modified where necessary to make the database internally consistent and usable for analysis. Exhibit 2.1 in the Data Quality Report provides a complete list of States or territories that submitted data and a description of the use of these data.

In this EA, EPA included data from 37 primacy agencies (35 States and 2 Tribes). Records included data for:

- PWS information (system type, population served, source water type)
- Sample type (routine, repeat, special purpose)
- Analytical result
- Sampling location—entry point, distribution system and, for repeat samples, original location, downstream, upstream, and other
- Analytical method
- Disinfectant residual data collected at TCR monitoring sites

As discussed in greater detail in section 4.2.2.1 of the Proposed RTCR EA (USEPA 2010a), EPA used 2005 data exclusively in the analyses supporting the proposed RTCR because the 2005 data set was the most complete year of data among the Six-Year Review 2 data (USEPA 2010e). The 2005 data was also the most recent data available suggesting that it may be the most representative of present conditions.

The Six-Year Review 2 data (USEPA 2010e) also informed EPA's assumptions regarding the proportions of GWSs serving 1,000 or fewer people that sample monthly, quarterly, or annually.

Disinfection Byproduct Regulations

Drinking water chlorination has contributed to a dramatic decline in waterborne disease rates and increased life expectancy in the United States. Largely because of this success, many Americans take it for granted that their tap water will be free of disease-causing organisms. In recent years, regulators and the general public have focused greater attention on potential health risks from chemical contaminants in drinking water. One such concern relates to disinfection byproducts (DBPs), chemical compounds formed unintentionally when chlorine and other disinfectants react with certain organic matter in water.

In the early 1970s, EPA scientists first determined that drinking water chlorination could form a group of byproducts known as trihalomethanes (THMs), including chloroform. Concerned that these chemicals may be carcinogenic to humans, EPA set the first regulatory limits for THMs in 1979. Since that time, a wealth of research has improved our understanding of how DBPs are formed, their potential health risks, and how they can be controlled. It is now recognized that all chemical disinfectants form some potentially harmful byproducts. The byproducts of chlorine disinfection are by far the most thoroughly studied.

While the available evidence does not prove that DBPs in drinking water cause adverse health effects in humans, high levels of these chemicals are certainly undesirable. Cost-effective methods to reduce DBP formation are available and should be adopted where possible. However, the International Programme on Chemical Safety (IPCS), a joint venture of the United Nations Environment Programme, the International Labor Organization, and the World Health Organization (IPCS 2000, p. 13) strongly cautions:

The health risks from these byproducts at the levels at which they occur in drinking water are extremely small in comparison with the risks associated with inadequate disinfection. Thus, it is important that disinfection not be compromised in attempting to control such byproducts.

Recent EPA regulations have further limited THMs and other DBPs in drinking water. Most water systems are meeting these new standards by controlling the amount of natural organic matter prior to disinfection, while ensuring that microbial protection remains the top priority. DBPs and Human Cancer Risk Toxicology studies have reported that high doses of some DBPs, including THMs and haloacetic acids (HAAs), can cause cancer in laboratory animals. Based largely on these animal data, EPA considers individual THMs and HAAs to be either possible or probable human carcinogens, although any risk from the low levels found in drinking water would be slight. After reviewing the full body of toxicology studies, the IPCS concluded, “None of the chlorination byproducts studied to date is a potent carcinogen at concentrations normally found in drinking water” (IPCS 2000, p. 376).

Some epidemiology studies have reported an association between human exposure to DBPs and elevated cancer risks, while other studies have found no association. EPA evaluated the existing cancer epidemiology studies and found that only for bladder cancer were associations with chlorinated water somewhat consistent. Even in these studies, cancer risks were not strongly correlated to measured THM levels, indicating that other factors cannot be ruled out (Craun et al., 2001). EPA has concluded, “The present epidemiologic data do not support a causal relationship between exposure to chlorinated drinking water and development of cancer at this time” (EPA 1998). The IPCS reached a similar conclusion in 2000, noting that a causal relationship between DBPs and increased cancer remains an open question (IPCS 2000).

Balancing DBP and Microbial Risks

Continuing evidence of waterborne disease occurrence suggests that microbial risks should receive a much higher level of attention than disinfection byproducts. For this reason, The American Academy of Microbiology (Ford and Colwell, 1996) has recommended, the health risks posed by microbial pathogens should be placed as the highest priority in water treatment to protect public health. A report published by the International Society of Regulatory Toxicology and Pharmacology (Coulston and Kolbye, 1994) stated “The reduction in mortality due to waterborne infectious diseases, attributed largely to chlorination of potable water supplies, appears to outweigh any theoretical cancer risks (which may be as low as zero) posed by the minute quantities of chlorinated organic chemicals reported in drinking waters disinfected with chlorine.”

The IPCS (IPCS 2000, p. 375) reached similar conclusions:
Disinfection is unquestionably the most important step in the treatment of water for drinking water supplies. The microbial quality of drinking water should not be compromised because of concern over the potential long-term effects of disinfectants and DBPs. The risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from disinfectants and DBPs.

Controlling Disinfection Byproducts
Treatment techniques are available that provide water suppliers the opportunity to maximize potable water safety and quality while minimizing the risk of DBP risks. Generally, the best approach to reduce DBP formation is to remove natural organic matter precursors prior to disinfection. EPA has published a guidance document for water system operators entitled, Controlling Disinfection byproducts and Microbial Contaminants in Drinking Water (EPA, 2001).

The EPA guidance discusses three processes to effectively remove natural organic matter prior to disinfection:

1. Coagulation and Clarification
Most treatment plants optimize their coagulation process for turbidity (particle) removal. However, coagulation processes can also be optimized for natural organic matter removal with higher doses of inorganic coagulants (such as alum or iron salts), and optimization of pH.

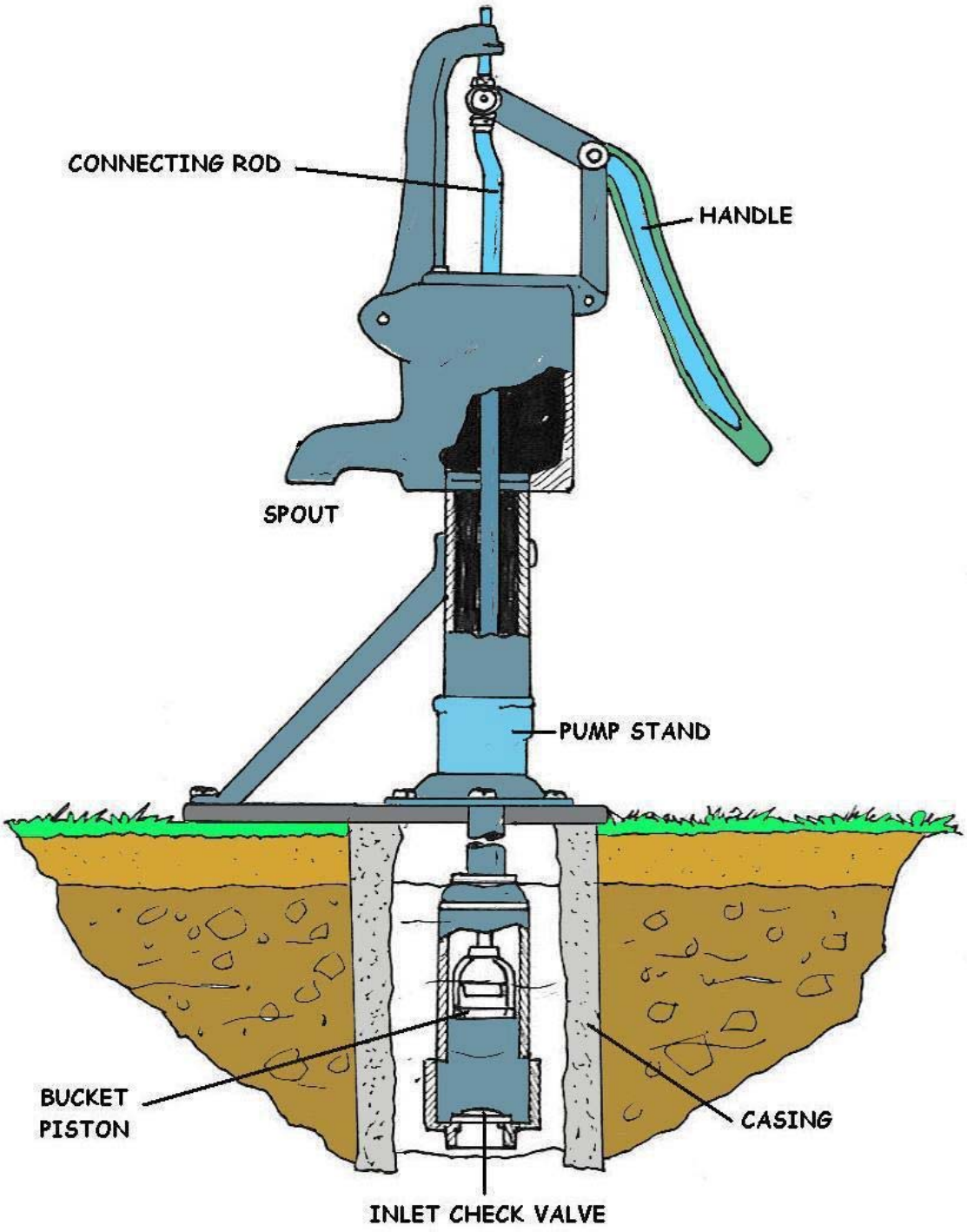
2. Absorption
Activated carbon can be used to absorb soluble organics that react with disinfectants to form byproducts.

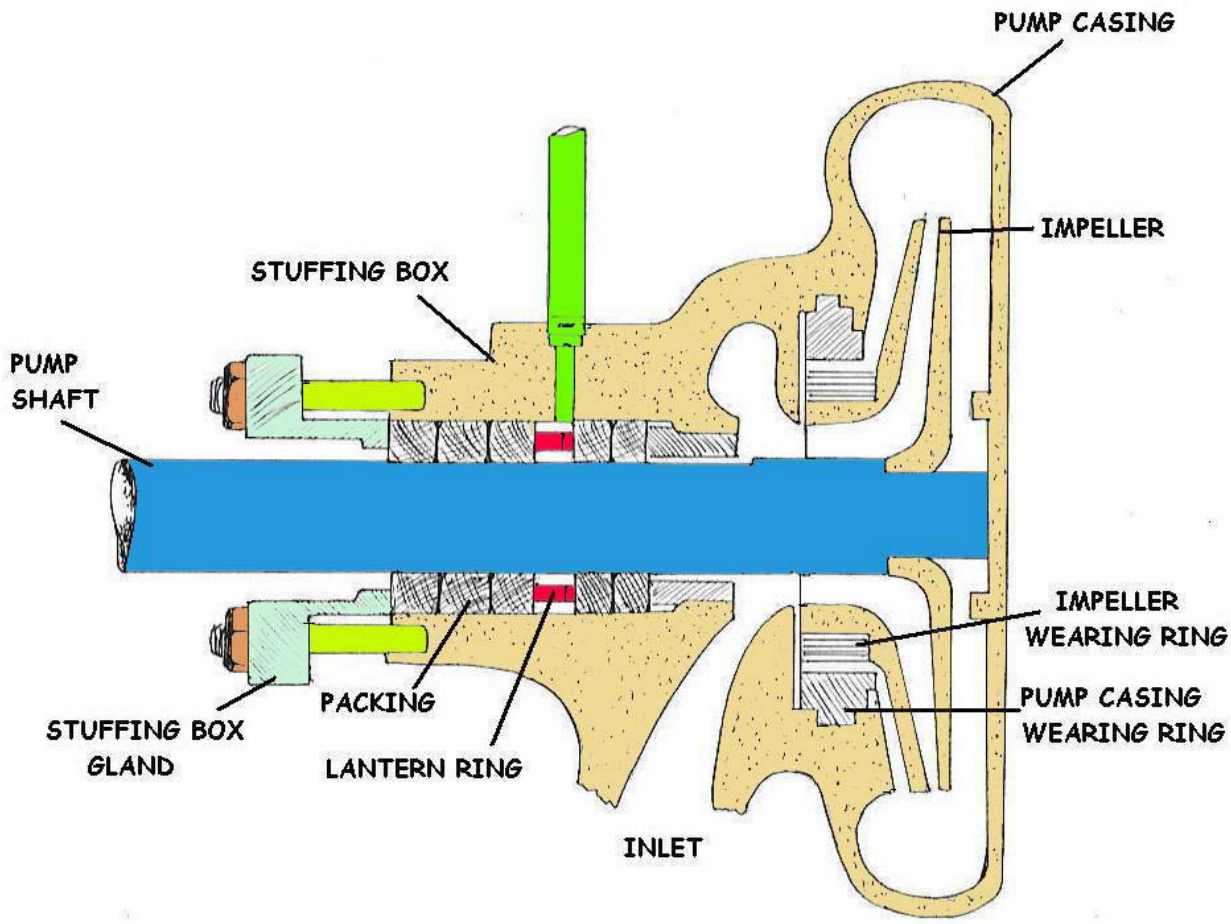
3. Membrane Technology
Membranes, used historically to desalinate brackish waters, have also demonstrated excellent removal of natural organic matter. Membrane processes use hydraulic pressure to force water through a semi-permeable membrane that rejects most contaminants. Variations of this technology include reverse osmosis (RO), nanofilitration (low pressure RO), and microfiltration (comparable to conventional sand filtration).

Other conventional methods of reducing DBP formation include changing the point of chlorination and using chloramines for residual disinfection. EPA predicts that most water systems will be able to achieve compliance with new DBP regulations through the use of one or more of these relatively low cost methods (EPA, 1998).

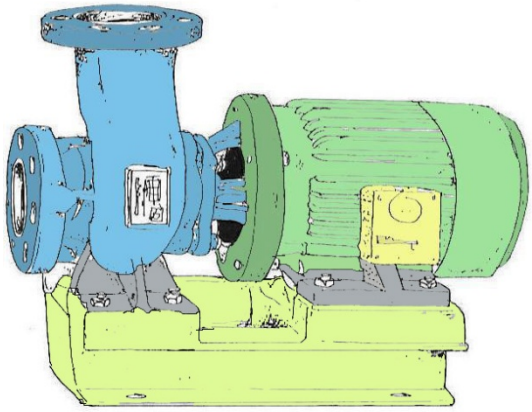
Water system managers may also consider switching from chlorine to alternative disinfectants to reduce formation of THMs and HAAs. However, all chemical disinfectants form some DBPs. Much less is known about the byproducts of these alternatives than is known about chlorination byproducts. Furthermore, each disinfection method has other distinct advantages and disadvantages.

Pump, Motor and Hydraulic Section





A centrifugal pump has two main components:
I. A rotating component comprised of an impeller and a shaft
II. A stationary component comprised of a casing, casing cover, and bearings.



END SUCTION CENTRIFUGAL PUMP

Common Hydraulic Terms

Head
The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid.

Head, Friction
The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type, and conditions of conductors and fittings, and the fluid characteristics.

Head, static
The height of a column or body of fluid above a given point.

Hydraulics
Engineering science pertaining to liquid pressure and flow.

Hydrokinetics
Engineering science pertaining to the energy of liquid flow and pressure.

Pascal's Law
A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

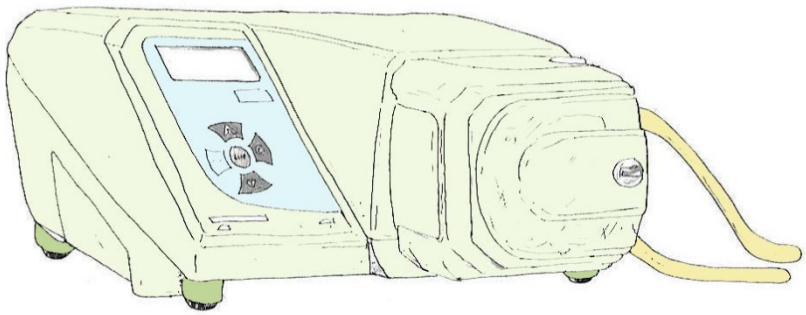
Pressure
The application of continuous force by one body upon another that it is touching; compression. Force per unit area, usually expressed in pounds per square inch (Pascal or bar).

Pressure, Absolute
The pressure above zone absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

Pressure, Atmospheric
Pressure exported by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

Pressure, Gauge
Pressure differential above or below ambient atmospheric pressure.

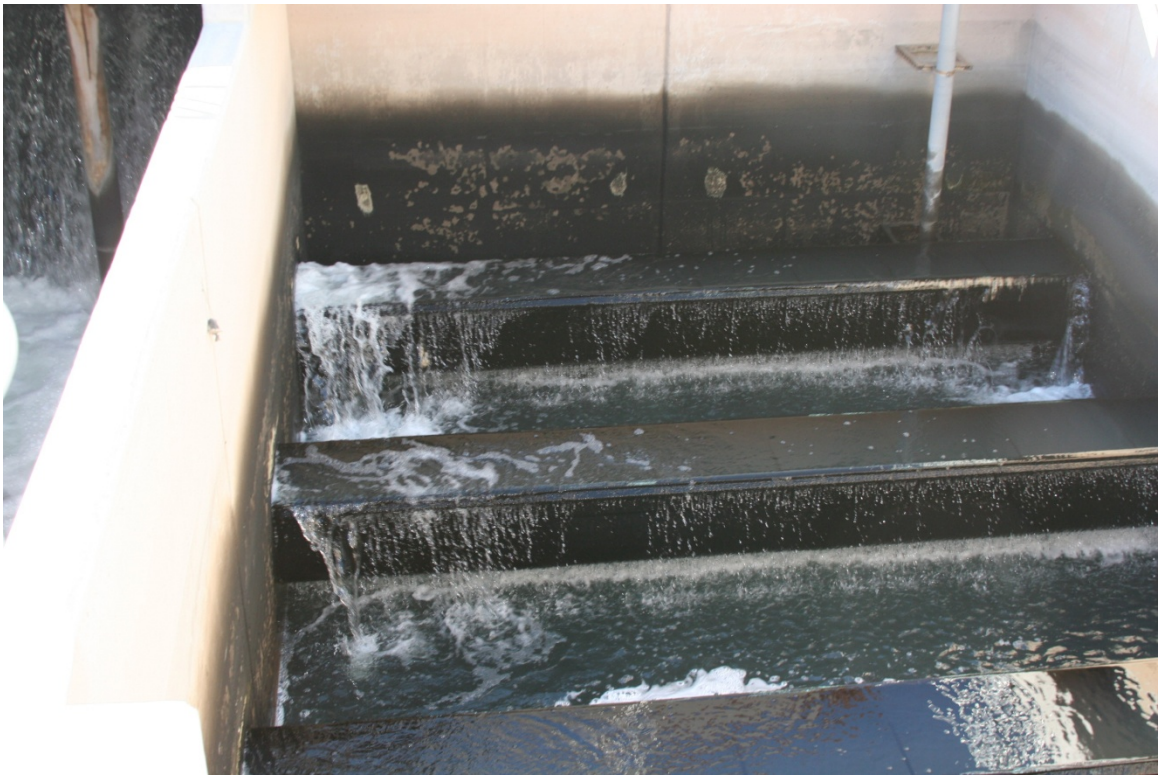
Pressure, Static
The pressure in a fluid at rest.



PERISTALTIC PUMP



Top- Compartment style Flocculation Basins
Bottom – Filter backwash draining filter



Hydraulic Principles Section

Definition **Hydraulics** is a branch of engineering concerned mainly with moving liquids. The term is applied commonly to the study of the mechanical properties of water, other liquids, and even gases when the effects of compressibility are small. Hydraulics can be divided into two areas, hydrostatics and hydrokinetics.

Hydraulics ***The Engineering science pertaining to liquid pressure and flow.***
The word ***hydraulics*** is based on the Greek word for water, and originally covered the study of the physical behavior of water at rest and in motion. Use has broadened its meaning to include the behavior of all liquids, although it is primarily concerned with the motion of liquids.
Hydraulics includes the manner in which liquids act in tanks and pipes, deals with their properties, and explores ways to take advantage of these properties.



Hydrostatics, the consideration of liquids at rest, involves problems of buoyancy and flotation, pressure on dams and submerged devices, and hydraulic presses. The relative incompressibility of liquids is one of its basic principles. Hydrodynamics, the study of liquids in motion, is concerned with such matters as friction and turbulence generated in pipes by flowing liquids, the flow of water over weirs and through nozzles, and the use of hydraulic pressure in machinery.

Hydrostatics
Hydrostatics is about the pressures exerted by a fluid at rest. Any fluid is meant, not just water. Research and careful study on water yields many useful results of its own, however, such as forces on dams, buoyancy and hydraulic actuation, and is well worth studying for such practical reasons. Hydrostatics is an excellent example of deductive mathematical physics, one that can be understood easily and completely from a very few fundamentals, and in which the predictions agree closely with experiment.

There are few better illustrations of the use of the integral calculus, as well as the principles of ordinary statics, available to the student. A great deal can be done with only elementary mathematics. Properly adapted, the material can be used from the earliest introduction of school science, giving an excellent example of a quantitative science with many possibilities for hands-on experiences.

The definition of a fluid deserves careful consideration. Although time is not a factor in hydrostatics, it enters in the approach to hydrostatic equilibrium. It is usually stated that a fluid is a substance that cannot resist a shearing stress, so that pressures are normal to confining surfaces. Geology has now shown us clearly that there are substances which can resist shearing forces over short time intervals, and appear to be typical solids, but which flow like liquids over long time intervals. Such materials include wax and pitch, ice, and even rock.

A ball of pitch, which can be shattered by a hammer, will spread out and flow in months. Ice, a typical solid, will flow in a period of years, as shown in glaciers, and rock will flow over hundreds of years, as in convection in the mantle of the earth.

Shear earthquake waves, with periods of seconds, propagate deep in the earth, though the rock there can flow like a liquid when considered over centuries. The rate of shearing may not be strictly proportional to the stress, but exists even with low stress.

Viscosity may be the physical property that varies over the largest numerical range, competing with electrical resistivity. There are several familiar topics in hydrostatics which often appears in expositions of introductory science, and which are also of historical interest and can enliven their presentation. Let's start our study with the principles of our atmosphere.

Atmospheric Pressure

The atmosphere is the entire mass of air that surrounds the earth. While it extends upward for about 500 miles, the section of primary interest is the portion that rests on the earth's surface and extends upward for about 7 1/2 miles. This layer is called the troposphere.

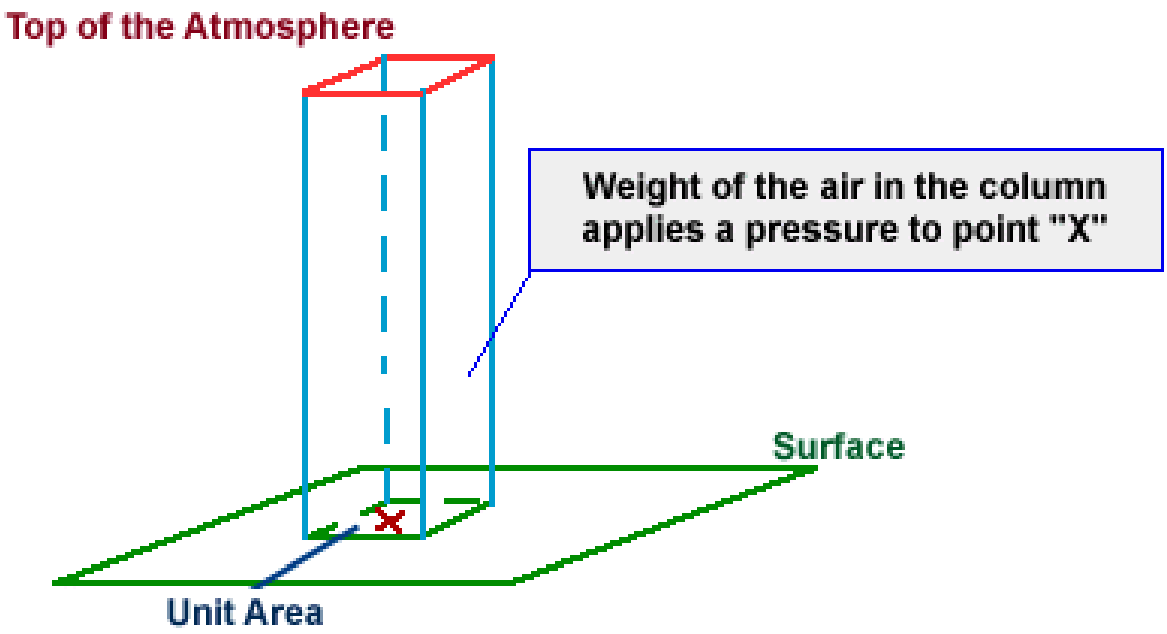
If a column of air 1-inch square extending all the way to the "*top*" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

As one ascends, the atmospheric pressure decreases by approximately 1.0 psi for every 2,343 feet. However, below sea level, in excavations and depressions, atmospheric pressure increases. Pressures under water differ from those under air only because the weight of the water must be added to the pressure of the air.

Atmospheric pressure can be measured by any of several methods. The common laboratory method uses the mercury column barometer. The height of the mercury column serves as an indicator of atmospheric pressure. At sea level and at a temperature of 0° Celsius (**C**), the height of the mercury column is approximately 30 inches, or 76 centimeters. This represents a pressure of approximately 14.7 psi. The 30-inch column is used as a reference standard.

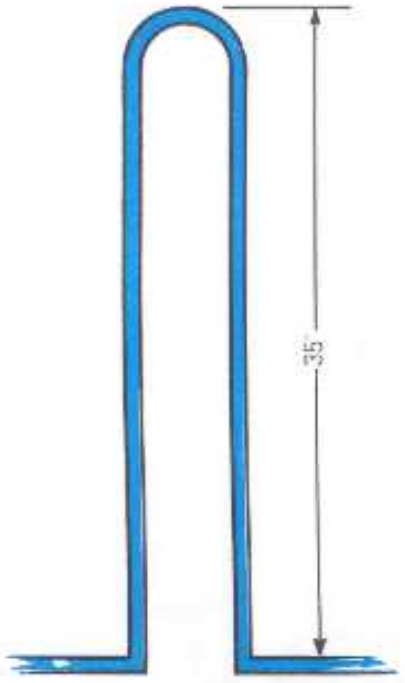
Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure. The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. This movement is transmitted through a system of levers to a pointer, which indicates the pressure.

The atmospheric pressure does not vary uniformly with altitude. It changes very rapidly. Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. In the diagram on the following page, the pressure at point "**X**" increases as the weight of the air above it increases. The same can be said about decreasing pressure, where the pressure at point "**X**" decreases if the weight of the air above it also decreases.



Barometric Loop

The barometric loop consists of a continuous section of supply piping that abruptly rises to a height of approximately 35 feet and then returns back down to the originating level. It is a loop in the piping system that effectively protects against backsiphonage. It may not be used to protect against back-pressure.



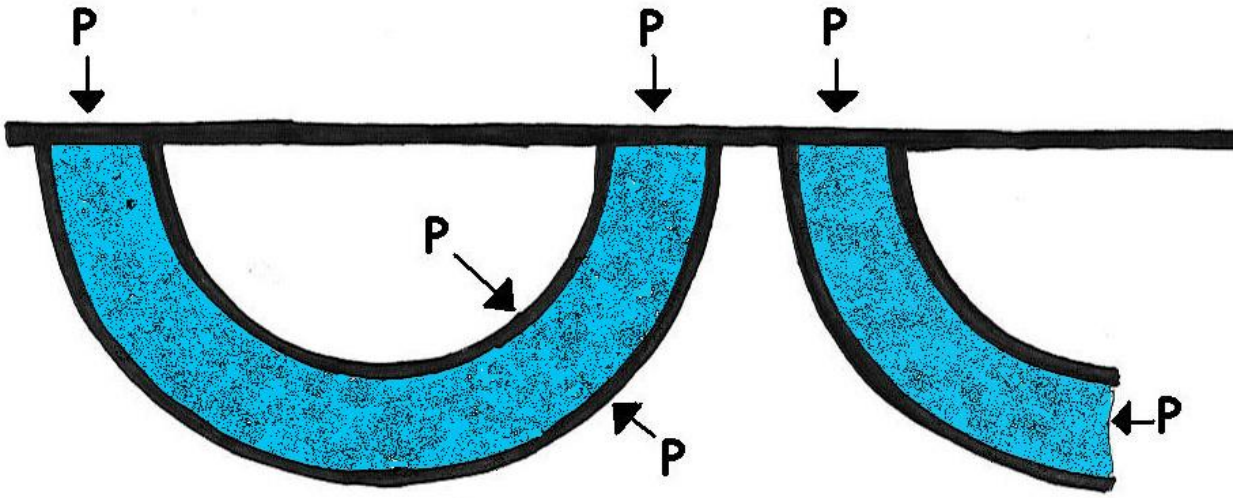
Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet. In general, barometric loops are locally fabricated, and are 35 feet high.

Pressure may be referred to using an absolute scale, pounds per square inch absolute (**psia**), or gauge scale, (**psiag**). Absolute pressure and gauge pressure are related. Absolute pressure is equal to gauge pressure plus the atmospheric pressure. At sea level, the atmospheric pressure is 14.7 psai.

Absolute pressure is the total pressure. Gauge pressure is simply the pressure read on the gauge. If there is no pressure on the gauge other than atmospheric, the gauge will read zero. Then the absolute pressure would be equal to 14.7 psi, which is the atmospheric pressure.

Pressure

By a fluid, we have a material in mind like water or air, two very common and important fluids. Water is incompressible, while air is very compressible, but both are fluids. Water has a definite volume; air does not. Water and air have low viscosity; that is, layers of them slide very easily on one another, and they quickly assume their permanent shapes when disturbed by rapid flows. Other fluids, such as molasses, may have high viscosity and take a long time to come to equilibrium, but they are no less fluids. The coefficient of viscosity is the ratio of the shearing force to the velocity gradient. Hydrostatics deals with permanent, time-independent states of fluids, so viscosity does not appear, except as discussed in the Introduction.



EQUALITY OF PRESSURE

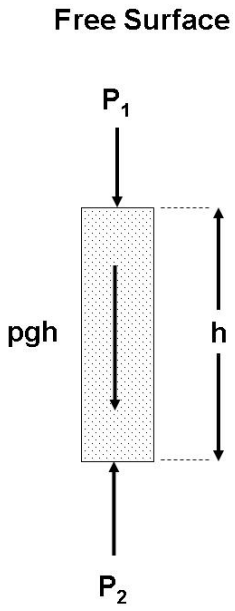
A fluid, therefore, is a substance that cannot exert any permanent forces tangential to a boundary. Any force that it exerts on a boundary must be normal to the boundary. Such a force is proportional to the area on which it is exerted, and is called a pressure. We can imagine any surface in a fluid as dividing the fluid into parts pressing on each other, as if it were a thin material membrane, and so think of the pressure at any point in the fluid, not just at the boundaries. In order for any small element of the fluid to be in equilibrium, the pressure must be the same in all directions (or the element would move in the direction of least pressure), and if no other forces are acting on the body of the fluid, the pressure must be the same at all neighboring points.

Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as dyne/cm^2, N/cm^2 (pascal), pounds/in^2 (psi) or pounds/ft^2 (psf). The axiom that if a certain volume of fluid were somehow made solid, the equilibrium of forces would not be disturbed, is useful in reasoning about forces in fluids.

On earth, fluids are also subject to the force of gravity, which acts vertically downward, and has a magnitude $\gamma = \rho g$ per unit volume, where g is the acceleration of gravity, approximately 981 cm/s^2 or 32.15 ft/s^2, ρ is the density, the mass per unit volume, expressed in g/cm^3, kg/m^3, or slug/ft^3, and γ is the specific weight, measured in lb/in^3, or lb/ft^3 (pcf).

Gravitation is an example of a body force that disturbs the equality of pressure in a fluid. The presence of the gravitational body force causes the pressure to increase with depth, according to the equation dp = ρg dh, in order to support the water above. We call this relation the barometric equation, for when this equation is integrated, we find the variation of pressure with height or depth. If the fluid is incompressible, the equation can be integrated at once, and the pressure as a function of depth h is p = ρgh + p0.

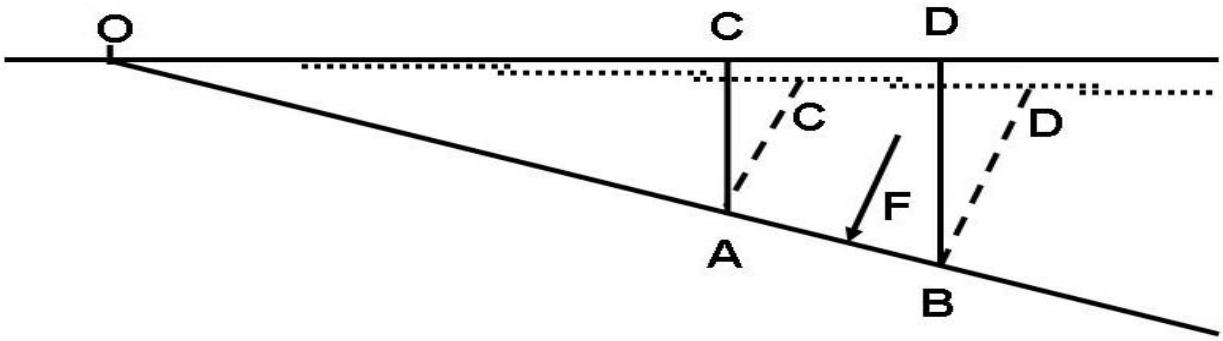
The density of water is about 1 g/cm^3, or its specific weight is 62.4 pcf. We may ask what depth of water gives the normal sea-level atmospheric pressure of 14.7 psi, or 2117 psf.



Increase of Pressure with Depth

This is simply 2117 / 62.4 = 33.9 ft of water. This is the maximum height to which water can be raised by a suction pump, or, more correctly, can be supported by atmospheric pressure. Professor James Thomson (brother of William Thomson, Lord Kelvin) illustrated the equality of pressure by a "curtain-ring" analogy shown in the diagram. A section of the toroid was identified, imagined to be solidified, and its equilibrium was analyzed.

The forces exerted on the curved surfaces have no component along the normal to a plane section, so the pressures at any two points of a plane must be equal, since the fluid represented by the curtain ring was in equilibrium. The right-hand part of the diagram illustrates the equality of pressures in orthogonal directions. This can be extended to any direction whatever, so Pascal's Principle is established. This demonstration is similar to the usual one using a triangular prism and considering the forces on the end and lateral faces separately.



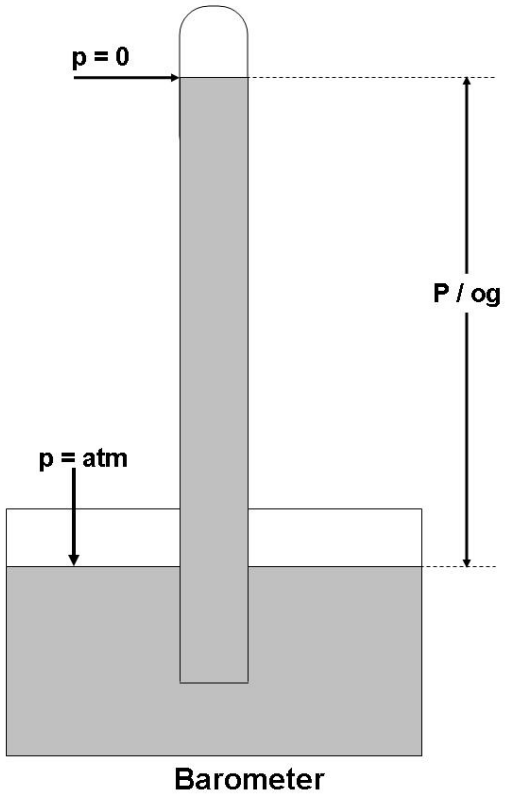
Thrust on a Plane

Free Surface Perpendicular to Gravity

When gravity acts, the liquid assumes a free surface perpendicular to gravity, which can be proved by Thomson's method. A straight cylinder of unit cross-sectional area (assumed only for ease in the arithmetic) can be used to find the increase of pressure with depth. Indeed, we see that p2 = p1 + ρgh. The upper surface of the cylinder can be placed at the free surface if desired. The pressure is now the same in any direction at a point, but is greater at points that lie deeper. From this same figure, it is easy to prove Archimedes' Principle that the buoyant force is equal to the weight of the displaced fluid, and passes through the center of mass of this displaced fluid.

Geometric Arguments

Ingenious geometric arguments can be used to substitute for easier, but less transparent arguments using calculus. For example, the force acting on one side of an inclined plane surface whose projection is AB can be found as in the diagram on the previous page. O is the point at which the prolonged projection intersects the free surface. The line AC' perpendicular to the plane is made equal to the depth AC of point A, and line BD' is similarly drawn equal to BD. The line OD' also passes through C', by proportionality of triangles OAC' and OAD'. Therefore, the thrust F on the plane is the weight of a prism of fluid of cross-section AC'D'B, passing through its centroid normal to plane AB. Note that the thrust is equal to the density times the area times the depth of the center of the area; its line of action does not pass through the center, but below it, at the center of thrust. The same result can be obtained with calculus by summing the pressures and the moments.



Barometer

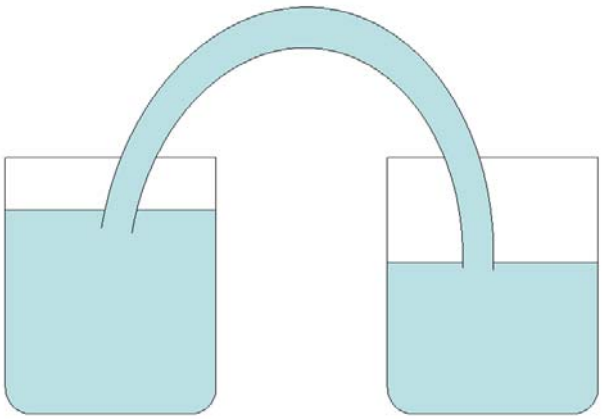
Atmospheric Pressure and its Effects

Suppose a vertical pipe is stood in a pool of water, and a vacuum pump applied to the upper end. Before we start the pump, the water levels outside and inside the pipe are equal, and the pressures on the surfaces are also equal and are equal to the atmospheric pressure.

Now start the pump. When it has sucked all the air out above the water, the pressure on the surface of the water inside the pipe is zero, and the pressure at the level of the water on the outside of the pipe is still the atmospheric pressure. Of course, there is the vapor pressure of the water to worry about if you want to be precise, but we neglect this complication in making our point. We require a column of water 33.9 ft high inside the pipe, with a vacuum above it, to balance the atmospheric pressure. Now do the same thing with liquid mercury, whose density at 0 °C is 13.5951 times that of water. The height of the column is 2.494 ft, 29.92 in, or 760.0 mm.

Standard Atmospheric Pressure

This definition of the standard atmospheric pressure was established by Regnault in the mid-19th century. In Britain, 30 in. Hg (inches of mercury) had been used previously. As a practical matter, it is convenient to measure pressure differences by measuring the height of liquid columns, a practice known as manometry. The barometer is a familiar example of this, and atmospheric pressures are traditionally given in terms of the length of a mercury column. To make a barometer, the barometric tube, closed at one end, is filled with mercury and then inverted and placed in a mercury reservoir. Corrections must be made for temperature, because the density of mercury depends on the temperature, and the brass scale expands for capillarity if the tube is less than about 1 cm in diameter, and even slightly for altitude, since the value of g changes with altitude.



Siphon

The vapor pressure of mercury is only 0.001201 mmHg at 20°C, so a correction from this source is negligible. For the usual case of a mercury column (α = 0.000181792 per °C) and a brass scale (&alpha = 0.0000184 per °C) the temperature correction is -2.74 mm at 760 mm and 20°C. Before reading the barometer scale, the mercury reservoir is raised or lowered until the surface of the mercury just touches a reference point, which is mirrored in the surface so it is easy to determine the proper position. An aneroid barometer uses a partially evacuated chamber of thin metal that expands and contracts according to the external pressure. This movement is communicated to a needle that revolves in a dial. The materials and construction are arranged to give a low temperature coefficient. The instrument must be calibrated before use, and is usually arranged to read directly in elevations. An aneroid barometer is much easier to use in field observations, such as in reconnaissance surveys. In a particular case, it would be read at the start of the day at the base camp, at various points in the vicinity, and then finally at the starting point, to determine the change in pressure with time. The height differences can be calculated from h = 60,360 log (P/p) [1 + (T + t - 64)/986) feet, where P and p are in the same units, and T, t are in °F.

An absolute pressure is referring to a vacuum, while a gauge pressure is referring to the atmospheric pressure at the moment. A negative gauge pressure is a (partial) vacuum. When a vacuum is stated to be so many inches, this means the pressure below the atmospheric pressure of about 30 in. A vacuum of 25 inches is the same thing as an absolute pressure of 5 inches (of mercury).

Vacuum

The term *vacuum* indicates that the absolute pressure is less than the atmospheric pressure and that the gauge pressure is negative. A complete or total vacuum would mean a pressure of 0 psia or –14.7 psig. Since it is impossible to produce a total vacuum, the term vacuum, as used in this document, will mean all degrees of partial vacuum. In a partial vacuum, the pressure would range from slightly less than 14.7 psia (0 psig) to slightly greater than 0 psia (-14.7 psig). Backsiphonage results from atmospheric pressure exerted on a liquid, forcing it toward a supply system that is under a vacuum.

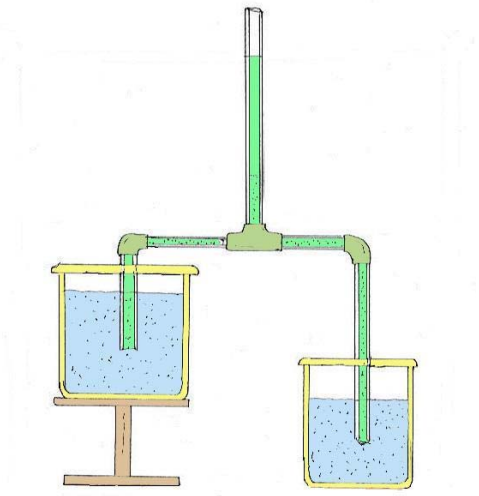
Water Pressure

The weight of a cubic foot of water is 62.4 pounds per square foot. The base can be subdivided into 144-square inches with each subdivision being subjected to a pressure of 0.433 psig. Suppose you placed another cubic foot of water on top of the first cubic foot. The pressure on the top surface of the first cube which was originally atmospheric, or 0 psig, would now be 0.4333 psig as a result of the additional cubic foot of water. The pressure of the base of the first cubic foot would be increased by the same amount of 0.866 psig or two times the original pressure.

Pressures are very frequently stated in terms of the height of a fluid. If it is the same fluid whose pressure is being given, it is usually called "head," and the factor connecting the head and the pressure is the weight density ρg. In the English engineer's system, weight density is in pounds per cubic inch or cubic foot. A head of 10 ft is equivalent to a pressure of 624 psf, or 4.33 psi. It can also be considered an energy availability of ft-lb per lb. Water with a pressure head of 10 ft can furnish the same energy as an equal amount of water raised by 10 ft. Water flowing in a pipe is subject to head loss because of friction.

Take a jar and a basin of water. Fill the jar with water and invert it under the water in the basin. Now raise the jar as far as you can without allowing its mouth to come above the water surface. It is always a little surprising to see that the jar does not empty itself, but the water remains with no visible means of support. By blowing through a straw, one can put air into the jar, and as much water leaves as air enters. In fact, this is a famous method of collecting insoluble gases in the chemical laboratory, or for supplying hummingbird feeders. It is good to remind oneself of exactly the balance of forces involved.

Another application of pressure is the siphon. The name is Greek for the tube that was used for drawing wine from a cask. This is a tube filled with fluid connecting two containers of fluid, normally rising higher than the water levels in the two containers, at least to pass over their rims. In the diagram, the two water levels are the same, so there will be no flow. When a siphon goes below the free water levels, it is called an inverted siphon. If the levels in the two basins are not equal, fluid flows from the basin with the higher level into the one with the lower level, until the levels are equal.



PASCAL'S SIPHON

A siphon can be made by filling the tube, closing the ends, and then putting the ends under the surface on both sides. Alternatively, the tube can be placed in one fluid and filled by sucking on it. When it is full, the other end is put in place. The analysis of the siphon is easy, and should be obvious. The pressure rises or falls as described by the barometric equation through the siphon tube. There is obviously a maximum height for the siphon which is the same as the limit of the suction pump, about 34 feet. Inverted siphons are sometimes used in pipelines to cross valleys. Differences in elevation are usually too great to use regular siphons to cross hills, so the fluids must be pressurized by pumps so the pressure does not fall to zero at the crests.

Liquids at Rest

In studying fluids at rest, we are concerned with the transmission of force and the factors which affect the forces in liquids. Additionally, pressure in and on liquids and factors affecting pressure are of great importance.

Pressure and Force

Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

The terms ***force*** and ***pressure*** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

Force means a total push or pull. It is the push or pull exerted against the total area of a particular surface and is expressed in pounds or grams. Pressure means the amount of push or pull (force) applied to each unit area of the surface and is expressed in pounds per square inch (lb/in^2) or grams per square centimeter (gm/cm^2). Pressure maybe exerted in one direction, in several directions, or in all directions.

Computing Force, Pressure, and Area

A formula is used in computing force, pressure, and area in fluid power systems. In this formula, P refers to pressure, F indicates force, and A represents area. Force equals pressure times area. Thus, the formula is written:



General Pumping Fundamentals

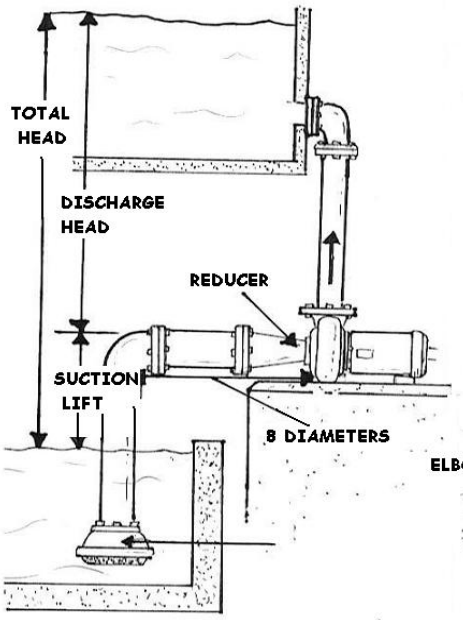


ILLUSTRATION 1

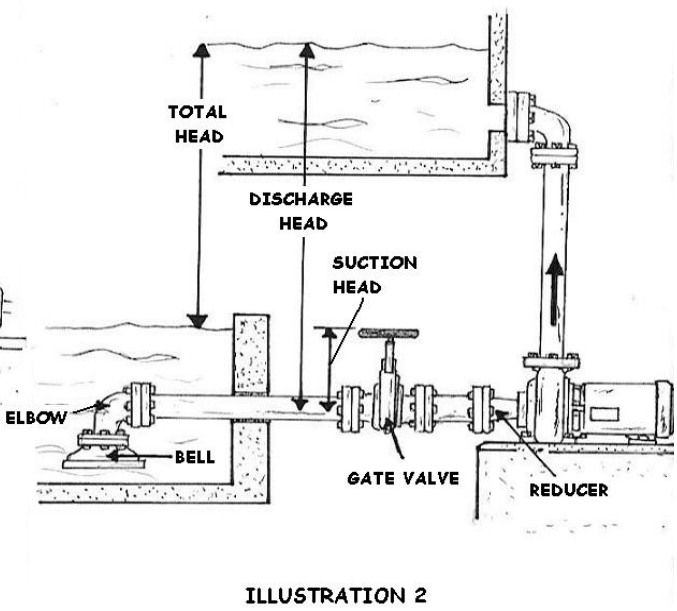


ILLUSTRATION 2

Here are the important points to consider about suction piping when the liquid being pumped is below the level of the pump:

- First, suction lift is when the level of water to be pumped is below the centerline of the pump. Sometimes suction lift is also referred to as 'negative suction head'.
- The ability of the pump to lift water is the result of a partial vacuum created at the center of the pump.
- This works similar to sucking soda from a straw. As you gently suck on a straw, you are creating a vacuum or a pressure differential. Less pressure is exerted on the liquid inside the straw, so that the greater pressure is exerted on the liquid around the outside of the straw, causing the liquid in the straw to move up. By sucking on the straw, this allows atmospheric pressure to move the liquid.
- Look at the diagram illustrated as "1". The foot valve is located at the end of the suction pipe of a pump. It opens to allow water to enter the suction side, but closes to prevent water from passing back out of the bottom end.
- The suction side of pipe should be one diameter larger than the pump inlet. The required eccentric reducer should be turned so that the top is flat and the bottom tapered.

Notice in illustration "2" that the liquid is above the level of the pump. Sometimes this is referred to as *'flooded suction'* or *'suction head'* situations.

Points to Note are:
If an elbow and bell are used, they should be at least one pipe diameter from the tank bottom and side. This type of suction piping must have a gate valve which can be used to prevent the reverse flow when the pump has to be removed. In the illustrations you can see in both cases the discharge head is from the centerline of the pump to the level of the discharge water. The total head is the difference between the two liquid levels.

Pump Definitions *(Larger Glossary in the rear of this manual)*

Fluid: Any substance that can be pumped such as oil, water, refrigerant, or even air.

Gasket: Flat material that is compressed between two flanges to form a seal.

Gland follower: A bushing used to compress the packing in the stuffing box and to control leakoff.

Gland sealing line: A line that directs sealing fluid to the stuffing box.

Horizontal pumps: Pumps in which the center line of the shaft is horizontal.

Impeller: The part of the pump that increases the speed of the fluid being handled.

Inboard: The end of the pump closest to the motor.

Inter-stage diaphragm: A barrier that separates stages of a multi-stage pump.

Key: A rectangular piece of metal that prevents the impeller from rotating on the shaft.

Keyway: The area on the shaft that accepts the key.

Kinetic energy: Energy associated with motion.

Lantern ring: A metal ring located between rings of packing that distributes gland sealing fluid.

Leak-off: Fluid that leaks from the stuffing box.

Mechanical seal: A mechanical device that seals the pump stuffing box.

Mixed flow pump: A pump that uses both axial-flow and radial-flow components in one impeller.

Multi-stage pumps: Pumps with more than one impeller.

Outboard: The end of the pump farthest from the motor.

Packing: Soft, pliable material that seals the stuffing box.

Positive displacement pumps: Pumps that move fluids by physically displacing the fluid inside the pump.

Radial bearings: Bearings that prevent shaft movement in any direction outward from the center line of the pump.

Radial flow: Flow at 90° to the center line of the shaft.

Retaining nut: A nut that keeps the parts in place.

Rotor: The rotating parts, usually including the impeller, shaft, bearing housings, and all other parts included between the bearing housing and the impeller.

Score: To cause lines, grooves or scratches.

Shaft: A cylindrical bar that transmits power from the driver to the pump impeller.

Shaft sleeve: A replaceable tubular covering on the shaft.

Shroud: The metal covering over the vanes of an impeller.

Slop drain: The drain from the area that collects leak-off from the stuffing box.

Slurry: A thick, viscous fluid, usually containing small particles.

Stages: Impellers in a multi-stage pump.

Stethoscope: A metal device that can amplify and pinpoint pump sounds.

Strainer: A device that retains solid pieces while letting liquids through.

Stuffing box: The area of the pump where the shaft penetrates the casing.

Suction: The place where fluid enters the pump.

Suction eye: The place where fluid enters the pump impeller.

Throat bushing: A bushing at the bottom of the stuffing box that prevents packing from being pushed out of the stuffing box into the suction eye of the impeller.

Thrust: Force, usually along the center line of the pump.

Thrust bearings: Bearings that prevent shaft movement back and forth in the same direction as the center line of the shaft.

Troubleshooting: Locating a problem.

Vanes: The parts of the impeller that push and increase the speed of the fluid in the pump.

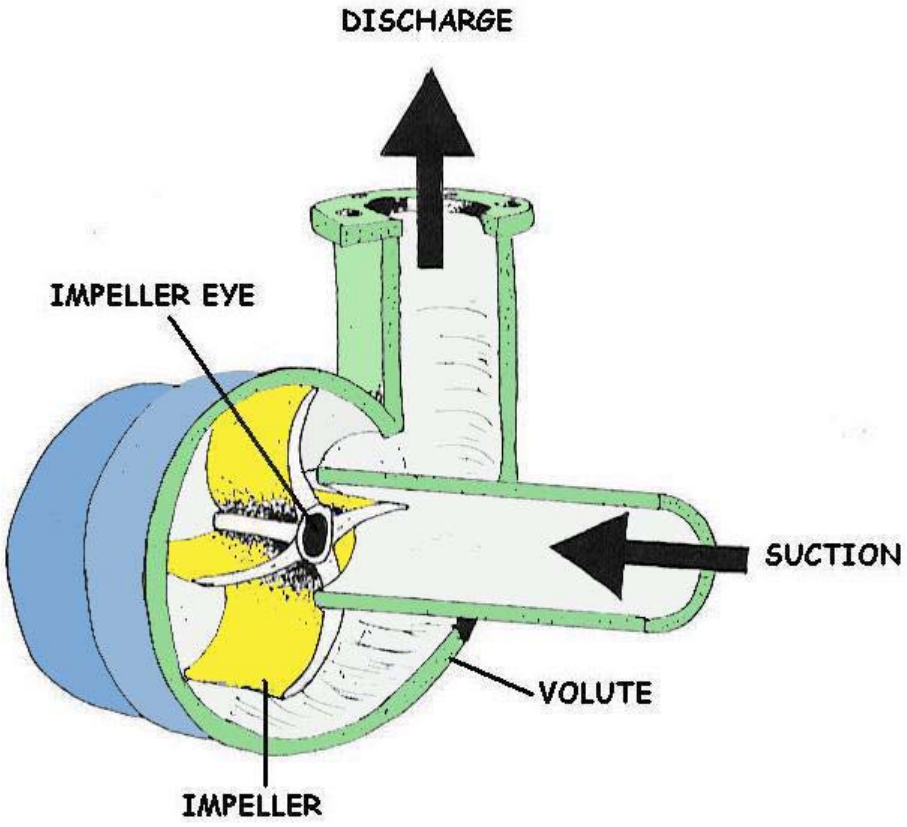
Vertical pumps: Pumps in which the center line of the shaft runs vertically.

Volute: The part of the pump that changes the speed of the fluid into pressure.

Wearing rings: Replaceable rings on the impeller or the casing that wear as the pump operates.

Basic Pump

Pumps are used to move or raise fluids. They are not only very useful, but are excellent examples of hydrostatics. Pumps are of two general types, hydrostatic or positive displacement pumps, and pumps depending on dynamic forces, such as centrifugal pumps. Here we will only consider positive displacement pumps, which can be understood purely by hydrostatic considerations. They have a piston (or equivalent) moving in a closely-fitting cylinder and forces are exerted on the fluid by motion of the piston.



We have already seen an important example of this in the hydraulic lever or hydraulic press, which we have called quasi-static. The simplest pump is the syringe, filled by withdrawing the piston and emptied by pressing it back in, as its port is immersed in the fluid or removed from it.

More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow passage in one direction, and close automatically to prevent reverse flow. There are many kinds of valves, and they are usually the most trouble-prone and complicated part of a pump. The force pump has two check valves in the cylinder, one for supply and the other for delivery. The supply valve opens when the cylinder volume increases, the delivery valve when the cylinder volume decreases.

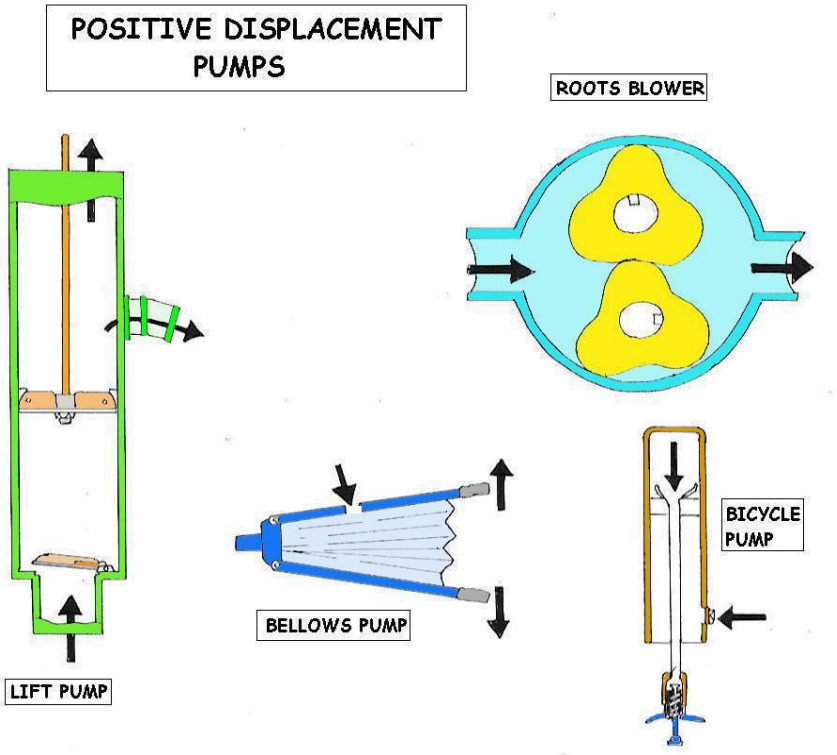
The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.

Diaphragm pumps are force pumps in which the oscillating diaphragm takes the place of the piston. The diaphragm may be moved mechanically, or by the pressure of the fluid on one side of the diaphragm.

Some positive displacement pumps are shown below. The force and lift pumps are typically used for water. The force pump has two valves in the cylinder, while the lift pump has one valve in the cylinder and one in the piston. The maximum lift, or "suction," is determined by the atmospheric pressure, and either cylinder must be within this height of the free surface. The force pump, however, can give an arbitrarily large pressure to the discharged fluid, as in the case of a diesel engine injector. A nozzle can be used to convert the pressure to velocity, to produce a jet, as for firefighting. Fire fighting force pumps usually have two cylinders feeding one receiver alternately. The air space in the receiver helps to make the water pressure uniform.

The three pumps below are typically used for air, but would be equally applicable to liquids. The Roots blower has no valves, their place taken by the sliding contact between the rotors and the housing. The Roots blower can either exhaust a receiver or provide air under moderate pressure, in large volumes. The Bellows is a very old device, requiring no accurate machining. The single valve is in one or both sides of the expandable chamber. Another valve can be placed at the nozzle if required. The valve can be a piece of soft leather held close to holes in the chamber. The Bicycle pump uses the valve on the valve stem of the tire or inner tube to hold pressure in the tire. The piston, which is attached to the discharge tube, has a flexible seal that seals when the cylinder is moved to compress the air, but allows air to pass when the movement is reversed.

Diaphragm and vane pumps are not shown, but they act the same way by varying the volume of a chamber, and directing the flow with check valves.



Types of Pumps

The family of pumps comprises a large number of types based on application and capabilities. The two major groups of pumps are dynamic and positive displacement.

Dynamic Pumps (Centrifugal Pump)

Centrifugal pumps are classified into three general categories:
Radial flow—a centrifugal pump in which the pressure is developed wholly by centrifugal force.
Mixed flow—a centrifugal pump in which the pressure is developed partly by centrifugal force and partly by the lift of the vanes of the impeller on the liquid.
Axial flow—a centrifugal pump in which the pressure is developed by the propelling or lifting action of the vanes of the impeller on the liquid.

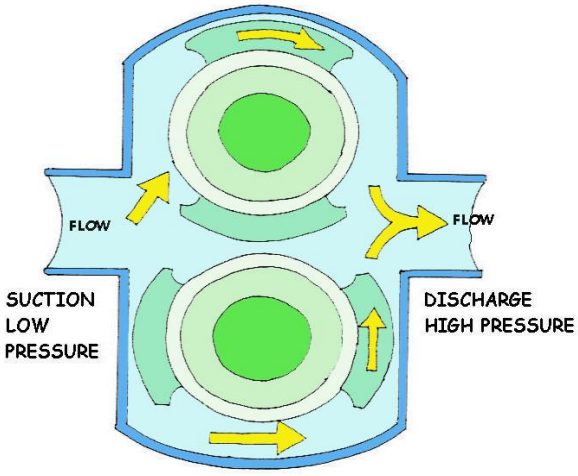
Positive Displacement Pumps

A Positive Displacement Pump has an expanding cavity on the suction side of the pump and a decreasing cavity on the discharge side. Liquid is allowed to flow into the pump as the cavity on the suction side expands and the liquid is forced out of the discharge as the cavity collapses. This principle applies to all types of Positive Displacement Pumps whether the pump is a rotary lobe, gear within a gear, piston, diaphragm, screw, progressing cavity, etc.

A Positive Displacement Pump, unlike a Centrifugal Pump, will produce the same flow at a given RPM no matter what the discharge pressure is. A Positive Displacement Pump cannot be operated against a closed valve on the discharge side of the pump, i.e. it does not have a shut-off head like a Centrifugal Pump does. If a Positive Displacement Pump is allowed to operate against a closed discharge valve it will continue to produce flow which will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.

Types of Positive Displacement Pumps

Single Rotor	Multiple Rotor
Vane	Gear
Piston	Lobe
Flexible Member	Circumferential Piston
Single Screw	Multiple Screw



There are many types of positive displacement pumps. We will look at:

- Plunger pumps
- Diaphragm pumps
- Progressing cavity pumps, and
- Screw pumps

Single Rotator

Component	Description
Vane	The vane(s) may be blades, buckets, rollers, or slippers that cooperate with a dam to draw fluid into and out of the pump chamber.
Piston	Fluid is drawn in and out of the pump chamber by a piston(s) reciprocating within a cylinder(s) and operating port valves.
Flexible Member	Pumping and sealing depends on the elasticity of a flexible member(s) that may be a tube, vane, or a liner.
Single Screw	Fluid is carried between rotor screw threads as they mesh with internal threads on the stator.

Multiple Rotator

Component	Description
Gear	Fluid is carried between gear teeth and is expelled by the meshing of the gears that cooperate to provide continuous sealing between the pump inlet and outlet.
Lobe	Fluid is carried between rotor lobes that cooperate to provide continuous sealing between the pump inlet and outlet.
Circumferential piston	Fluid is carried in spaces between piston surfaces not requiring contacts between rotor surfaces.
Multiple Screw	Fluid is carried between rotor screw threads as they mesh.

What kind of mechanical device do you think is used to provide this positive displacement in the:

Plunger pump?

Diaphragm pump?

In the same way, the progressing cavity and the screw are two other types of mechanical action that can be used to provide movement of the liquid through the pump.

Plunger Pump
The plunger pump is a positive displacement pump that uses a plunger or piston to force liquid from the suction side to the discharge side of the pump. It is used for heavy sludge. The movement of the plunger or piston inside the pump creates pressure inside the pump, so you have to be careful that this kind of pump is never operated against any closed discharge valve.

All discharge valves must be open before the pump is started, to prevent any fast build-up of pressure that could damage the pump.

Diaphragm Pumps
In this type of pump, a diaphragm provides the mechanical action used to force liquid from the suction to the discharge side of the pump. The advantage the diaphragm has over the plunger is that the diaphragm pump does not come in contact with moving metal. This can be important when pumping abrasive or corrosive materials.

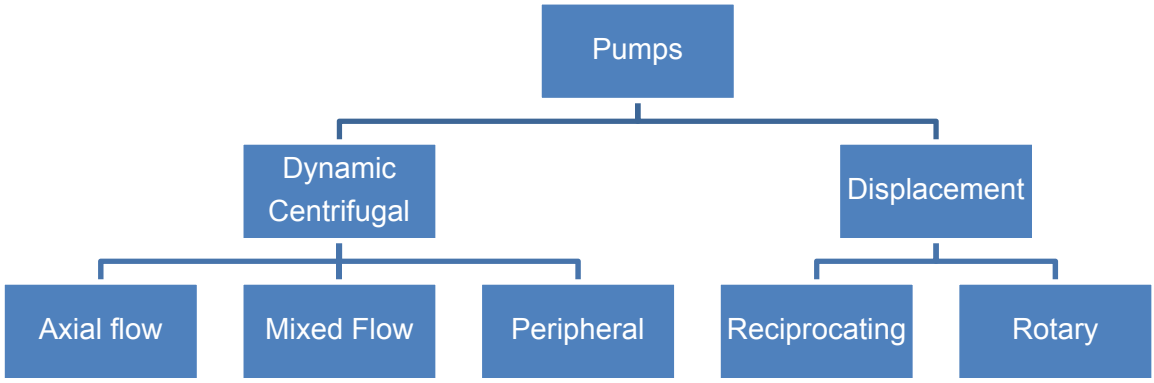
There are three main types of diaphragm pumps available:

1. Diaphragm sludge pump
2. Chemical metering or proportional pump
3. Air-powered double-diaphragm pump

Pump Categories

Let's cover the essentials first. The key to the whole operation is, of course, the *pump.* And regardless of what type it is (reciprocating piston, centrifugal, turbine or jet-ejector, for either shallow or deep well applications), its purpose is to move water and generate the delivery force we call pressure. Sometimes — with centrifugal pumps in particular — pressure is not referred to in pounds per square inch but rather as the equivalent in elevation, called head. No matter; head in feet divided by 2.31 equals pressure, so it's simple enough to establish a common figure.

Pumps may be classified on the basis of the application they serve. All pumps may be divided into two major categories: (1) dynamic, in which energy is continuously added to increase the fluid velocities within the machine, and (2) displacement, in which the energy is periodically added by application of force.





Split-case centrifugal pump.

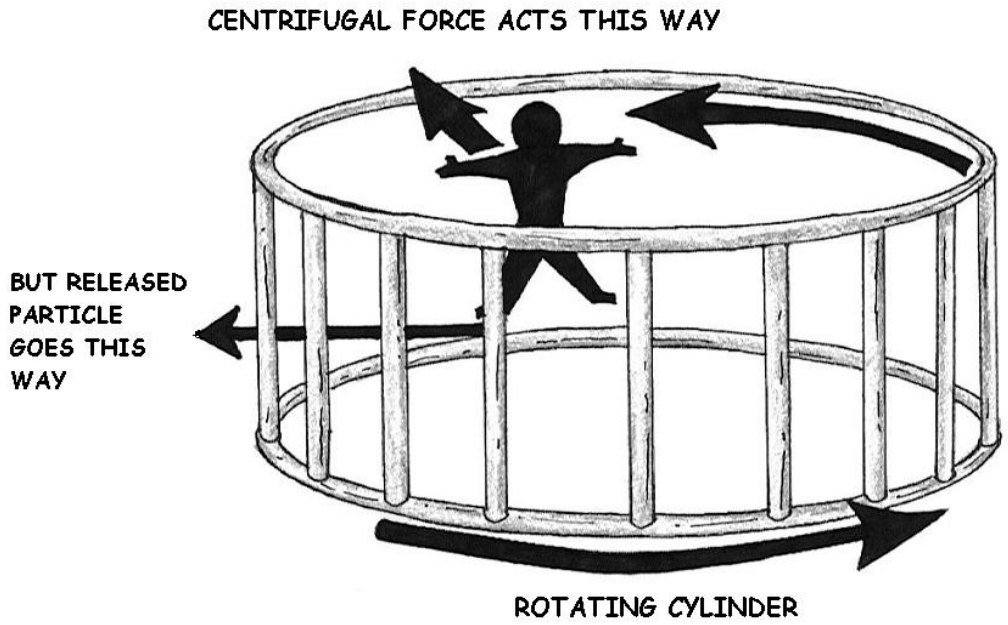


BFP – 12 inch diameter multi-bowl vertical turbine well pump.

Understanding the Water Pump

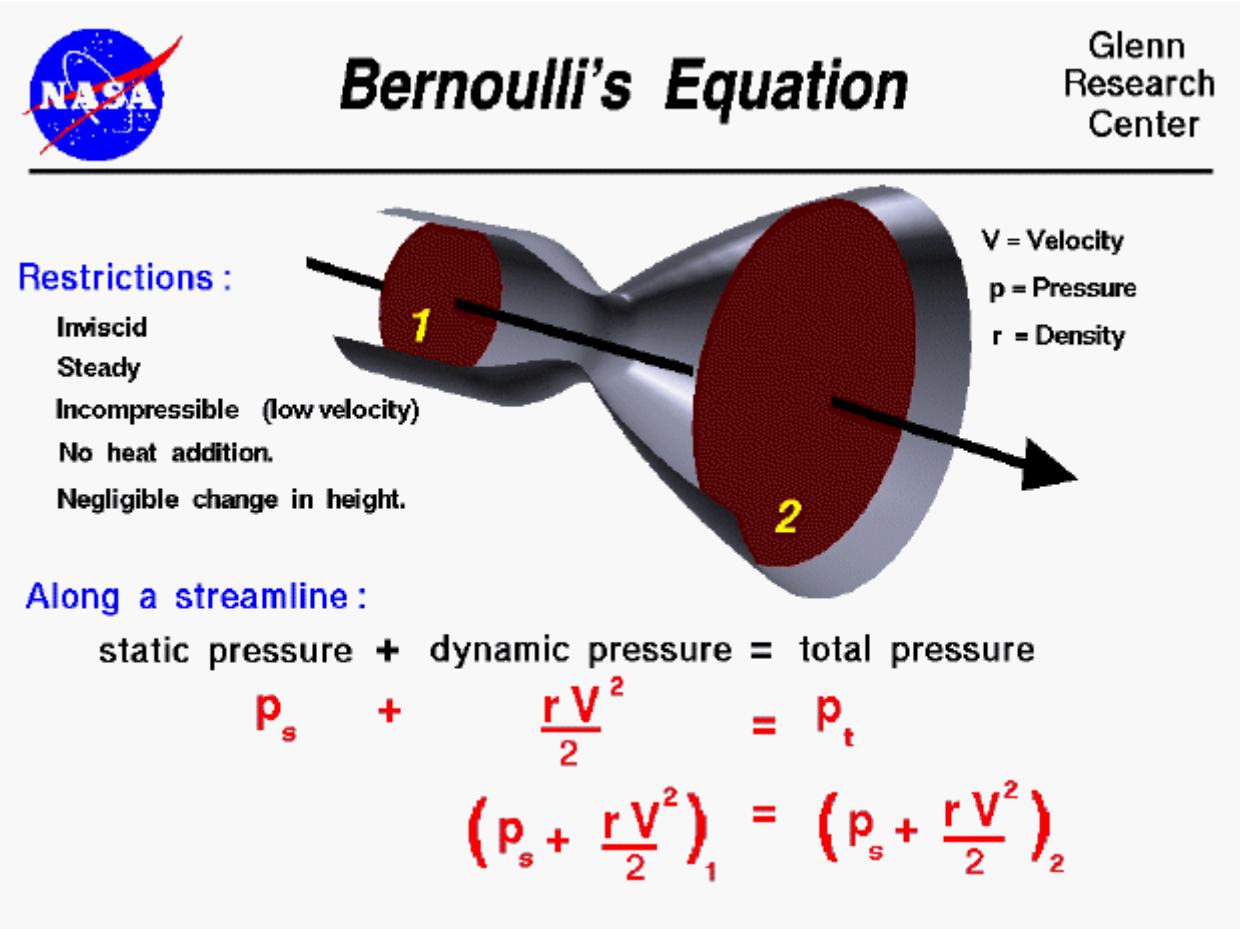
The water pump commonly found in our systems is centrifugal pumps. These pumps work by spinning water around in a circle inside a cylindrical pump housing. The pump makes the water spin by pushing it with an impeller. The blades of this impeller project outward from an axle like the arms of a turnstile and, as the impeller spins, the water spins with it. As the water spins, the pressure near the outer edge of the pump housing becomes much higher than near the center of the impeller.

There are many ways to understand this rise in pressure, and here are two:

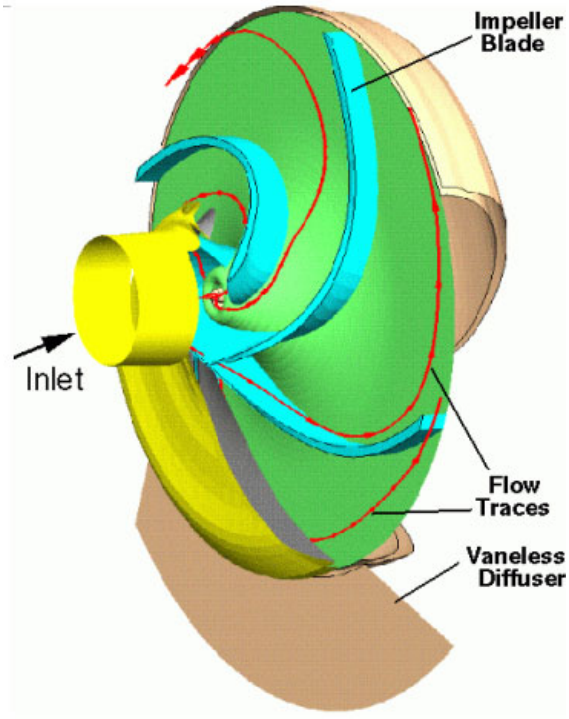


First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin. Without such an inward force, an object will travel in a straight line and will not complete the circle. In a centrifugal pump, that inward force is provided by high-pressure water near the outer edge of the pump housing. The water at the edge of the pump pushes inward on the water between the impeller blades and makes it possible for that water to travel in a circle. The water pressure at the edge of the turning impeller rises until it is able to keep water circling with the impeller blades.

You can also view the water as an incompressible fluid, one that obeys Bernoulli's equation in the appropriate contexts. As water drifts outward between the impeller blades of the pump, it must move faster and faster because its circular path is getting larger and larger. The impeller blades cause the water to move faster and faster. By the time the water has reached the outer edge of the impeller, it is moving quite fast. However, when the water leaves the impeller and arrives at the outer edge of the cylindrical pump housing, it slows down.



Here is where Bernoulli's equation figures in. As the water slows down and its kinetic energy decreases, that water's pressure potential energy increases (***to conserve energy***). Thus, the slowing is accompanied by a pressure rise. That is why the water pressure at the outer edge of the pump housing is higher than the water pressure near the center of the impeller. When water is actively flowing through the pump, arriving through a hole near the center of the impeller and leaving through a hole near the outer edge of the pump housing, the pressure rise between center and edge of the pump is not as large.



Types of Water Pumps

The most common type of water pumps used for municipal and domestic water supplies are *variable displacement* pumps. A variable displacement pump will produce at different rates relative to the amount of pressure or lift the pump is working against. *Centrifugal* pumps are variable displacement pumps that are by far used the most. The water production well industry almost exclusively uses *Turbine* pumps, which are a type of centrifugal pump.

The turbine pump utilizes *impellers* enclosed in single or multiple *bowls or stages* to lift water by *centrifugal force*. The impellers may be of either a *semi-open or closed type*. Impellers are rotated by the *pump motor*, which provides the horsepower needed to overcome the pumping head. A more thorough discussion of how these and other pumps work is presented later in this section. The size and number of stages, horsepower of the motor and pumping head are the key components relating to the pump's lifting capacity.

Vertical turbine pumps are commonly used in groundwater wells. These pumps are driven by a shaft rotated by a motor on the surface. The shaft turns the impellers within the pump housing while the water moves up the column.

This type of pumping system is also called a *line-shaft turbine*. The rotating shaft in a line shaft turbine is actually housed within the column pipe that delivers the water to the surface. The size of the column, impeller, and bowls are selected based on the desired pumping rate and lift requirements.

Column pipe sections can be threaded or coupled together while the drive shaft is coupled and suspended within the column by *spider bearings*. The spider bearings provide both a seal at the column pipe joints and keep the shaft aligned within the column. The water passing through the column pipe serves as the lubricant for the bearings. Some vertical turbines are lubricated by oil rather than water. These pumps are essentially the same as water lubricated units; only the drive shaft is enclosed within an *oil tube*.

Food grade oil is supplied to the tube through a gravity feed system during operation. The oil tube is suspended within the column by *spider flanges,* while the line shaft is supported within the oil tube by *brass or redwood bearings*. A continuous supply of oil lubricates the drive shaft as it proceeds downward through the oil tube.

A small hole located at the top of the pump bow unit allows excess oil to enter the well. This results in the formation of an oil film on the water surface within oil-lubricated wells. Careful operation of oil lubricated turbines is needed to ensure that the pumping levels do not drop enough to allow oil to enter the pump. Both water and oil lubricated turbine pump units can be driven by electric or fuel powered motors. Most installations use an electric motor that is connected to the drive shaft by a keyway and nut. However, where electricity is not readily available, fuel powered engines may be connected to the drive shaft by a right angle drive gear. Also, both oil and water lubricated systems will have a strainer attached to the intake to prevent sediment from entering the pump.

When the line shaft turbine is turned off, water will flow back down the column, turning the impellers in a reverse direction. A pump and shaft can easily be broken if the motor were to turn on during this process. This is why a *time delay* or *ratchet* assembly is often installed on these motors to either prevent the motor from turning on before reverse rotation stops or simply not allow it to reverse at all.

There are three main types of diaphragm pumps:
In the first type, the diaphragm is sealed with one side in the fluid to be pumped, and the other in air or hydraulic fluid. The diaphragm is flexed, causing the volume of the pump chamber to increase and decrease. A pair of non-return check valves prevents reverse flow of the fluid.

As described above, the second type of diaphragm pump works with volumetric positive displacement, but differs in that the prime mover of the diaphragm is neither oil nor air; but is electro-mechanical, working through a crank or geared motor drive. This method flexes the diaphragm through simple mechanical action, and one side of the diaphragm is open to air. The third type of diaphragm pump has one or more unsealed diaphragms with the fluid to be pumped on both sides. The diaphragm(s) again are flexed, causing the volume to change.

When the volume of a chamber of either type of pump is increased (the diaphragm moving up), the pressure decreases, and fluid is drawn into the chamber. When the chamber pressure later increases from decreased volume (the diaphragm moving down), the fluid previously drawn in is forced out. Finally, the diaphragm moving up once again draws fluid into the chamber, completing the cycle. This action is similar to that of the cylinder in an internal combustion engine.

Cavitation
Cavitation is defined as the phenomenon of formation of vapor bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation and non-inertial cavitation. Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Such cavitation often occurs in pumps, propellers, impellers, and in the vascular tissues of plants. Non-inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers etc.

Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. When the cavitation bubbles collapse, they force liquid energy into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are a source of noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar. Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller's or pump's lifetime. After a surface is initially affected by cavitation, it tends to erode at an accelerating pace. The cavitation pits increase the turbulence of the fluid flow and create crevasses that act as nucleation sites for additional cavitation bubbles. The pits also increase the component's surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

Impeller
An impeller is a rotating component of a centrifugal pump, usually made of iron, steel, aluminum or plastic, which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the center of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. Impellers are usually short cylinders with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radically, and a splined center to accept a driveshaft.

Submersible Pumps

Submersible pumps are in essence very similar to turbine pumps. They both use impellers rotated by a shaft within the bowls to pump water. However, the pump portion is directly connected to the motor.

The pump shaft has a keyway in which the splined motor end shaft inserts. The motor is bolted to the pump housing. The pump's intake is located between the motor and the pump and is normally screened to prevent sediment from entering the pump and damaging the impellers.

The efficient cooling of submersible motors is very important, so these types of pumps are often installed such that flow through the well screen can occur upwards past the motor and into the intake. If the motor end is inserted below the screened interval or below all productive portions of the aquifer, it will not be cooled, resulting in premature motor failure.

Some pumps may have *pump shrouds* installed on them to force all the water to move past the motor to prevent overheating.

The shroud is a piece of pipe that attaches to the pump housing with an open end below the motor. As with turbine pumps, the size of the bowls and impellers, number of stages, and horsepower of the motor are adjusted to achieve the desired production rate within the limitations of the pumping head.



Cut away of a small submersible pump.



Insertion of motor spline into the pump keyway.

Key Pump Words

NPSH: Net positive suction head - related to how much suction lift a pump can achieve by creating a partial vacuum. Atmospheric pressure then pushes liquid into the pump. A method of calculating if the pump will work or not.

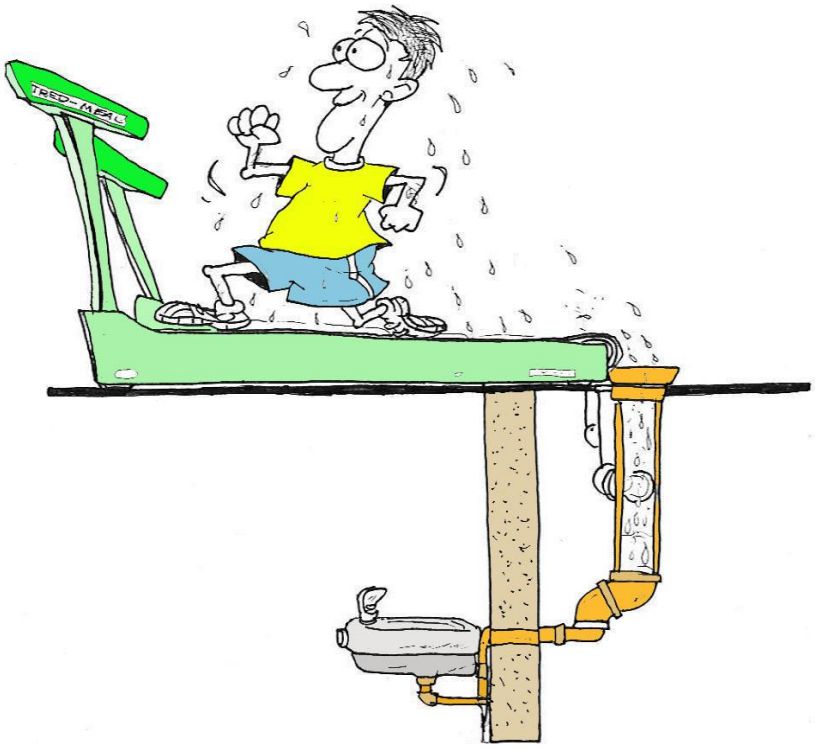
S.G.: Specific gravity. The weight of liquid in comparison to water at approx. 20 degrees C (SG = 1).

Specific Speed: A number which is the function of pump flow, head, efficiency etc. Not used in day to day pump selection, but very useful, as pumps with similar specific speed will have similar shaped curves, similar efficiency / NPSH / solids handling characteristics.

Vapor Pressure: If the vapor pressure of a liquid is greater than the surrounding air pressure, the liquid will boil.

Viscosity: A measure of a liquid's resistance to flow. i.e.: how thick it is. The viscosity determines the type of pump used, the speed it can run at, and with gear pumps, the internal clearances required.

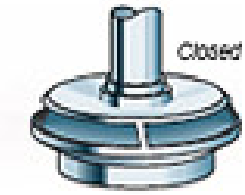
Friction Loss: The amount of pressure / head required to 'force' liquid through pipe and fittings.



Understanding the Operation of a Vertical Turbine Pump



Vertical turbine pumps are available in deep well, shallow well, or canned configurations. VHS or VSS motors will be provided to fulfill environmental requirements. Submersible motors are also available. These pumps are also suitable industrial, municipal, commercial and agricultural applications.



Deep well turbine pumps are adapted for use in cased wells or where the water surface is below the practical limits of a centrifugal pump. Turbine pumps are also used with surface water systems. Since the intake for the turbine pump is continuously under water, priming is not a concern. Turbine pump efficiencies are comparable to, or greater than most centrifugal pumps. They are usually more expensive than centrifugal pumps and more difficult to inspect and repair. The turbine pump has three main parts: (1) the head assembly, (2) the shaft and column assembly and (3) the pump bowl assembly. The head is normally cast iron and designed to be installed on a foundation. It supports the column, shaft, and bowl assemblies, and provides a discharge for the water. It also will support either an electric motor, a right angle gear drive or a belt drive.

Bowl Assembly
The bowl assembly is the heart of the vertical turbine pump. The impeller and diffuser type casing is designed to deliver the head and capacity that the system requires in the most efficient way. Vertical turbine pumps can be multi-staged, allowing maximum flexibility both in the initial pump selection and in the event that future system modifications require a change in the pump rating. The submerged impellers allow the pump to be started without priming. The discharge head changes the direction of flow from vertical to horizontal, and couples the pump to the system piping, in addition to supporting and aligning the driver.

Drivers
A variety of drivers may be used; however, electric motors are most common. For the purposes of this manual, all types of drivers can be grouped into two categories:
1. Hollow shaft drivers where the pump shaft extends through a tube in the center of the rotor and is connected to the driver by a clutch assembly at the top of the driver.
2. Solid shaft drivers where the rotor shaft is solid and projects below the driver mounting base. This type of driver requires an adjustable flanged coupling for connecting to the pump.

Discharge Head Assembly
The discharge head supports the driver and bowl assembly as well as supplying a discharge connection (the "**NUF**" type discharge connection which will be located on one of the column pipe sections below the discharge head). A shaft sealing arrangement is located in the discharge head to seal the shaft where it leaves the liquid chamber. The shaft seal will usually be either a mechanical seal assembly or stuffing box.

Column Assembly
The shaft and column assembly provides a connection between the head and pump bowls. The line shaft transfers the power from the motor to the impellers and the column carries the water to the surface. The line shaft on a turbine pump may be either water lubricated or oil lubricated.
The oil-lubricated pump has an enclosed shaft into which oil drips, lubricating the bearings. The water-lubricated pump has an open shaft. The bearings are lubricated by the pumped water. If there is a possibility of fine sand being pumped, select the oil lubricated pump because it will keep the sand out of the bearings. If the water is for domestic or livestock use, it must be free of oil and a water-lubricated pump must be used.

Line shaft bearings are commonly placed on 10-foot centers for water-lubricated pumps operating at speeds under 2,200 RPM and at 5-foot centers for pumps operating at higher speeds. Oil-lubricated bearings are commonly placed on 5-foot centers.

A pump bowl encloses the impeller. Due to its limited diameter, each impeller develops a relatively low head. In most deep well turbine installations, several bowls are stacked in series one above the other. This is called staging. A four-stage bowl assembly contains four impellers, all attached to a common shaft and will operate at four times the discharge head of a single-stage pump.

Impellers used in turbine pumps may be either semi-open or enclosed. The vanes on semi-open impellers are open on the bottom and they rotate with a close tolerance to the bottom of the pump bowl. The tolerance is critical and must be adjusted when the pump is new. During the initial break-in period the line shaft couplings will tighten, therefore, after about 100 hours of operation, the impeller adjustments should be checked. After break-in, the tolerance must be checked and adjusted every three to five years or more often if pumping sand.

Column assembly is of two basic types, either of which may be used:
1. Open lineshaft construction utilizes the fluid being pumped to lubricate the lineshaft bearings.
2. Enclosed lineshaft construction has an enclosing tube around the lineshaft and utilizes oil, grease or injected liquid (usually clean water) to lubricate the lineshaft bearings.

Column assembly will consist of:
1) column pipe, which connects the bowl assembly to the discharge head,
2) shaft, connecting the bowl shaft to the driver and,
3) may contain bearings, if required, for the particular unit. Column pipe may be either threaded or flanged.
Note: Some units will not require column assembly, having the bowl assembly connected directly to the discharge head instead.

Bowl Assemblies
The bowl consists of:
1) impellers rigidly mounted on the bowl shaft, which rotate and impart energy to the fluid,
2) bowls to contain the increased pressure and direct the fluid,
3) suction bell or case which directs the fluid into the first impeller, and
4) bearings located in the suction bell (or case) and in each bowl.

Both types of impellers may cause inefficient pump operation if they are not properly adjusted. Mechanical damage will result if the semi-open impellers are set too low and the vanes rub against the bottom of the bowls. The adjustment of enclosed impellers is not as critical; however, they must still be checked and adjusted.

Impeller adjustments are made by tightening or loosening a nut on the top of the head assembly. Impeller adjustments are normally made by lowering the impellers to the bottom of the bowls and adjusting them upward. The amount of upward adjustment is determined by how much the line shaft will stretch during pumping. The adjustment must be made based on the lowest possible pumping level in the well. The proper adjustment procedure if often provided by the pump manufacturer.

Basic Operation of a Vertical Turbine

Pre-start
Before starting the pump, the following checks should be made:
1. Rotate the pump shaft by hand to make sure the pump is free and the impellers are correctly positioned.
2. Is the head shaft adjusting nut properly locked into position?
3. Has the driver been properly lubricated in accordance with the instructions furnished with the driver?
4. Has the driver been checked for proper rotation? If not, the pump must be disconnected from the driver before checking. The driver must rotate COUNTER CLOCKWISE when looking down at the top of the driver.
5. Check all connections to the driver and control equipment.
6. Check that all piping connections are tight.
7. Check all anchor bolts for tightness.
8. Check all bolting and tubing connections for tightness (driver mounting bolts, flanged coupling bolts, glad plate bolts, seal piping, etc.).
9. On pumps equipped with stuffing box, make sure the gland nuts are only finger tight — DO NOT TIGHTEN packing gland before starting.
10. On pumps equipped with mechanical seals, clean fluid should be put into the seal chamber. With pumps under suction pressure this can be accomplished by bleeding all air and vapor out of the seal chamber and allowing the fluid to enter. With pumps not under suction pressure, the seal chamber should be flushed liberally with clean fluid to provide initial lubrication. Make sure the mechanical seal is properly adjusted and locked
into place.

NOTE: After initial start-up, pre-lubrication of the mechanical seal will usually not be required, as enough liquid will remain in the seal chamber for subsequent start-up lubrication.
11. On pumps equipped with enclosed lineshaft, lubricating liquid must be available and should be allowed to run into the enclosing tube in sufficient quantity to thoroughly lubricate all lineshaft bearings.

Initial Start-Up
1. If the discharge line has a valve in it, it should be partially open for initial starting — Min. 10%.
2. Start lubrication liquid flow on enclosed lineshaft units.
3. Start the pump and observe the operation. If there is any difficulty, excess noise or vibration, stop the pump immediately.
4. Open the discharge valve as desired.
5. Check complete pump and driver for leaks, loose connections or improper operation.
6. If possible, the pump should be left running for approximately ½ hour on the initial start-up. This will allow the bearings, packing or seals, and other parts to “run-in” and reduce the possibility of trouble on future starts.

NOTE: If abrasives or debris are present upon startup, the pump should be allowed to run until the pumpage is clean. Stopping the pump when handling large amounts of abrasives (as sometimes present on initial starting) may lock the pump and cause more damage than if the pump is allowed to continue operation.

CAUTION: Every effort should be made to keep abrasives out of lines, sumps, etc. so that abrasives will not enter the pump.

Stuffing Box Adjustment
On the initial starting it is very important that the packing gland not be tightened too much. New packing must be "run in" properly to prevent damage to the shaft and shortening of the packing life. The stuffing box must be allowed to leak for proper operation. The proper amount of leakage can be determined by checking the temperature of the leakage; this should be cool or just lukewarm — NOT HOT. When adjusting the packing gland, bring both nuts down evenly and in small steps until the leakage is reduced as required. The nuts should only be tightened about ½ turn at a time at 20 to 30 minute intervals to allow the packing to "run in". Under proper operation, a set of packing will last a long time. Occasionally a new ring of packing will need to be added to keep the box full. After adding two or three rings of packing, or when proper adjustment cannot be achieved, the stuffing box should be cleaned completely of all old packing and re-packed.

Lineshaft Lubrication
Open lineshaft bearings are lubricated by the pumped fluid and on close coupled units (less than 30' long), will usually not require pre or post lubrication. Enclosed lineshaft bearings are lubricated by extraneous liquid (usually oil or clean water), which is fed to the tension nut by either a gravity flow system or pressure injection system. The gravity flow system utilizing oil is the most common arrangement. The oil reservoir must be kept filled with a good quality light turbine oil (about 150 SSU at operating temperature) and adjusted to feed 10 to 12 drops per minute plus one (1) drop per 100' of setting. Injection systems are designed for each installation — injection pressure and quantity of lubricating liquid will vary. Refer to packing slip or separate instruction sheet for requirements when unit is designed for injection lubrication.

General Maintenance Section
A periodic inspection is recommended as the best means of preventing breakdown and keeping maintenance costs to a minimum. Maintenance personnel should look over the whole installation with a critical eye each time the pump is inspected — a change in noise level, amplitude or vibration, or performance can be an indication of impending trouble. Any deviation in performance or operation from what is expected can be traced to some specific cause. Determination of the cause of any misperformance or improper operation is essential to the correction of the trouble — whether the correction is done by the user, the dealer or reported back to the factory. Variances from initial performance will indicate changing system conditions or wear or impending breakdown of unit.

Deep well turbine pumps must have correct alignment between the pump and the power unit. Correct alignment is made easy by using a head assembly that matches the motor and column/pump assembly. It is very important that the well is straight and plumb. The pump column assembly must be vertically aligned so that no part touches the well casing. Spacers are usually attached to the pump column to prevent the pump assembly from touching the well casing. If the pump column does touch the well casing, vibration will wear holes in the casing. A pump column out of vertical alignment may also cause excessive bearing wear.

The head assembly must be mounted on a good foundation at least 12 inches above the ground surface. A foundation of concrete provides a permanent and trouble-free installation. The foundation must be large enough to allow the head assembly to be securely fastened. The foundation should have at least 12 inches of bearing surface on all sides of the well. In the case of a gravel-packed well, the 12-inch clearance is measured from the outside edge of the gravel packing.

Vertical Turbine Pump



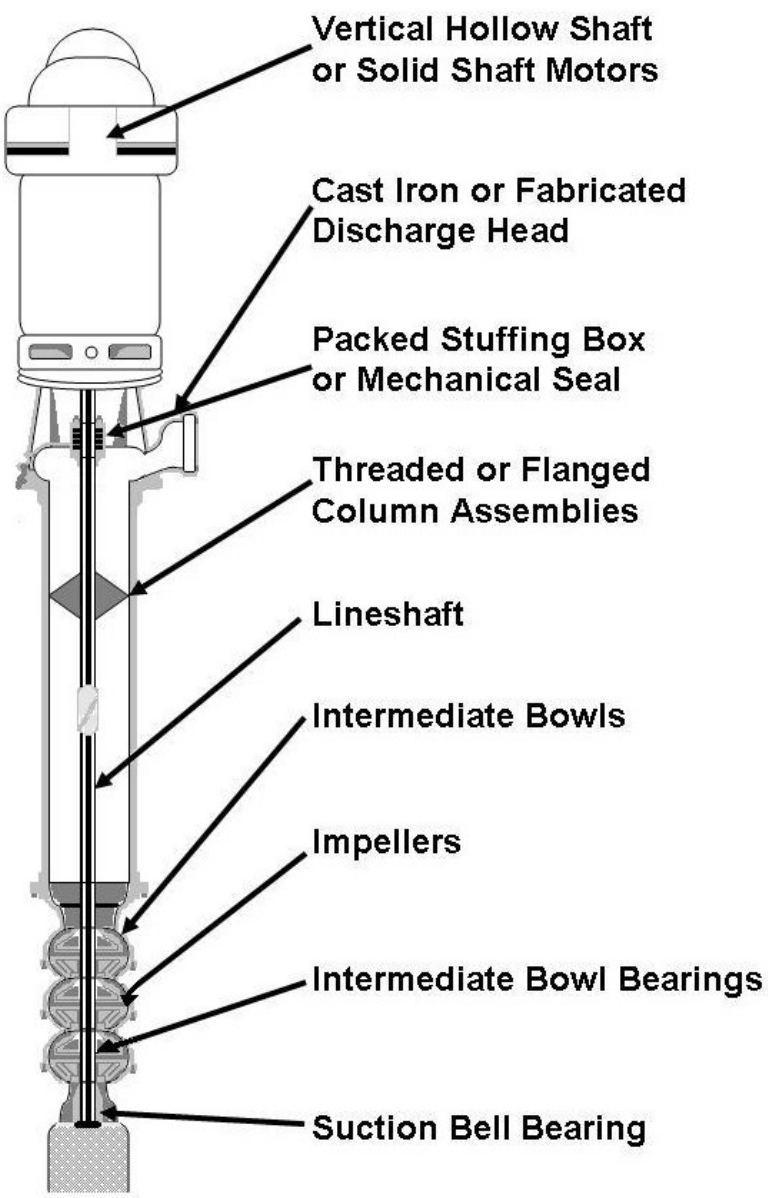


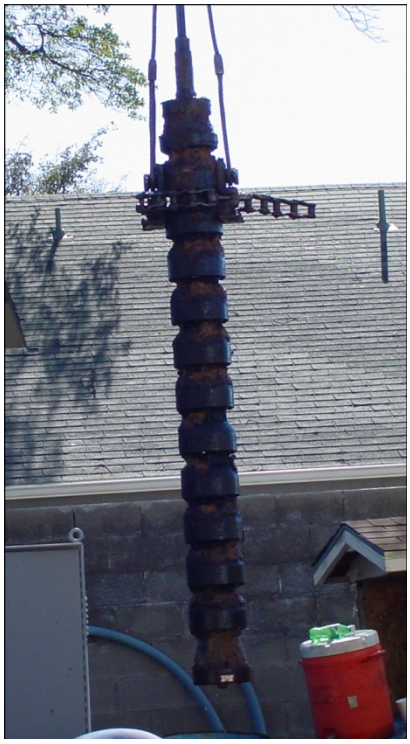


Large Diameter Submersible Pump, Motor, and Column Pipe

Larger check valve installed on submersible pump to prevent water hammer (notice motor shaft splines.)

Common Elements of Vertical Turbines





Above, Vertical Turbine
Pump Being Removed
(Notice line shaft)

Below
Closed Pump Impeller



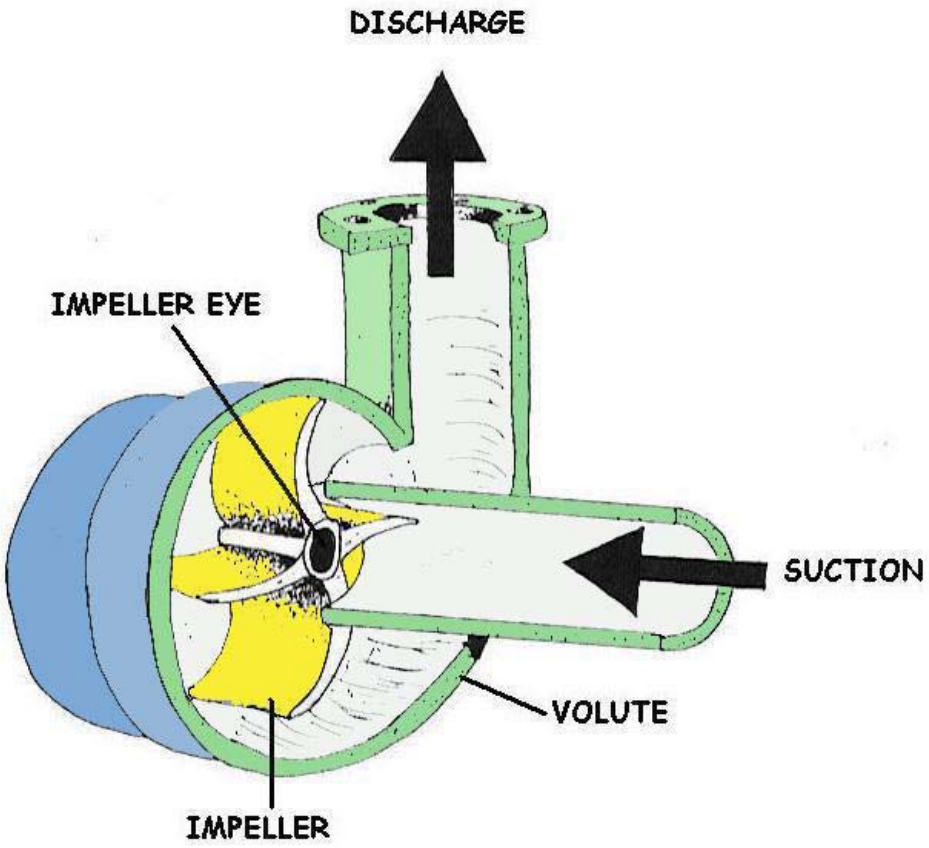
Centrifugal Pump

By definition, a centrifugal pump is a machine. More specifically, it is a machine that imparts energy to a fluid. This energy infusion can cause a liquid to flow, rise to a higher level, or both.

The centrifugal pump is an extremely simple machine. It is a member of a family known as rotary machines and consists of two basic parts: 1) the rotary element or impeller and 2) the stationary element or casing (volute). The figure at the bottom of the page is a cross section of a centrifugal pump and shows the two basic parts.

In operation, a centrifugal pump "slings" liquid out of the impeller via centrifugal force. One fact that must always be remembered: A pump does not create pressure, it only provides flow. Pressure is just an indication of the amount of resistance to flow.

Centrifugal pumps may be classified in several ways. For example, they may be either SINGLE STAGE or MULTI-STAGE. A single-stage pump has only one impeller. A multi-stage pump has two or more impellers housed together in one casing.



As a rule, each impeller acts separately, discharging to the suction of the next stage impeller. This arrangement is called series staging. Centrifugal pumps are also classified as HORIZONTAL or VERTICAL, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as SINGLE SUCTION or DOUBLE SUCTION. The single-suction impeller allows liquid to enter the eye from one side only. The double-suction impeller allows liquid to enter the eye from two directions.

Impellers are also classified as CLOSED or OPEN. Closed impellers have side walls that extend from the eye to the outer edge of the vane tips. Open impellers do not have these side walls. Some small pumps with single-suction impellers have only a casing wearing ring and no impeller ring. In this type of pump, the casing wearing ring is fitted into the end plate.

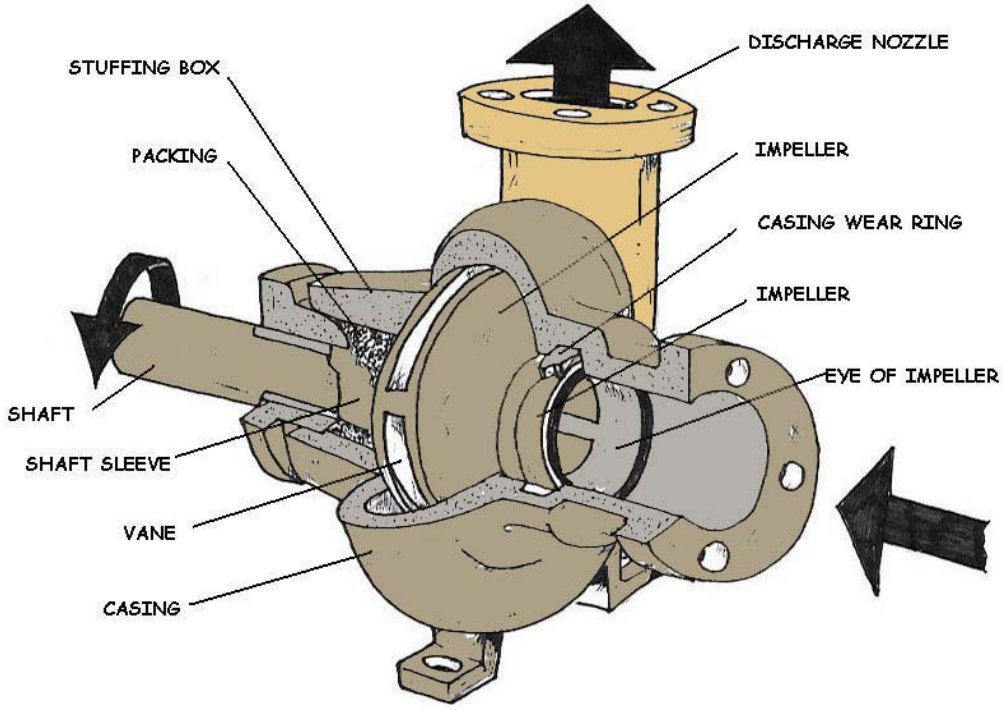
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

Seal piping is installed to cool the shaft and the packing, to lubricate the packing, and to seal the rotating joint between the shaft and the packing against air leakage. A lantern ring spacer is inserted between the rings of the packing in the stuffing box.

Seal piping leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft (between the shaft and the packing).

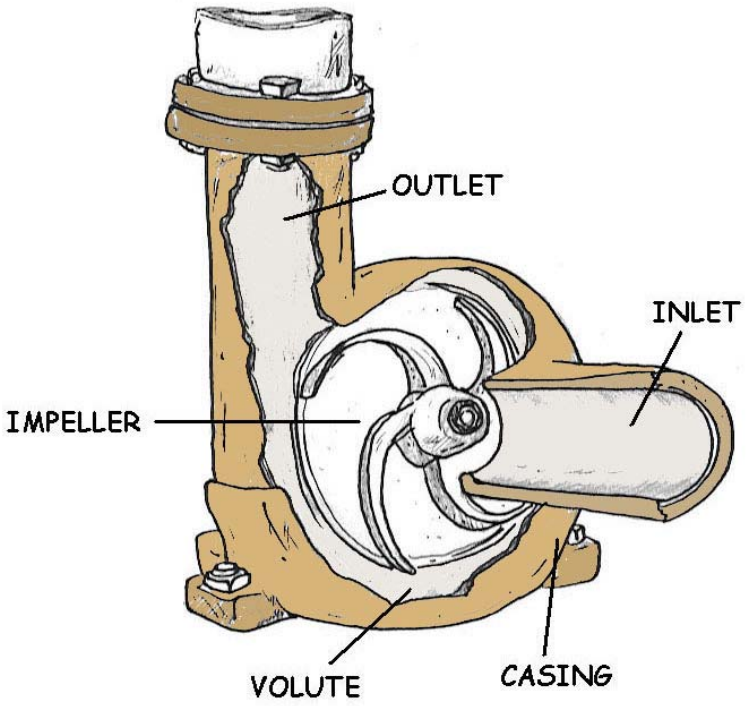
Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

Look at the components of the centrifugal pump.

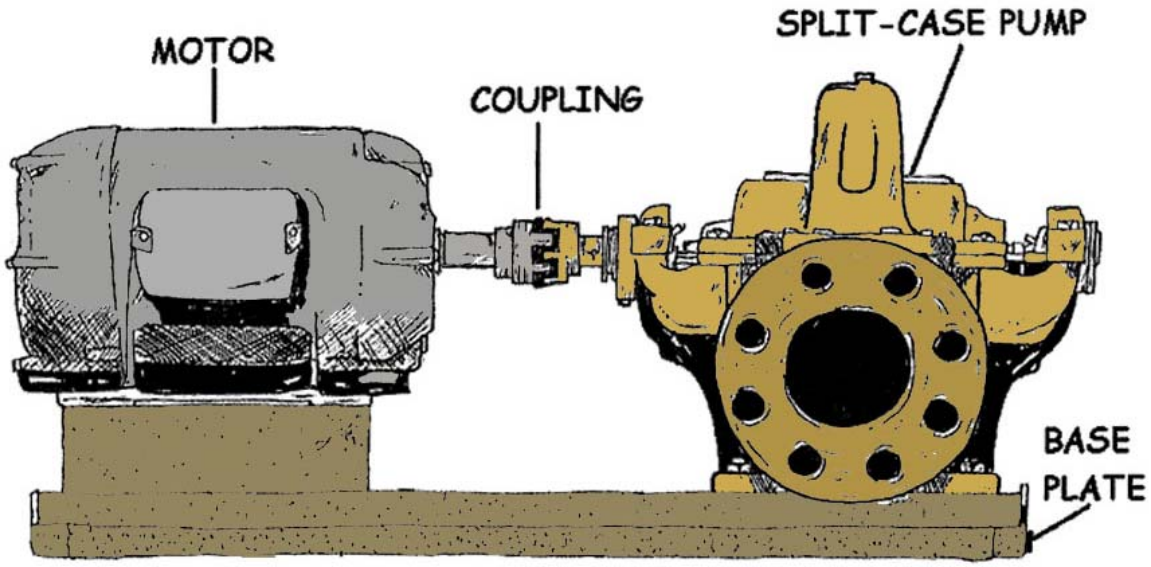


Centrifugal Pump

As the impeller rotates, it sucks the liquid into the center of the pump and throws it out under pressure through the outlet. The casing that houses the impeller is referred to as the volute, the impeller fits on the shaft inside. The volute has an inlet and outlet that carries the water as shown above.



These pictures illustrate the components that are common to most pump assemblies.



NPSH - Net Positive Suction Head

If you accept that a pump creates a partial vacuum and atmospheric pressure forces water into the suction of the pump, then you will find NPSH a simple concept.

NPSH (a) is the Net Positive Suction Head Available, which is calculated as follows:

NPSH (a) = p + s - v - f

Where:
'p'= atmospheric pressure,
's'= static suction (If liquid is below pump, it is shown as a negative value)
'v'= liquid vapor pressure
'f'= friction loss

NPSH (a) must exceed NPSH(r) to allow pump operation without cavitation. (It is advisable to allow approximately 1 meter difference for most installations.) The other important fact to remember is that water will boil at much less than 100 deg C^{O} if the pressure acting on it is less than its vapor pressure, i.e. water at 95 deg C is just hot water at sea level, but at 1500m above sea level it is boiling water and vapor.

The vapor pressure of water at 95 deg C is 84.53 kPa, there was enough atmospheric pressure at sea level to contain the vapor, but once the atmospheric pressure dropped at the higher elevation, the vapor was able to escape. This is why vapor pressure is always considered in NPSH calculations when temperatures exceed 30 to 40 deg C.

NPSH(r) is the Net Positive Suction Head Required by the pump, which is read from the pump performance curve. (Think of NPSH(r) as friction loss caused by the entry to the pump suction.)

Affinity Laws

The Centrifugal Pump is a very capable and flexible machine. Because of this it is unnecessary to design a separate pump for each job. The performance of a centrifugal pump can be varied by changing the impeller diameter or its rotational speed. Either change produces approximately the same results. Reducing impeller diameter is probably the most common change and is usually the most economical. The speed can be altered by changing pulley diameters or by changing the speed of the driver. In some cases both speed and impeller diameter are changed to obtain the desired results.

When the driven speed or impeller diameter of a centrifugal pump changes, operation of the pump changes in accordance with three fundamental laws. These laws are known as the "Laws of Affinity". They state that:
1) Capacity varies directly as the change in speed
2) Head varies as the square of the change in speed
3) Brake horsepower varies as the cube of the change in speed
If, for example, the pump speed were doubled:
1) Capacity will double
2) Head will increase by a factor of 4 (2 to the second power)
3) Brake horsepower will increase by a factor of 8 (2 to the third power)
These principles apply regardless of the direction (up or down) of the speed or change in diameter.

Consider the following example. A pump operating at 1750 RPM, delivers 210 GPM at 75' TDH, and requires 5.2 brake horsepower. What will happen if the speed is increased to 2000 RPM? First we find the speed ratio.

Speed Ratio = 2000/1750 = 1.14

From the laws of Affinity:
1) Capacity varies directly or:
1.14 X 210 GPM = 240 GPM
2) Head varies as the square or:

1.14 X 1.14 X 75 = 97.5' TDH
3) BHP varies as the cube or:

1.14 X 1.14 X 1.14 X 5.2 = 7.72 BHP
Theoretically the efficiency is the same for both conditions. By calculating several points a new curve can be drawn.

Whether it be a speed change or change in impeller diameter, the Laws of Affinity give results that are approximate. The discrepancy between the calculated values and the actual values obtained in test are due to hydraulic efficiency changes that result from the modification. The Laws of Affinity give reasonably close results when the changes are not more than 50% of the original speed or 15% of the original diameter.

Suction conditions are some of the most important factors affecting centrifugal pump operation. If they are ignored during the design or installation stages of an application, they will probably come back to haunt you.

Suction Lift

A pump cannot pull or "suck" a liquid up its suction pipe because liquids do not exhibit tensile strength. Therefore, they cannot transmit tension or be pulled. When a pump creates a suction, it is simply reducing local pressure by creating a partial vacuum. Atmospheric or some other external pressure acting on the surface of the liquid pushes the liquid up the suction pipe into the pump.

Atmospheric pressure at sea level is called absolute pressure (PSIA) because it is a measurement using absolute zero (a perfect vacuum) as a base. If pressure is measured using atmospheric pressure as a base it is called gauge pressure (PSIG or simply PSI).

Atmospheric pressure, as measured at sea level, is 14.7 PSIA. In feet of head it is:
Head = PSI X 2.31 / Specific Gravity

For Water it is:
Head = 14.7 X 2.31 / 1.0 = 34 Ft

Thus, 34 feet is the theoretical maximum suction lift for a pump pumping cold water at sea level. No pump can attain a suction lift of 34 ft; however, well designed ones can reach 25 ft quite easily. You will note, from the equation above, that specific gravity can have a major effect on suction lift. For example, the theoretical maximum lift for brine (Specific Gravity = 1.2) at sea level is 28 ft.. The realistic maximum is around 20ft. Remember to always factor in specific gravity if the liquid being pumped is anything but clear, cold (68 degrees F) water.

In addition to pump design and suction piping, there are two physical properties of the liquid being pumped that affect suction lift.

1) Maximum suction lift is dependent upon the pressure applied to the surface of the liquid at the suction source. Maximum suction lift decreases as pressure decreases.

2) 2) Maximum suction lift is dependent upon the vapor pressure of the liquid being pumped. The vapor pressure of a liquid is the pressure necessary to keep the liquid from vaporizing (boiling) at a given temperature. Vapor pressure increases as liquid temperature increases. Maximum suction lift decreases as vapor pressure rises.

It follows then, that the maximum suction lift of a centrifugal pump varies inversely with altitude. Conversely, maximum suction lift will increase as the external pressure on its source increases (for example: a closed pressure vessel).

Cavitation - Two Main Causes:

A. NPSH (r) EXCEEDS NPSH (a)
Due to low pressure the water vaporizes (boils), and higher pressure implodes into the vapor bubbles as they pass through the pump, causing reduced performance and potentially major damage.
B. Suction or discharge recirculation. The pump is designed for a certain flow range, if there is not enough or too much flow going through the pump, the resulting turbulence and vortexes can reduce performance and damage the pump.

Affinity Laws - Centrifugal Pumps

If the speed or impeller diameter of a pump changes, we can calculate the resulting performance change using:

Affinity laws
a. The flow changes proportionally to speed
i.e.: double the speed / double the flow
b. The pressure changes by the square of the difference
i.e.: double the speed / multiply the pressure by 4
c. The power changes by the cube of the difference
i.e.: double the speed / multiply the power by 8

Notes:
1. These laws apply to operating points at the same efficiency.
2. Variations in impeller diameter greater than 10% are hard to predict due to the change in relationship between the impeller and the casing. For rough calculations you can adjust a duty point or performance curve to suit a different speed. NPSH (r) is affected by speed / impeller diameter change = **DANGER !**

Pump Casing

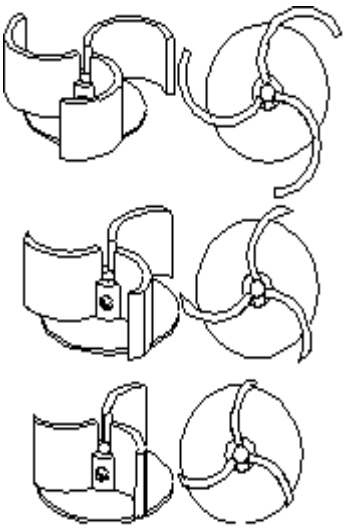
There are many variations of centrifugal pumps. The most common type is an end suction pump. Another type of pump used is the split case. There are many variations of split case, such as; two-stage, single suction, and double suction. Most of these pumps are horizontal.

There are variations of vertical centrifugal pumps. The line shaft turbine is really a multistage centrifugal pump.

Impeller

In most centrifugal pumps, the impeller looks like a number of cupped vanes on blades mounted on a disc or shaft. Notice in the picture below how the vanes of the impeller force the water into the outlet of the pipe.

The shape of the vanes of the impeller is important. As the water is being thrown out of the pump, this means you can run centrifugal pumps with the discharged valve closed for a **SHORT** period of time. Remember the motor sends energy along the shaft, and if the water is in the volute too long it will heat up and create steam. Not good!



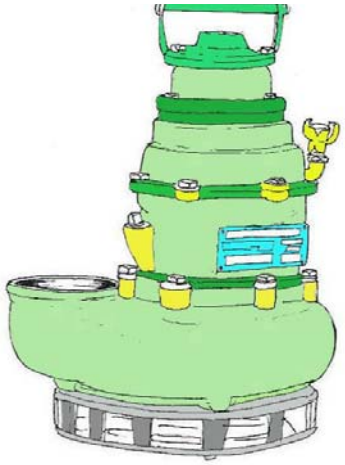
Impellers are designed in various ways. We will look at:

- Closed impellers
- Semi-open impellers
- Opened impellers, and
- Recessed impellers

The impellers all cause a flow from the eye of the impeller to the outside of the impeller. These impellers cause what is called radial flow, and they can be referred to as radial flow impellers.

The critical distance of the impeller and how it is installed in the casing will determine if it is high volume / low pressure or the type of liquid that could be pumped.

Axial flow impellers look like a propeller and create a flow that is parallel to the shaft.

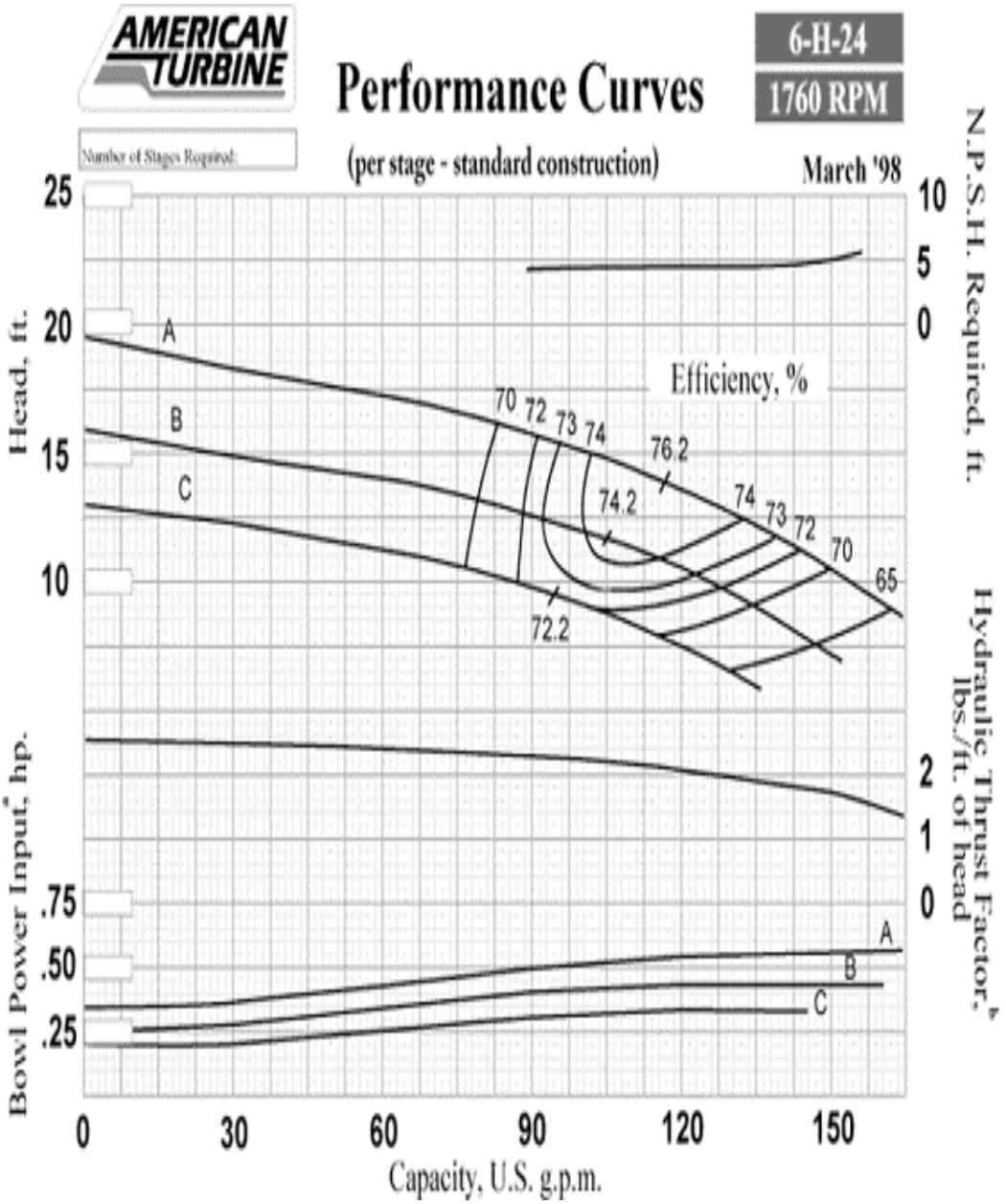


PNUEMATIC SUBMERSIBLE PUMP

Pump Performance and Curves

Let's looks at the big picture. Before you make that purchase of the pump and motor you need to know the basics such as:

- Total dynamic head, the travel distance
- Capacity, how much water you need to provide
- Efficiency, help determine the impeller size
- HP, how many squirrels you need
- RPM, how fast the squirrels run



Motor and Pump Calculations

The centrifugal pump pumps the difference between the suction and the discharge heads. There are three kinds of discharge head:

- **Static head.** The height we are pumping to, or the height to the discharge piping outlet that is filling the tank from the top. Note: that if you are filling the tank from the bottom, the static head will be constantly changing.
- **Pressure head.** If we are pumping to a pressurized vessel (like a boiler) we must convert the pressure units (psi. or Kg.) to head units (feet or meters).
- **System or dynamic head.** Caused by friction in the pipes, fittings, and system components. We get this number by making the calculations from published charts.

Suction head is measured the same way.

- If the liquid level is above the pump center line, that level is a positive suction head. If the pump is lifting a liquid level from below its center line, it is a negative suction head.
- If the pump is pumping liquid from a pressurized vessel, you must convert this pressure to a positive suction head. A vacuum in the tank would be converted to a negative suction head.
- Friction in the pipes, fittings, and associated hardware is a negative suction head.
- Negative suction heads are added to the pump discharge head, positive suctions heads are subtracted from the pump discharge head.

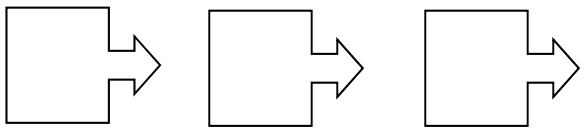
Total Dynamic Head (TDH) is the total height that a fluid is to be pumped, taking into account friction losses in the pipe.

TDH = Static Lift + Static Height + Friction Loss

where:
Static Lift is the height the water will rise before arriving at the pump (also known as the 'suction head').

Static Height is the maximum height reached by the pipe after the pump (also known as the 'discharge head').

Friction Loss is the head equivalent to the energy losses due to viscose drag of fluid flowing in the pipe (both on the suction and discharge sides of the pump). It is calculated via a formula or a chart, taking into account the pipe diameter and roughness and the fluid flow rate, density, and viscosity.



Motor hp **Brake hp** **Water hp**

Horsepower

Work involves the operation of force over a specific distance. The rate of doing work is called power.
The rate in which a horse could work was determined to be about 550 ft-lbs/sec or 33,000 ft-lbs/min.

1 hp = 33,000 ft-lbs/min

Motor Horsepower (mhp)

1 hp = 746 watts or .746 Kilowatts

MHP refers to the horsepower supplied in the form of electrical current. The efficiency of most motors range from 80-95%. (Manufactures will list efficiency %)

Brake Horsepower (bhp)

$$\text{Brake hp} = \frac{\text{Water hp}}{\text{Pump Efficiency}}$$

BHP refers to the horsepower supplied to the pump from the motor. As the power moves through the pump, additional horsepower is lost, resulting from slippage and friction of the shaft and other factors.

Water Horsepower

$$\text{Water hp} = \frac{(\text{flow gpm})(\text{total hd})}{3960}$$

Water horsepower refers to the actual horse power available to pump the water.

Horsepower and Specific Gravity

The specific gravity of a liquid is an indication of its density or weight compared to water. The difference in specific gravity, include it when calculating ft-lbs/min pumping requirements.

$$\frac{(\text{ft})(\text{lbs/min})(\text{sp.gr.})}{33{,}000 \text{ ft-lbs/min/hp}} = \text{whp}$$

MHP and Kilowatt requirements

$$1 \text{ hp} = 0.746 \text{ kW} \quad \text{or} \quad \frac{(\text{hp})\ (746 \text{ watts/hp})}{1000 \text{ watts/kW}}$$

Well Calculations

1. Well drawdown

Drawdown ft = Pumping water level, ft - Static water level, ft

2. Well yield

$$\text{Well yield, gpm} = \frac{\text{Flow, gallons}}{\text{Duration of test, min}}$$

3. Specific yield

$$\text{Specific yield, gpm/ft} = \frac{\text{Well yield, gpm}}{\text{Drawdown, ft}}$$

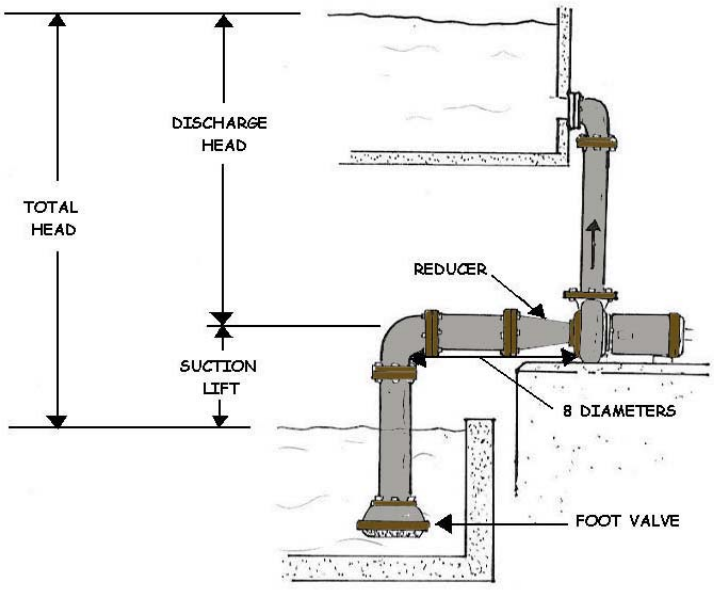
4. Deep well turbine pump calculations.

Discharge head, ft = (pressure measured) (2.31 ft/psi)

Field head, ft = pumping water + discharge head, ft

Bowl head, ft = field head + column friction

1 psi = 2.31 feet of head
1 foot of head = .433 psi



Example 1

A centrifugal pump is located at an elevation of 722 ft. This pump is used to move water from reservoir **A** to reservoir **B**. The water level in reservoir **A** is 742 ft and the water level in reservoir **B** is 927 ft. Based on these conditions answer the following questions:

1. **If the pump is not running and pressure gauges are installed on the suction and discharge lines, what pressures would the gauges read?**

   Suction side:

   Discharge side:

2. **How can you tell if this is a suction head condition?**

3. **Calculate the following head measurements:**

SSH:

SDH:

TSH:

4. **Convert the pressure gauge readings to feet:**

6 psi:

48 psi:

110 psi:

5. **Calculate the following head in feet to psi:**

20 ft:

205 ft:

185 ft:

Motor, Coupling and Bearing Section

We will now refer to the motor, coupling, and bearings. The power source of the pump is usually an electric motor. The motor is connected by a coupling to the pump shaft. The purpose of the bearings is to hold the shaft firmly in place, yet allow it to rotate. The bearing house supports the bearings and provides a reservoir for the lubricant. An impeller is connected to the shaft. The pump assembly can be a vertical or horizontal set-up; the components for both are basically the same.

Motors
The purpose of this discussion on pump motors is to identify and describe the main types of motors, starters, enclosures, and motor controls, as well as to provide you with some basic maintenance and troubleshooting information. Although pumps could be driven by diesel or gasoline engines, pumps driven by electric motors are commonly used in our industry.

There are two general categories of electric motors:

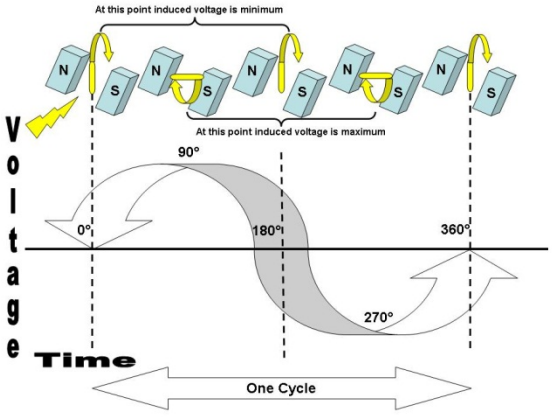
- D-C motors, or direct current
- A-C motors, or alternating current



You can expect most motors at facilities to be A-C type.

D-C Motors
The important characteristic of the D-C motor is that its speed will vary with the amount of current used. There are many different kinds of D-C motors, depending on how they are wound and their speed/torque characteristics.

A-C Motors
There are a number of different types of alternating current motors, such as Synchronous, Induction, wound rotor, and squirrel cage. The synchronous type of A-C motor requires complex control equipment, since they use a combination of A-C and D-C. This also means that the synchronous type of A-C motor is used in large horsepower sizes, usually above 250 HP. The induction type motor uses only alternating current. The squirrel cage motor provides a relatively constant speed. The wound rotor type could be used as a variable speed motor.



Define the Following Terms:

Voltage:

EMF:

Power:

Current:

Resistance:

Conductor:

Phase:

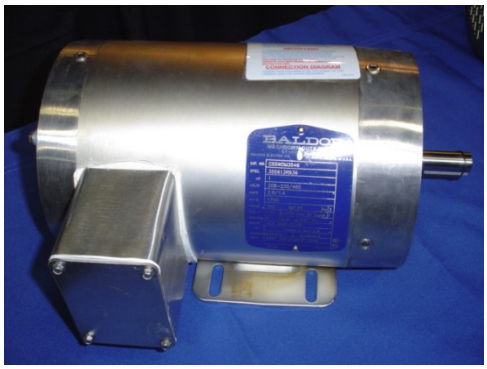
Single Phase:

Three Phase:

Hertz:

Motor Starters
All electric motors, except very small ones such as chemical feed pumps, are equipped with starters, either full voltage or reduced voltage. This is because motors draw a much higher current when they are starting and gaining speed. The purpose of the reduced voltage starter is to prevent the load from coming on until the amperage is low enough.

How do you think keeping the discharge valve closed on a centrifugal pump could reduce the startup load?



Motor Enclosures
Depending on the application, motors may need special protection. Some motors are referred to as open motors. They allow air to pass through to remove heat generated when current passes through the windings. Other motors use specific enclosures for special environments or safety protection.

Can you think of any locations within your facility that requires special enclosures?

Two Types of Totally Enclosed Motors Commonly Used are:

- **TENV**, or totally enclosed non-ventilated motor
- **TEFC**, or totally enclosed fan cooled motor

Totally enclosed motors include dust-proof, water-proof and explosion-proof motors. An explosion proof enclosure must be provided on any motor where dangerous gases might accumulate.

Motor Controls
All pump motors are provided with some method of control, typically a combination of manual and automatic. Manual pump controls can be located at the central control panel at the pump or at the suction or discharge points of the liquid being pumped.

There are a number of ways in which automatic control of a pump motor can be regulated:

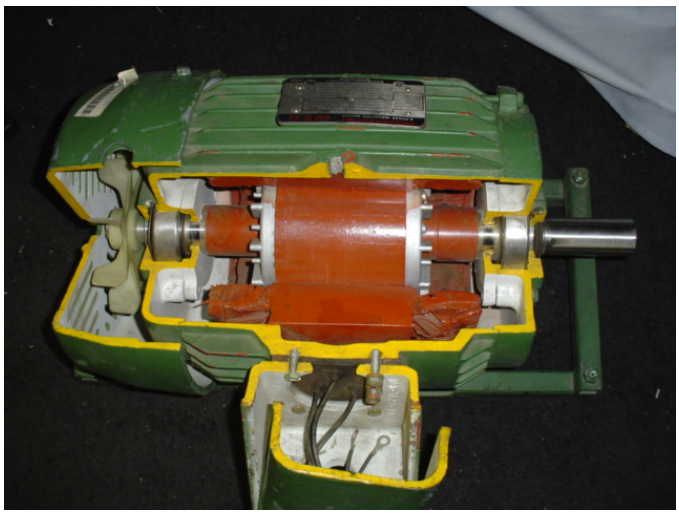
- Pressure and vacuum sensors
- Preset time intervals
- Flow sensors
- Level sensors



Two typical level sensors are the float sensor and the bubble regulator. The float sensor is pear-shaped and hangs in the wet well. As the height increases, the float tilts, and the mercury in the glass tube flows toward the end of the tube that has two wires attached to it. When the mercury covers the wires, it closes the circuit.

A low pressure air supply is allowed to escape from a bubbler pipe in the wet well. The back-pressure on the air supply will vary with the liquid level over the pipe. Sensitive air pressure switches will detect this change and use this information to control pump operation.

Motor Maintenance
Motors should be kept clean, free of moisture, and lubricated properly. Dirt, dust, and grime will plug the ventilating spaces and can actually form an insulating layer over the metal surface of the motor.



What condition would occur if the ventilation becomes blocked?

Moisture

Moisture harms the insulation on the windings to the point where they may no longer provide the required insulation for the voltage applied to the motor. In addition, moisture on windings tend to absorb acid and alkali fumes, causing damage to both insulation and metals. To reduce problems caused by moisture, the most suitable motor enclosure for the existing environment will normally be used. It is recommended to run stand by motors to dry up any condensation which accumulates in the motor.

Motor Lubrication

Friction will cause wear in all moving parts, and lubrication is needed to reduce this friction. It is very important that all your manufacturer's recommended lubrication procedures are strictly followed. You have to be careful not to add too much grease or oil, as this could cause more friction and generate heat.

To grease the motor bearings, this is the usual approach:

1. Remove the protective plugs and caps from the grease inlet and relief holes.
2. Pump grease in until fresh starts coming from the relief hole.

If fresh grease does not come out of the relief hole, this could mean that the grease has been pumped into the motor windings. The motor must then be taken apart and cleaned by a qualified service representative.

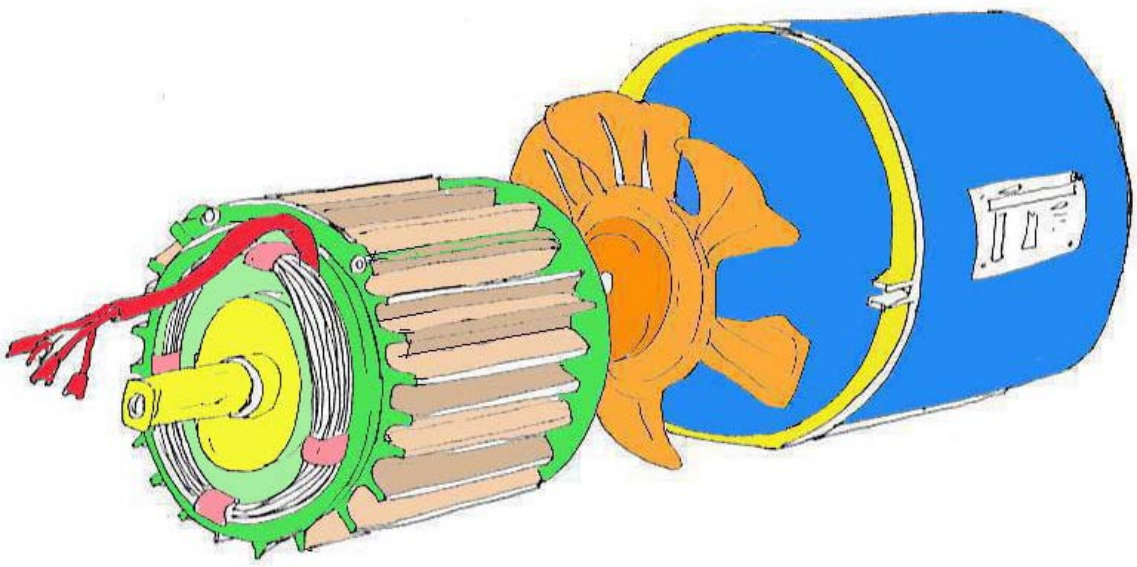
To change the oil in an oil lubricated motor, this is the usual approach:

1. Remove all plugs and let the oil drain.
2. Check for metal shearing.
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

Never mix oils, since the additives of different oils when combined can cause breakdown of the oil.



More Detailed Information on Motors



The classic division of electric motors has been that of Direct Current (DC) types vs. Alternating Current (AC) types. This is more a de facto convention, rather than a rigid distinction. For example, many classic DC motors run happily on AC power.

The ongoing trend toward electronic control further muddles the distinction, as modern drivers have moved the commutator out of the motor shell. For this new breed of motor, driver circuits are relied upon to generate sinusoidal AC drive currents, or some approximation of. The two best examples are: the brushless DC motor and the stepping motor, both being polyphase AC motors requiring external electronic control.

There is a clearer distinction between a synchronous motor and asynchronous types. In the synchronous types, the rotor rotates in synchrony with the oscillating field or current (e.g. permanent magnet motors). In contrast, an asynchronous motor is designed to slip; the most ubiquitous example being the common AC induction motor which must slip in order to generate torque.

A DC motor is designed to run on DC electric power. Two examples of pure DC designs are Michael Faraday's homopolar motor (which is uncommon), and the ball bearing motor, which is (so far) a novelty. By far the most common DC motor types are the brushed and brushless types, which use internal and external commutation respectively to create an oscillating AC current from the DC source -- so they are not purely DC machines in a strict sense.

Brushed DC motors
The classic DC motor design generates an oscillating current in a wound rotor with a split ring commutator, and either a wound or permanent magnet stator. A rotor consists of a coil wound around a rotor, which is then powered by any type of battery. Many of the limitations of the classic commutator DC motor are due to the need for brushes to press against the commutator. This creates friction. At higher speeds, brushes have increasing difficulty in maintaining contact. Brushes may bounce off the irregularities in the commutator surface, creating sparks. This limits the maximum speed of the machine.

The current density per unit area of the brushes limits the output of the motor. The imperfect electric contact also causes electrical noise. Brushes eventually wear out and require replacement, and the commutator itself is subject to wear and maintenance. The commutator assembly on a large machine is a costly element, requiring precision assembly of many parts.

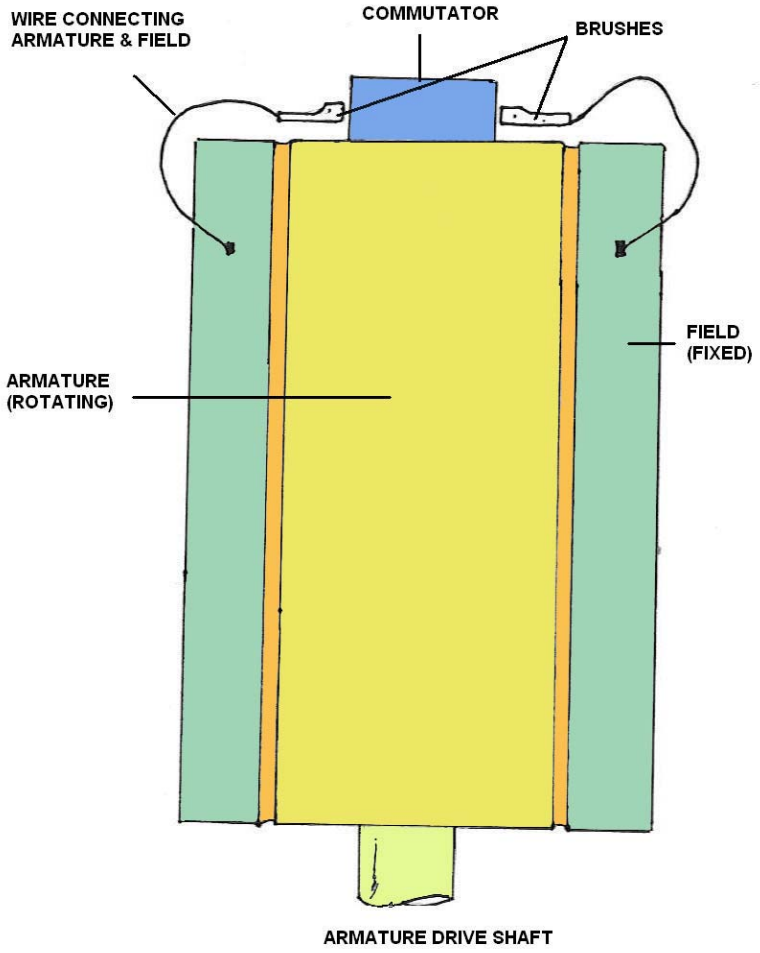


DIAGRAM SHOWING MECHANICAL CONSTRUCTION OF A DC SERIES WOUND MOTOR

Brushless DC motors

Some of the problems of the brushed DC motor are eliminated in the brushless design. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brush gear are typically 75-80% efficient.

Midway between ordinary DC motors and stepper motors lies the realm of the brushless DC motor. Built in a fashion very similar to stepper motors, these often use a permanent magnet external rotor, three phases of driving coils, one or more Hall effect sensors to sense the position of the rotor, and the associated drive electronics.

The coils are activated one phase after the other by the drive electronics, as cued by the signals from the Hall effect sensors. In effect, they act as three-phase synchronous motors containing their own variable-frequency drive electronics. Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, CD-ROM (etc.) drives, and mechanisms within office products such as fans, laser printers ,and photocopiers.

They have several advantages over conventional motors:

* Compared to AC fans using shaded-pole motors, they are very efficient, running much cooler than the equivalent AC motors. This cool operation leads to much-improved life of the fan's bearings.
* Without a commutator to wear out, the life of a DC brushless motor can be significantly longer compared to a DC motor using brushes and a commutator. Commutation also tends to cause a great deal of electrical and RF noise; without a commutator or brushes, a brushless motor may be used in electrically sensitive devices like audio equipment or computers.
* The same Hall Effect sensors that provide the commutation can also provide a convenient tachometer signal for closed-loop control (servo-controlled) applications. In fans, the tachometer signal can be used to derive a "fan OK" signal.
* The motor can be easily synchronized to an internal or external clock, leading to precise speed control.
* Brushless motors have no chance of sparking, unlike brushed motors, making them better suited to environments with volatile chemicals and fuels.
* Brushless motors are usually used in small equipment such as computers, and are generally used to get rid of unwanted heat.
* They are also very quiet motors, which is an advantage if being used in equipment that is affected by vibrations.

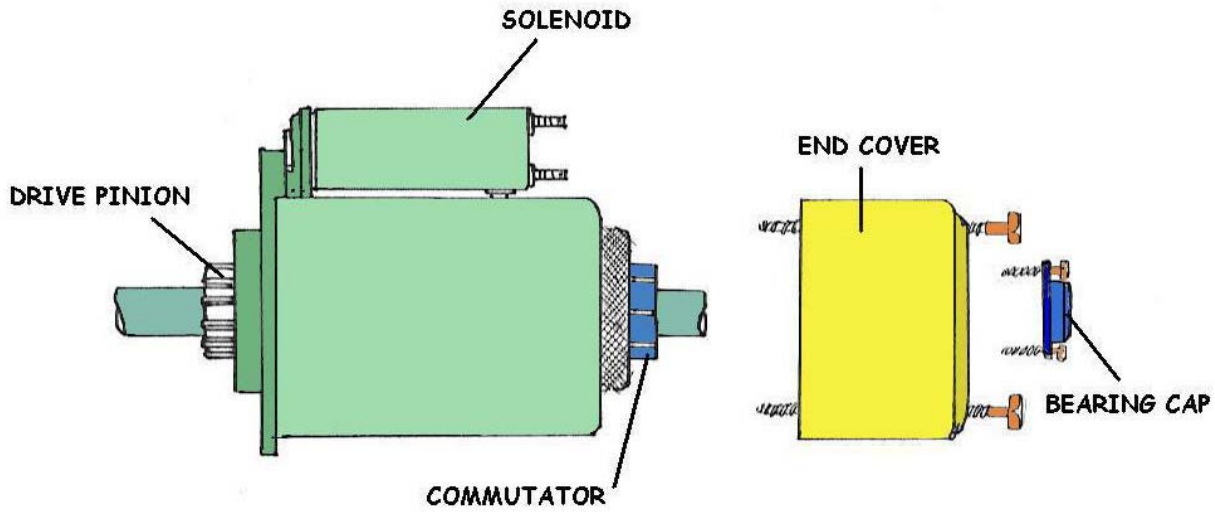
Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

Coreless DC Motors

Nothing in the design of any of the motors described above requires that the iron (steel) portions of the rotor actually rotate; torque is exerted only on the windings of the electromagnets. Taking advantage of this fact is the coreless DC motor, a specialized form of a brush or brushless DC motor. Optimized for rapid acceleration, these motors have a rotor that is constructed without any iron core. The rotor can take the form of a winding-filled cylinder inside the stator magnets, a basket surrounding the stator magnets, or a flat pancake (possibly formed on a printed wiring board) running between upper and lower stator magnets. The windings are typically stabilized by being impregnated with electrical epoxy potting systems. Filled epoxies that have moderate mixed viscosity and a long gel time. These systems are highlighted by low shrinkage and low exotherm.

Because the rotor is much lighter in weight (mass) than a conventional rotor formed from copper windings on steel laminations, the rotor can accelerate much more rapidly, often achieving a mechanical time constant under 1 ms. This is especially true if the windings use aluminum rather than the heavier copper. But because there is no metal mass in the rotor to act as a heat sink, even small coreless motors must often be cooled by forced air.

These motors were commonly used to drive the capstan(s) of magnetic tape drives and are still widely used in high-performance servo-controlled systems, like radio-controlled vehicles/aircraft, humanoid robotic systems, industrial automation, medical devices, etc.



STARTER MOTOR

Universal Motors

A variant of the wound field DC motor is the universal motor. The name derives from the fact that it may use AC or DC supply current, although in practice they are nearly always used with AC supplies. The principle is that in a wound field DC motor the current in both the field and the armature (and hence the resultant magnetic fields) will alternate (reverse polarity) at the same time, and hence the mechanical force generated is always in the same direction. In practice, the motor must be specially designed to cope with the AC current (impedance must be taken into account, as must the pulsating force), and the resultant motor is generally less efficient than an equivalent pure DC motor. Operating at normal power line frequencies, the maximum output of universal motors is limited and motors exceeding one kilowatt are rare. But universal motors also form the basis of the traditional railway traction motor in electric railways. In this application, to keep their electrical efficiency high, they were operated from very low frequency AC supplies, with 25 Hz and 16 2/3 hertz operation being common. Because they are universal motors, locomotives using this design were also commonly capable of operating from a third rail powered by DC.

The advantage of the universal motor is that AC supplies may be used on motors which have the typical characteristics of DC motors, specifically high starting torque and very compact design if high running speeds are used. The negative aspect is the maintenance and short life problems caused by the commutator. As a result, such motors are usually used in AC devices such as food mixers and power tools, which are used only intermittently.

Continuous speed control of a universal motor running on AC is very easily accomplished using a thyristor circuit, while stepped speed control can be accomplished using multiple taps on the field coil. Household blenders that advertise many speeds frequently combine a field coil with several taps and a diode that can be inserted in series with the motor (causing the motor to run on half-wave rectified AC).

Universal motors can rotate at relatively high revolutions per minute (rpm). This makes them useful for appliances such as blenders, vacuum cleaners, and hair dryers where high-speed operation is desired. Many vacuum cleaner and weed trimmer motors exceed 10,000 rpm; Dremel and other similar miniature grinders will often exceed 30,000 rpm. Motor damage may occur due to overspeed (rpm in excess of design specifications) if the unit is operated with no significant load. On larger motors, sudden loss of load is to be avoided, and the possibility of such an occurrence is incorporated into the motor's protection and control schemes. Often, a small fan blade attached to the armature acts as an artificial load to limit the motor speed to a safe value, as well as provide cooling airflow to the armature and field windings.

With the very low cost of semiconductor rectifiers, some applications that would have previously used a universal motor now use a pure DC motor, sometimes with a permanent magnet field.

AC Motors

In 1882, Nicola Tesla identified the rotating magnetic field principle, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888). Before the invention of the rotating magnetic field, motors operated by continually passing a conductor through a stationary magnetic field (as in homopolar motors). Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.

Components

A typical AC motor consists of two parts:

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

Torque Motors

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady stall torque to the load (hence the name). A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads. Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer world, torque motors are used with force feedback steering wheels.

Slip Ring

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip rings to which external impedances can be connected. The stator is the same as is used with a standard squirrel cage motor. By changing the impedance connected to the rotor circuit, the speed/current and speed/torque curves can be altered.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control.

Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced. When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the load will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

Stepper Motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position between the cog points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in pre-gigabyte era computer disk drives, where the precision they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision limitations of stepper motors made them obsolete for hard drives, thus newer hard disk drives use read/write head control systems based on voice coils. Stepper motors were up-scaled to be used in electric vehicles under the term SRM (switched reluctance machine).

Coupling Section

The pump coupling serves two main purposes:

- It couples or joins the two shafts together to transfer the rotation from motor to impeller.
- It compensates for small amounts of misalignment between the pump and the motor.

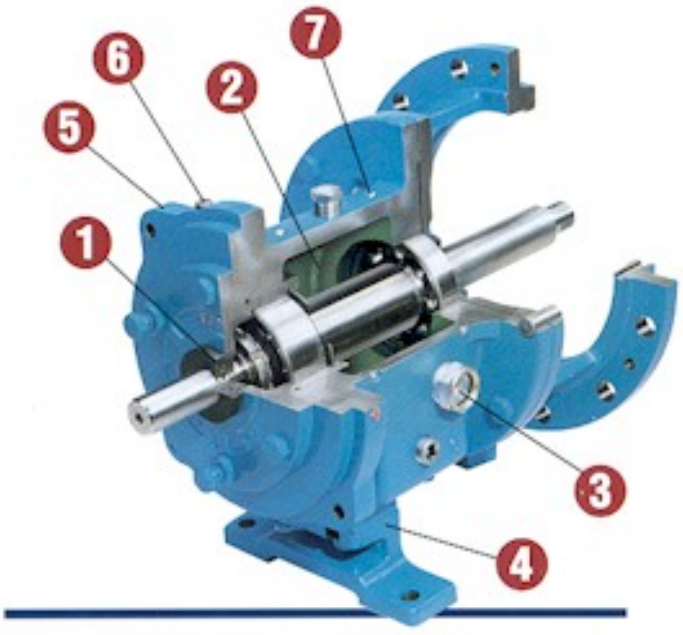
Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

There are three commonly used types of couplings: ***Rigid, Flexible and V-belts.***

Rigid Coupling
Rigid couplings are most commonly used on vertically mounted pumps. The rigid coupling is usually specially keyed or constructed for joining the coupling to the motor shaft and the pump shaft. There are two types of rigid couplings: the flanged coupling, and the split coupling.

Flexible Coupling. The flexible coupling provides the ability to compensate for small shaft misalignments. Shafts should be aligned as close as possible, regardless. The greater the misalignment, the shorter the life of the coupling. Bearing wear and life are also affected by misalignment.

1. Oil Seals
2. Large Oil Sump
3. Bulls Eye Sight Glass
4. Rigid Frame Foot
5. C-Face Mounting Flange
6. Lubrication Flexibility
7. Condition Monitoring Sites



Alignment of Flexible and Rigid Couplings

Both flexible and rigid couplings must be carefully aligned before they are connected. Misalignment will cause excessive heat and vibration, as well as bearing wear. Usually, the noise from the coupling will warn you of shaft misalignment problems.

Three types of shaft alignment problems are shown in the pictures below:



ANGULAR MISALIGNMENT



ANGULAR AND PARALLEL



PARALLEL MISALIGNMENT

Different couplings will require different alignment procedures. We will look at the general procedures for aligning shafts.

1. Place the coupling on each shaft.
2. Arrange the units so they appear to be aligned. (Place shims under the legs of one of the units to raise it.)
3. Check the run-out, or difference between the driver and driven unit, by rotating the shafts by hand.
4. Turn both units so that the maximum run-out is on top.

Now you can check the units for both parallel and angular alignment. Many techniques are used, such as: straight edge, needle deflection (dial indicators), calipers, tapered wedges, and laser alignment.

V-Belt Drive Couplings

V-belt drives connect the pump to the motor. A pulley is mounted on the pump and motor shaft. One or more belts are used to connect the two pulleys. Sometimes a separately mounted third pulley is used. This idler pulley is located off centerline between the two pulleys, just enough to allow tensioning of the belts by moving the idler pulley. An advantage of driving a pump with belts is that various speed ratios can be achieved between the motor and the pump.

Shaft Bearings

There are three types of bearings commonly used: ball bearings, roller bearings, and sleeve bearings. Regardless of the particular type of bearings used within a system--whether it is ball bearings, a sleeve bearing, or a roller bearing--the bearings are designed to carry the loads imposed on the shaft.

Bearings must be lubricated. Without proper lubrication, bearings will overheat and seize. Proper lubrication means using the correct type and the correct amount of lubrication. Similar to motor bearings, shaft bearings can be lubricated either by oil or by grease.

How can we prevent the water from leaking along the shaft?
A special seal is used to prevent liquid leaking out along the shaft. There are two types of seals commonly used:



- **Packing seal**
- **Mechanical seal**

Packing Seals

Should packing have leakage?

Leakage
During pump operation, a certain amount of leakage around the shafts and casings normally takes place.

This leakage must be controlled for two reasons: (1) to prevent excessive fluid loss from the pump, and (2) to prevent air from entering the area where the pump suction pressure is below atmospheric pressure.

The amount of leakage that can occur without limiting pump efficiency determines the type of shaft sealing selected. Shaft sealing systems are found in every pump. They can vary from simple packing to complicated sealing systems.

Packing is the most common and oldest method of sealing. Leakage is checked by the compression of packing rings that causes the rings to deform and seal around the pump shaft and casing. The packing is lubricated by liquid moving through a lantern ring in the center of the packing. The sealing slows down the rate of leakage. It does not stop it completely, since a certain amount of leakage is necessary during operation. Mechanical seals are rapidly replacing conventional packing on centrifugal pumps.

Some of the reasons for the use of mechanical seals are as follows:
1. Leaking causes bearing failure by contaminating the oil with water. This is a major problem in engine-mounted water pumps.

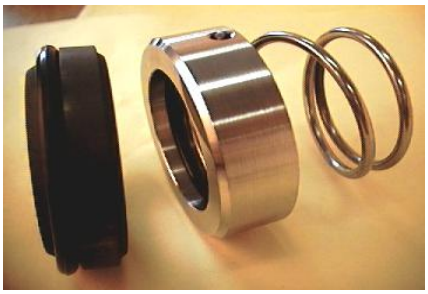
2. Properly installed mechanical seals eliminate leakoff on idle (vertical) pumps. This design prevents the leak (water) from bypassing the water flinger and entering the lower bearings.

Leakoff causes two types of seal leakage:
a. Water contamination of the engine lubrication oil.
b. Loss of treated fresh water that causes scale buildup in the cooling system.

Centrifugal pumps are versatile and have many uses. This type of pump is commonly used to pump all types of water and wastewater flows, including thin sludge.

Lantern Rings
Lantern rings are used to supply clean water along the shaft. This helps to prevent grit and air from reaching the area. Another component is the slinger ring. The slinger ring is an important part of the pump because it is used to protect the bearings. Other materials can be used to prevent this burier.

Mechanical Seals
Mechanical seals are commonly used to reduce leakage around the pump shaft. There are many types of mechanical seals. The photograph below illustrates the basic components of a mechanical seal. Similar to the packing seal, clean water is fed at a pressure greater than that of the liquid being pumped. There is little or no leakage through the mechanical seal. The wearing surface must be kept extremely clean. Even fingerprints on the wearing surface can introduce enough dirt to cause problems.



What care should be taken when storing mechanical seals?



Mechanical Seals

Wear Rings
Not all pumps have wear rings. However, when they are included, they are usually replaceable. Wear rings can be located on the suctions side and head side of the volute. Wear rings could be made of the same metal but of different alloys. The wear ring on the head side is usually a harder alloy.

It's called a ***"WEAR RING"*** and what would be the purpose?

Mechanical Seals

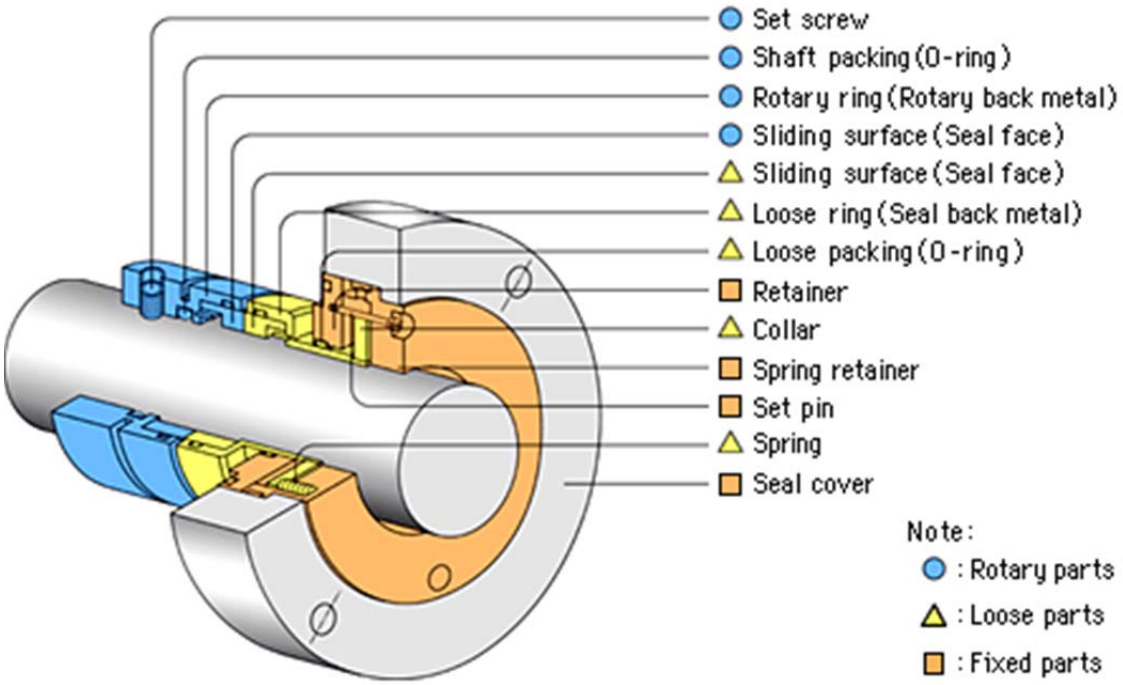
Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation.

The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

You should replace a mechanical seal whenever the seal is removed from the shaft for any reason, or whenever leakage causes undesirable effects on equipment or surrounding spaces. Do not touch a new seal on the sealing face because body acid and grease or dirt will cause the seal to pit prematurely and leak.

Mechanical shaft seals are positioned on the shaft by stub or step sleeves. Mechanical shaft seals must not be positioned by setscrews. Shaft sleeves are chamfered (beveled) on the outboard ends for easy mechanical seal mounting. Mechanical shaft seals serve to ensure that position liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.



Pump Troubleshooting Section

Some of the operating problems you may encounter with centrifugal pumps as an Operator, together with the probable causes, are discussed in the following paragraphs.

If a centrifugal pump **DOES NOT DELIVER ANY LIQUID**, the trouble may be caused by (1) insufficient priming; (2) insufficient speed of the pump; (3) excessive discharge pressure, such as might be caused by a partially closed valve or some other obstruction in the discharge line; (4) excessive suction lift; (5) clogged impeller passages; (6) the wrong direction of rotation (this may occur after motor overhaul); (7) clogged suction screen (if used); (8) ruptured suction line; or (9) loss of suction pressure.

If a centrifugal pump delivers some liquid but operates at **INSUFFICIENT CAPACITY**, the trouble may be caused by (1) air leakage into the suction line; (2) air leakage into the stuffing boxes in pumps operating at less than atmospheric pressure; (3) insufficient pump speed; (4) excessive suction lift; (5) insufficient liquid on the suction side; (6) clogged impeller passages; (7) excessive discharge pressure; or (8) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves.

If a pump **DOES NOT DEVELOP DESIGN DISCHARGE PRESSURE**, the trouble may be caused by (1) insufficient pump speed; (2) air or gas in the liquid being pumped; (3) mechanical defects, such as worn wearing rings, impellers, stuffing box packing, or sleeves; or (4) reversed rotation of the impeller (3-phase electric motor-driven pumps). If a pump **WORKS FOR A WHILE AND THEN FAILS TO DELIVER LIQUID,** the trouble may be caused by (1) air leakage into the suction line; (2) air leakage in the stuffing boxes; (3) clogged water seal passages; (4) insufficient liquid on the suction side; or (5) excessive heat in the liquid being pumped.

If a motor-driven centrifugal pump **DRAWS TOO MUCH POWER**, the trouble will probably be indicated by overheating of the motor. The basic causes may be (1) operation of the pump to excess capacity and insufficient discharge pressure; (2) too high viscosity or specific gravity of the liquid being pumped; or (3) misalignment, a bent shaft, excessively tight stuffing box packing, worn wearing rings, or other mechanical defects.

VIBRATION of a centrifugal pump is often caused by (1) misalignment; (2) a bent shaft; (3) a clogged, eroded, or otherwise unbalanced impeller; or (4) lack of rigidity in the foundation. Insufficient suction pressure may also cause vibration, as well as noisy operation and fluctuating discharge pressure, particularly in pumps that handle hot or volatile liquids. If the pump fails to build up pressure when the discharge valve is opened and the pump comes up to normal operating speed, proceed as follows:

1. Shut the pump discharge valve.
2. Secure the pump.
3. Open all valves in the pump suction line.
4. Prime the pump (***fill casing with the liquid being pumped***) and be sure that all air is expelled through the air cocks on the pump casing.
5. Restart the pump. If the pump is electrically driven, be sure the pump is rotating in the correct direction.
6. Open the discharge valve to "**load**" the pump. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller may be broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump and continue troubleshooting according to the technical manual for that unit.

Maintenance of Centrifugal Pumps

When properly installed, maintained and operated, centrifugal pumps are usually trouble-free. Some of the most common corrective maintenance actions that you may be required to perform are discussed in the following sections.



Repacking - Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When operating a centrifugal pump, be sure there is always a slight trickle of water coming out of the stuffing box or seal. How often the packing in a centrifugal pump should be renewed depends on several factors, such as the type of pump, condition of the shaft sleeve, and hours in use.

To ensure the longest possible service from pump packing, make certain the shaft or sleeve is smooth when the packing is removed from a gland. Rapid wear of the packing will be caused by roughness of the shaft sleeve (or shaft where no sleeve is installed). If the shaft is rough, it should be sent to the machine shop for a finishing cut to smooth the surface. If it is very rough, or has deep ridges in it, it will have to be renewed. It is absolutely necessary to use the correct packing. When replacing packing, be sure the packing fits uniformly around the stuffing box. If you have to flatten the packing with a hammer to make it fit, **YOU ARE NOT USING THE RIGHT SIZE.** Pack the box loosely, and set up the packing gland lightly. Allow a liberal leak-off for stuffing boxes that operate above atmospheric pressure.

Next, start the pump. Let it operate for about 30 minutes before you adjust the packing gland for the desired amount of leak-off. This gives the packing time to run-in and swell. You may then begin to adjust the packing gland. Tighten the adjusting nuts one flat at a time. Wait about 30 minutes between adjustments. Be sure to tighten the same amount on both adjusting nuts. If you pull up the packing gland unevenly (or cocked), it will cause the packing to overheat and score the shaft sleeves. Once you have the desired leak-off, check it regularly to make certain that sufficient flow is maintained.

Mechanical Seals



Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings. Mechanical seals are ideal for pumps that operate in closed systems (such as fuel service and air-conditioning, chilled-water, and various cooling systems). They not only conserve the fluid being pumped, but also improve system operation. The type of material used for the seal faces will depend upon the service of the pump. Most water service pumps use a carbon material for one of the seal faces and ceramic (tungsten carbide) for the other. When the seals wear out, they are simply replaced.

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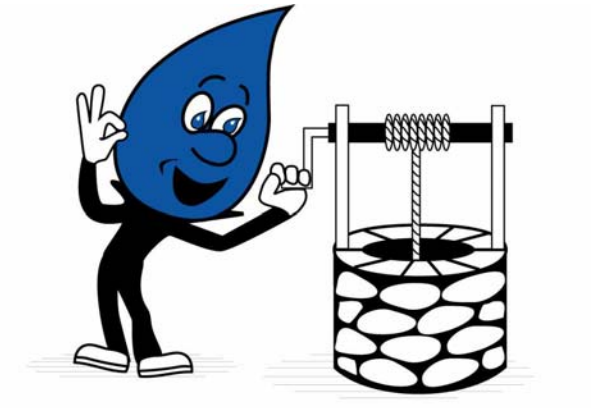
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Mechanical shaft seals serve to ensure that liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.



Troubleshooting Table for Well/Pump Problems

1. Well pump will not start.
2. Well pump will not shut off.
3. Well pump starts and stops too frequently (excessive cycle rate).
4. Sand sediment is present in the water.
5. Well pump operates with reduced flow.
6. Well house flooded without recent precipitation.
7. Red or black water complaints.
8. Raw water appears turbid or a light tan color following rainfall.
9. Coliform tests are positive.



Possible Causes

1A. Circuit breaker or overload relay tripped.
1B. Fuse(s) burned out.
1C. No power to switch box.
1D. Short, broken or loose wire.
1E. Low voltage.
1F. Defective motor.
1G. Defective pressure switch.
2A. Defective pressure switch.
2B. Cut-off pressure setting too high.
2C. Float switch or pressure transducer not functioning.
3A. Pressure switch settings too close.
3B. Pump foot valve leaking.
3C. Water-logged hydropneumatic tank.
4A. Problems with well screen or gravel envelope.
5A. Valve on discharge partially closed or line clogged.
5B. Well is over-pumped.
5C. Well screen clogged.
6A. Check valve not operating properly.
6B. Leakage occurring in discharge piping or valves.
7A. Water contains excessive iron (red brown) and/or manganese (black water).
7B. Complainant's hot water needs maintenance.
8A. Surface water entering or influencing well.
9A. Sample is invalid.
9B. Sanitary protection of well has been breached.

Possible Solutions

1A. Reset breaker or manual overload relay.
1B. Check for cause and correct, replace fuse(s).
1C. Check incoming power supply. Contact power company.
1D. Check for shorts and correct, tighten terminals, replace broken wires.
1E. Check incoming line voltage. Contact power company if low.
1F. Contact electrical contractor.
1G. Check voltage of incoming electric supply with pressure switch closed. Contact power company if voltage low. Perform maintenance on switch if voltage normal.
2A. Check switch for proper operation. Replace switch.
2B. Adjust setting.
2C. Check and replace components or cable as needed.
3A. Adjust settings.
3B. Check for backflow. Contact well contractor.

3C. Check air volume. Add air if needed. If persistent, check air compressor, relief valve, air lines and connections, and repair if needed.
4A. Contact well contractor.
5A. Open valve, unclog discharge line.
5B. Check static water level and compare to past readings. If significantly lower, notify well contractor.
5C. Contact well contractor.
6A. Repair or replace check valve.
6B. Inspect and repair/replace as necessary.
7A. Test for iron and manganese at well. If levels exceed 0.3 mg/L iron or 0.005mg/L manganese, contact regulatory agency, TA provider or water treatment contractor.
7B. Check hot water heater and flush if needed.
8A. Check well for openings that allow surface water to enter. Check area for sinkholes, fractures, or other physical evidence of surface water intrusion. Check water turbidity. Notify regulatory agency if >0.5 NTU. Check raw water for coliform bacteria. Notify regulatory agency immediately if positive.
9A. Check sampling technique, sampling container, and sampling location and tap.
9B. Notify regulatory agency immediately and re-sample for re-testing.



This brush is used to dislodge debris inside well casing. Just a big toilet cleaning brush.

SCADA

What is SCADA?

SCADA stands for Supervisory Control and Data Acquisition. As the name indicates, it is not a full control system, but rather focuses on the supervisory level. As such, it is a purely software package that is positioned on top of hardware to which it is interfaced, in general via Programmable Logic Controllers (PLCs), or other commercial hardware modules. Contemporary SCADA systems exhibit predominantly open-loop control characteristics and utilize predominantly long distance communications, although some elements of closed-loop control and/or short distance communications may also be present. Systems similar to SCADA systems are routinely seen in treatment plants and distribution systems. These are often referred to as Distributed Control Systems (DCS). They have similar functions to SCADA systems, but the field data gathering or control units are usually located within a more confined area. Communications may be via a local area network (LAN), and will normally be reliable and high speed. A DCS system usually employs significant amounts of closed loop control.

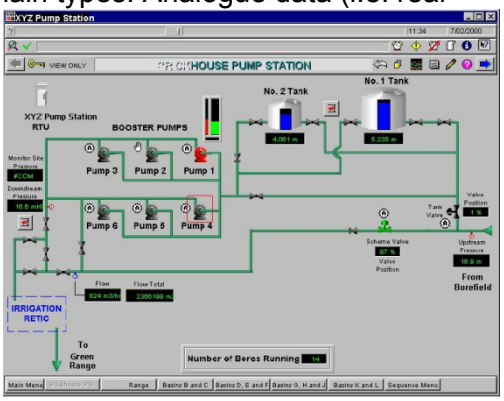
What is Data Acquisition?

Data acquisition refers to the method used to access and control information or data from the equipment being controlled and monitored. The data accessed are then forwarded onto a telemetry system ready for transfer to the different sites. They can be analog and digital information gathered by sensors, such as flowmeter, ammeter, etc. It can also be data to control equipment such as actuators, relays, valves, motors, etc.

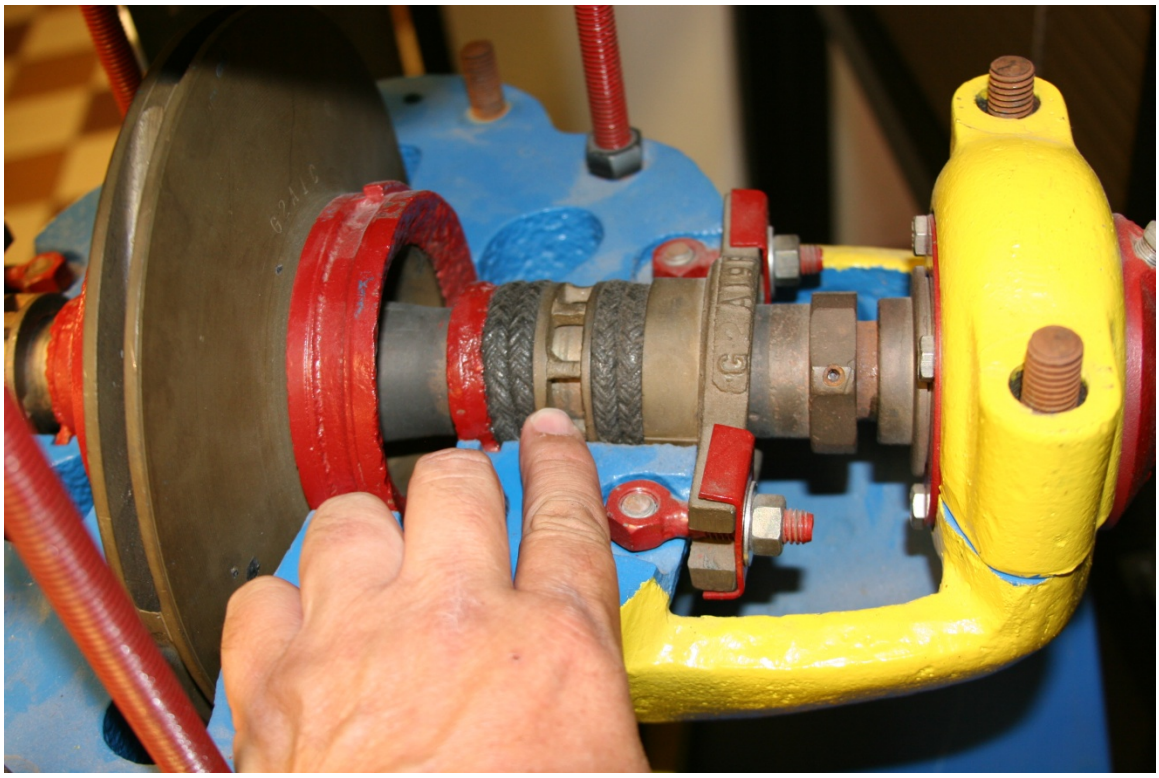
So Why or Where Would You Use SCADA?

SCADA can be used to monitor and control plant or equipment. The control may be automatic, or initiated by operator commands. The data acquisition is accomplished firstly by the RTU's (remote Terminal Units) scanning the field inputs connected to the RTU (RTU may also be called a PLC - programmable logic controller). This is usually at a fast rate. The central host will scan the RTU's (usually at a slower rate.)

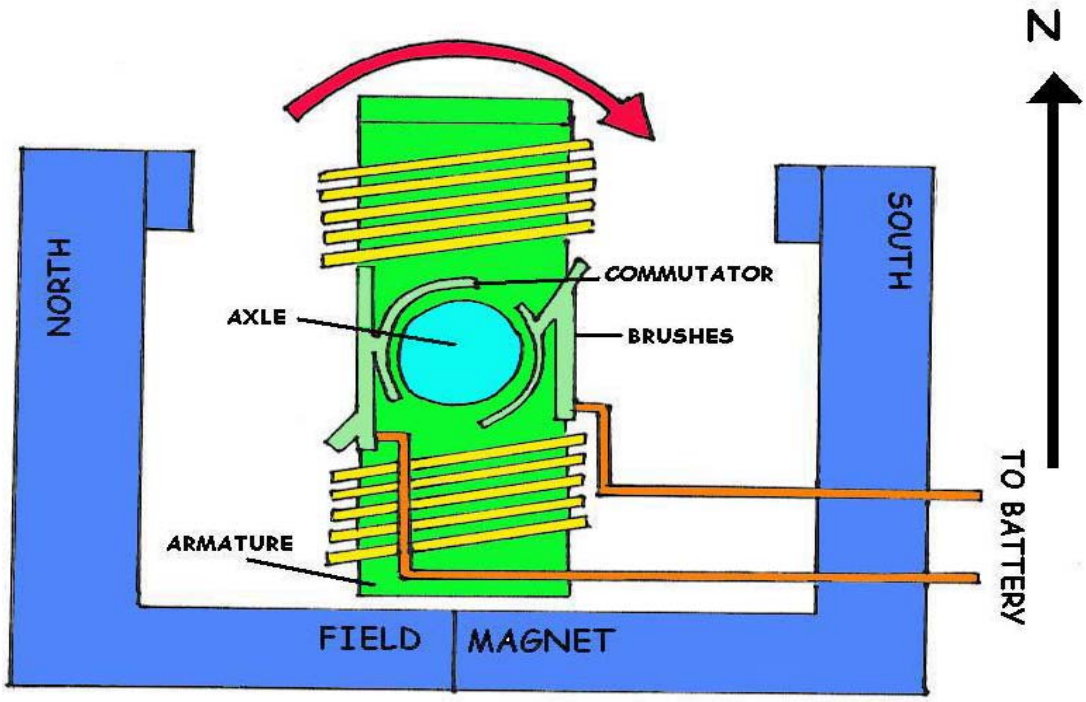
The data is processed to detect alarm conditions, and if an alarm is present, it will be displayed on special alarm lists. Data can be of three main types. Analogue data (i.e. real numbers) will be trended (i.e. placed in graphs). Digital data (on/off) may have alarms attached to one state or the other. Pulse data (e.g. counting revolutions of a meter) is normally accumulated or counted.



The primary interface to the operator is a graphical display (mimic) usually via a PC Screen which shows a representation of the plant or equipment in graphical form. Live data is shown as graphical shapes (foreground) over a static background. As the data changes in the field, the foreground is updated. A valve may be shown as open or closed. Analog data can be shown either as a number, or graphically. The system may have many such displays, and the operator can select from the relevant ones at any time.



Finger is shown pointing to a Lantern Ring. This old school method of sealing a pump is still out there. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow air to the Stuffing Box.



Backflow Cross-Connection Section



A Certified Backflow Tester examining a Double Check Detector check fire line assembly.

Notice the water meter which will detect any un-authorized water usage that will be used in the fire line.



Recent Backflow Situations

Oregon 1993
Water from a drainage pond, used for lawn irrigation, is pumped into the potable water supply of a housing development.

California 1994
A defective backflow device in the water system of the County Courthouse apparently caused a sodium nitrate contamination that sent 19 people to the hospital.

New York 1994
An 8-inch reduced pressure principle backflow assembly in the basement of a hospital discharged under backpressure conditions, dumping 100,000 gallons of water into the basement.

Nebraska 1994
While working on a chiller unit of an air conditioning system at a nursing home, a hole in the coil apparently allowed Freon to enter the circulating water and from there into the city water system.

California 1994
The blue tinted water in a pond at an amusement park backflowed into the city water system and caused colored water to flow from homeowners' faucets.

California 1994
A film company shooting a commercial for television accidentally introduced a chemical into the potable water system.

Iowa 1994
A backflow of water from the Capitol Building chilled water system contaminated potable water with Freon.

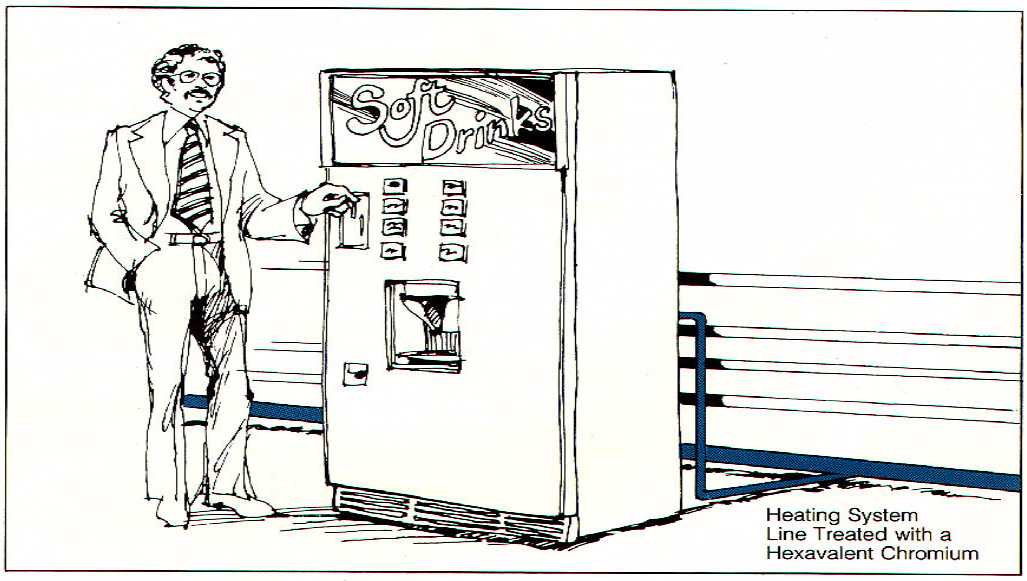
Indiana 1994
A water main break caused a drop in water pressure allowing anti- freeze from an air conditioning unit to backsiphon into the potable water supply.

Washington 1994
An Ethylene Glycol cooling system was illegally connected to the domestic water supply at a veterinarian hospital.

Ohio 1994
An ice machine connected to a sewer sickened dozens of people attending a convention.

Cross-Connection Terms

Cross-Connection
A cross-connection is any temporary or permanent connection between a public water system or consumer's potable (i.e., drinking) water system and any source or system containing nonpotable water or other substances. An example is the piping between a public water system or consumer's potable water system and an auxiliary water system, cooling system, or irrigation system.



Contaminant: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.

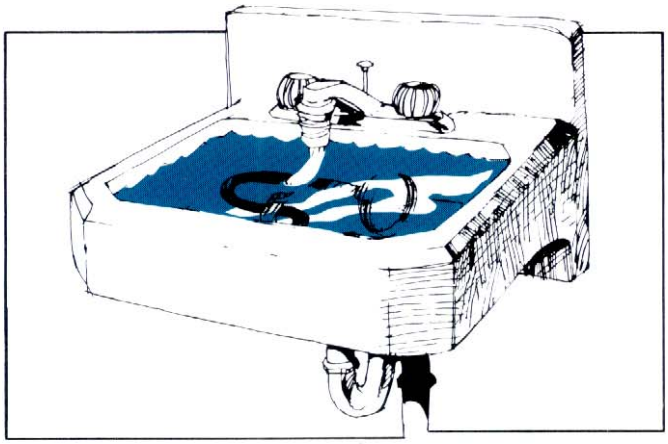
Contamination: To make something bad; to pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

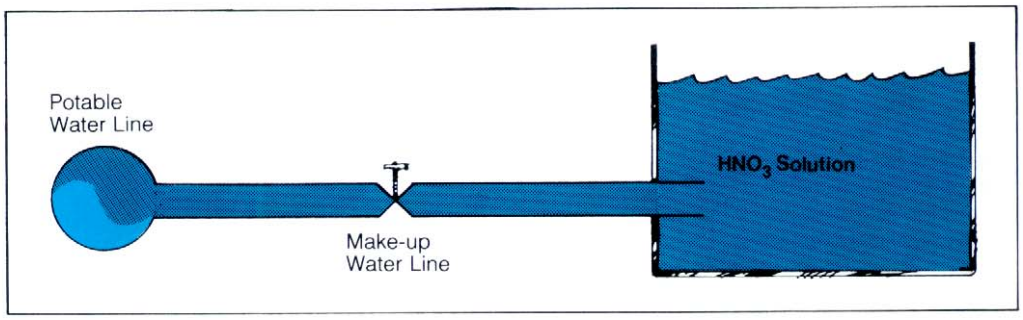
Corrosion: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

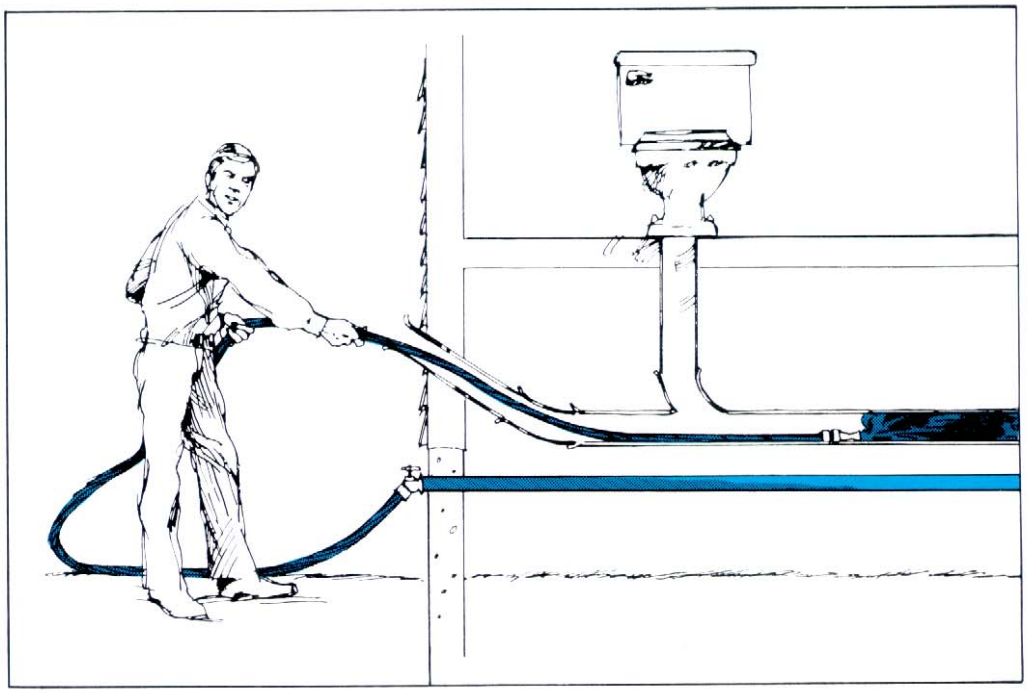
Cross-Connection Failure: Could be the source of an organic substance causing taste and odor problems in a water distribution system.

Cross-Connection: A physical connection between a public water system and any source of water or other substance that may lead to contamination of the water provided by the public water system through backflow. The mixing of two unlike qualities of water; for example, the mixing of good water with a polluting substance like a chemical.

Common Cross-Connections





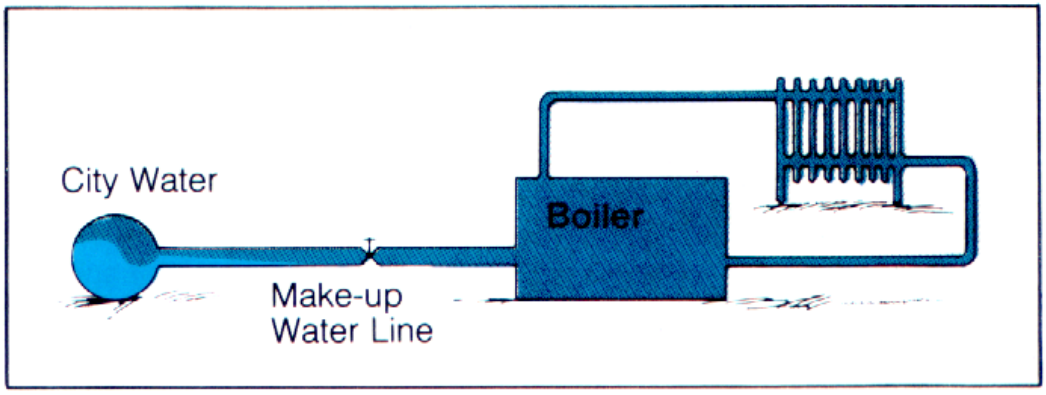


Backflow

Backflow is the undesirable reversal of flow of nonpotable water or other substances through a cross-connection and into the piping of a public water system or consumer's potable water system. There are two types of backflow--**backpressure** and **backsiphonage.**

Backsiphonage



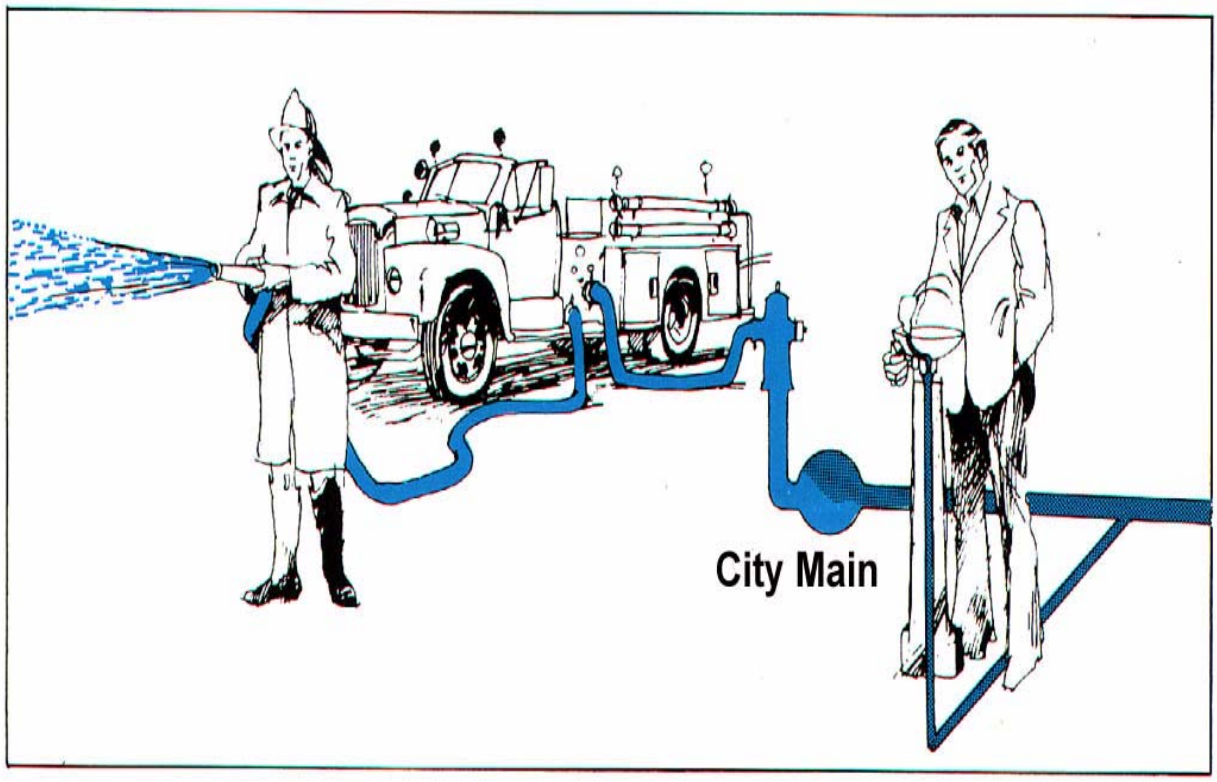


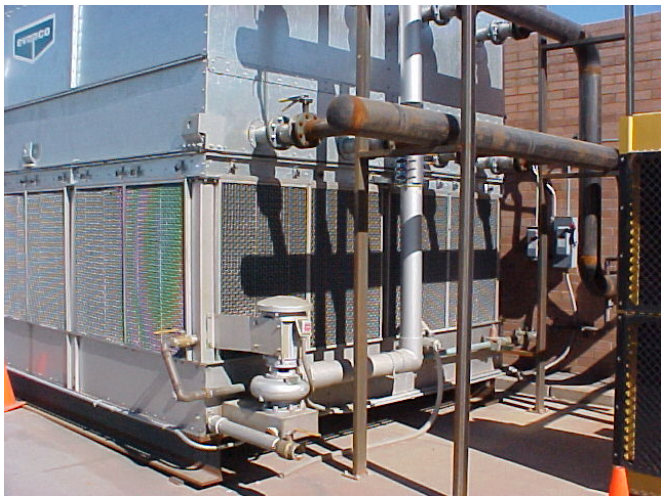
Backpressure

Backsiphonage

Backsiphonage is backflow caused by a negative pressure (i.e., a vacuum or partial vacuum) in a public water system or consumer's potable water system. The effect is similar to drinking water through a straw.

Backsiphonage can occur when there is a stoppage of water supply due to nearby firefighting, a break in a water main, etc.



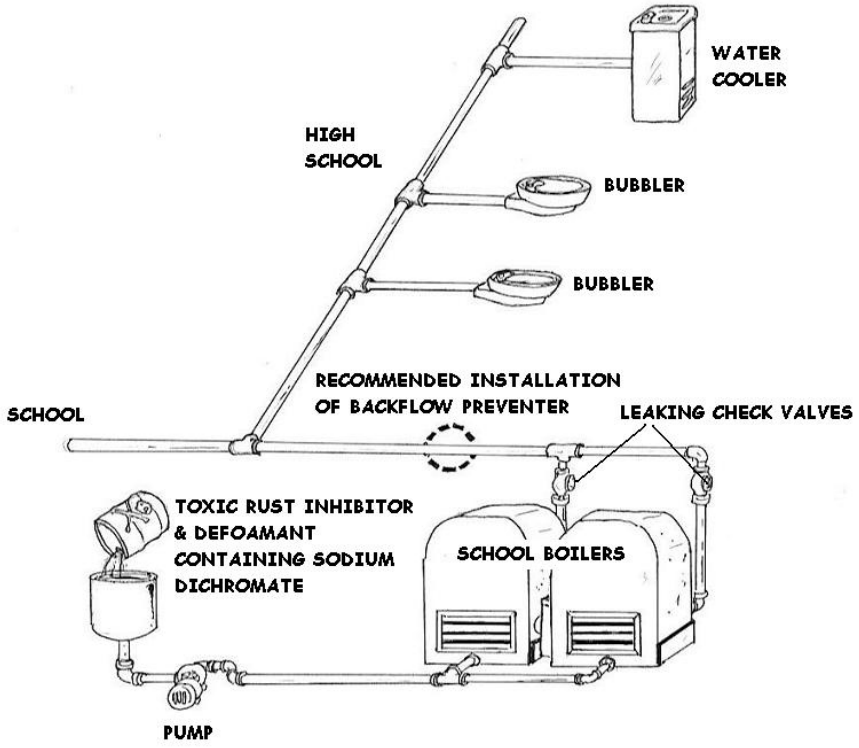


Cooling Tower - A common location for finding a cross-connection.

Backpressure

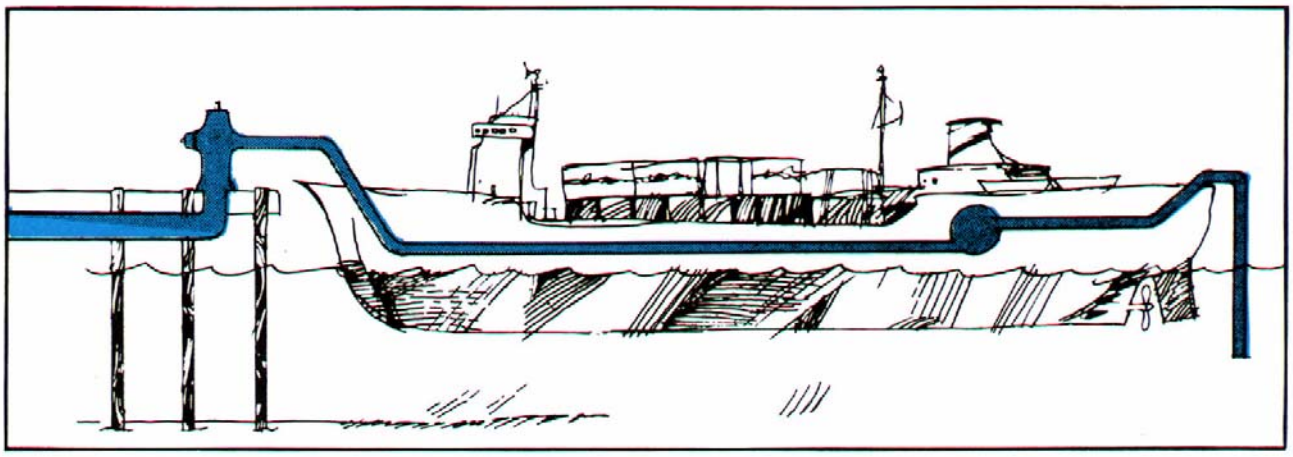
Backpressure backflow is backflow caused by a downstream pressure that is greater than the upstream or supply pressure in a public water system or consumer's potable water system. Backpressure (i.e., downstream pressure that is greater than the potable water supply pressure) can result from an increase in downstream pressure, a reduction in the potable water supply pressure, or a combination of both. Increases in downstream pressure can be created by pumps, temperature increases in boilers, etc.

Reductions in potable water supply pressure occur whenever the amount of water being used exceeds the amount of water being supplied, such as during water line flushing, firefighting, or breaks in water mains.



Backpressure Example:

Booster Pumps, Pressure Vessels, Boilers



Backflow and Cross-Connection Review Statements

Backflow Condition: A continuous positive pressure in a distribution system is essential for preventing what event?

Backflow or Cross-Connection Failure: What might be the source of an organic substance causing taste and odor problems in a water distribution system?

Backflow Prevention: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquids, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

Backflow: Minimum water pressure must be maintained to ensure adequate customer service during peak flow periods. However, minimum positive pressure must be maintained in mains to protect against backflow or backsiphonage from cross-connections.

Backflow: Name the most common ***CAUSE*** for public water supply contamination. Backflow or cross-connection.

Backflow: To reverse the natural and normal directional flow of liquids, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

Backflow: What does a backsiphonage condition usually cause? Reduced pressure or negative pressure on the service or supply side.

Backflow: What does a double check valve backflow assembly provide effective protection from? Both backpressure and backsiphonage of pollution only.

Backflow: What is equipment that utilizes water for cooling, lubrication, washing or as a solvent always susceptible to? A cross-connection.

Backflow: What is the definition of '***backflow***'? A reverse flow condition that causes water or mixtures of water and other liquids, gases, or substances to flow back into the distribution system.

Backflow: What is the difference between a reduced pressure principle backflow device and a double check backflow device? The RP has a relief valve.

Backflow: What is the maximum time period between having a backflow device tested by a certified backflow tester? 1 year.

Backflow: What must an operator ensure when installing a pressure vacuum breaker backflow device? It must be at least 12 inches above the highest downstream outlet.

Backflow Responsibility

The Public Water Purveyor

The primary responsibility of the water purveyor is to develop and maintain a program to prevent or control contamination from water sources of lesser quality or other contamination sources from entering into the public water system. Under the provisions of the Safe Drinking Water Act of 1974, (**SDWA**) and current Groundwater Protection rules the Federal Government, through the EPA (Environmental Protection Agency), set national standards of safe drinking water. The separate states are responsible for the enforcement of these standards as well as the supervision of public water systems and the sources of drinking water. The water purveyor or supplier is held responsible for compliance to the provisions of the Safe Drinking Water Act, to provide a warranty that water quality by their operation is in conformance with EPA standards at the source, and is delivered to the customer without the quality being compromised as it is delivered through the distribution system.

This is specified in the Code of Federal Regulations (Volume 40, Paragraph141.2 Section c)":

Maximum contaminant level means the permissible level of a contaminant in water which is delivered to the free flowing outlet of the ultimate user of a public water system, except in the case of turbidity where the maximum permissible level is measured at the point of entry (**POE**) to the distribution system. Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing caused by water quality, are excluded from this definition.

The Water Consumer

Has the responsibility to prevent contaminants from entering into the public water system by way of their individual plumbing system, and retain the expenses of installation, maintenance, and testing of the approved backflow prevention assemblies installed on their individual water service line.

The Certified General Backflow Tester

Has the responsibility to test, maintain, inspect, repair, and report/notify on approved backflow prevention assemblies as authorized by the persons that have jurisdiction over those assemblies.

Backflow into a public water system can pollute or contaminate the water in that system (i.e., backflow into a public water system can make the water in that system unusable or unsafe to drink), and each water supplier has a responsibility to provide water that is usable and safe to drink under all fore-seeable circumstances. Furthermore, consumers generally have absolute faith that water delivered to them through a public water system is always safe to drink. For these reasons, each water supplier must take reasonable precautions to protect its public water system against backflow.

What should water suppliers do to control cross-connections and protect their public water systems against backflow?

Water suppliers usually do not have the authority or capability to repeatedly inspect every consumer's premises for cross-connections and backflow protection. Alternatively, each water supplier should ensure that a proper backflow preventer is installed and maintained at the water service connection to each system or premises that pose a significant hazard to the public water system.

Generally, this would include the water service connection to each dedicated fire protection system or irrigation piping system and the water service connection to each of the following types of premises:

(1) Premises with an auxiliary or reclaimed water system.
(2) Industrial, medical, laboratory, marine or other facilities where objectionable substances are handled in a way that could cause pollution or contamination of the public water system.
(3) Premises exempt from the State Plumbing Code and premises where an internal backflow preventer required under the State Plumbing Code is not properly installed or maintained.
(4) Classified or restricted facilities; and
(5) Tall buildings.

Each water supplier should also ensure that a proper backflow preventer is installed and maintained at each water loading station owned or operated by the water supplier.

Degrees of Hazards (HAZARD RATINGS) High, *Contaminant* and Low, *Pollutional*

Containment Protection, *Secondary protection*
This approach utilizes a minimum of backflow devices and isolates the customer from the water main. It virtually insulates the customer from potentially contaminating or polluting the public water supply system. Containment protection does not protect the customer within his own building, it does effectively remove him from the possibility public water supply contamination. Containment protection is usually a backflow prevention device as close as possible to the customer's water meter and is often referred to as "***Secondary Protection***". This type of backflow protection is excellent for water purveyors and is the least expense to the water customer, but does not protect the occupants of the building.

Internal Protection, *Primary protection*
The water purveyor may elect to protect his customers on a domestic internal protective basis and/or "***fixture outlet protective basis***," in this case cross-connection-control devices (backflow preventors) are placed at internal hazard locations and at all locations where cross-connections may exist, including the ***"last free flowing outlet."*** This type of protection entails extensive cross-connection survey work usually performed by a plumbing inspector or a Cross-Connection Specialist. In a large water supply system, internal protection in itself is virtually impossible to achieve and police due to the quantity of systems involved, the complexity of the plumbing systems inherent in many industrial sites, and the fact that many plumbing changes are made within commercial establishments that do not get the plumbing department's approval or require that the water department inspects when the work is completed.

Internal protection is the most expensive and best type of backflow protection for both the water purveyor and the customer alike, but is very difficult to maintain. In order for the purveyor to provide maximum protection of the water distribution system, consideration should be given to requiring the owner of the premises to provide at his own expense, adequate proof that his internal water supply system complies with the local or state plumbing code(s).

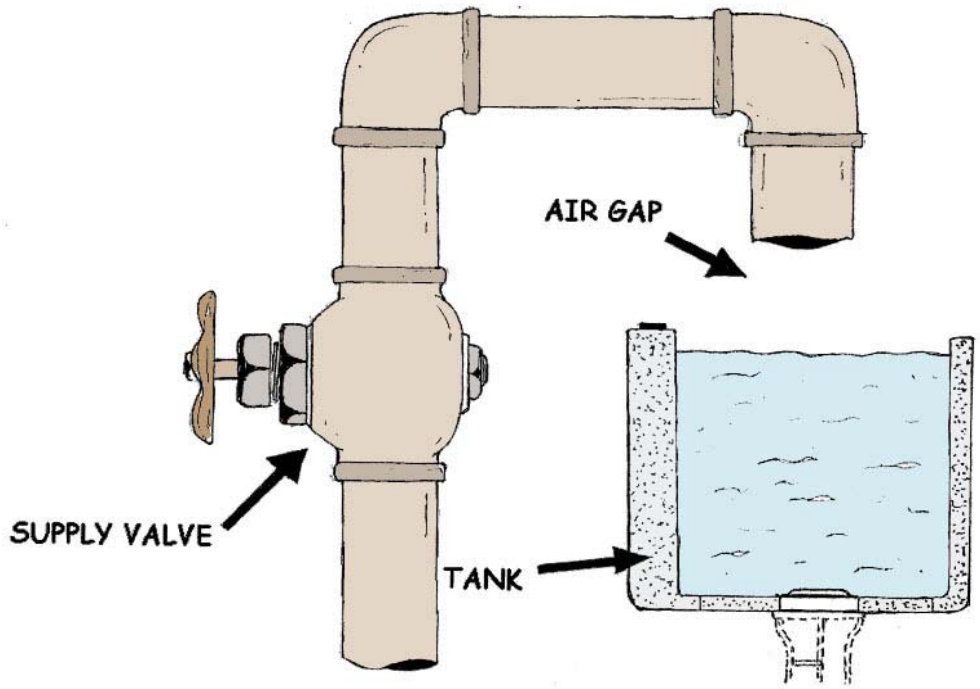
Backflow Prevention Methods and Assemblies

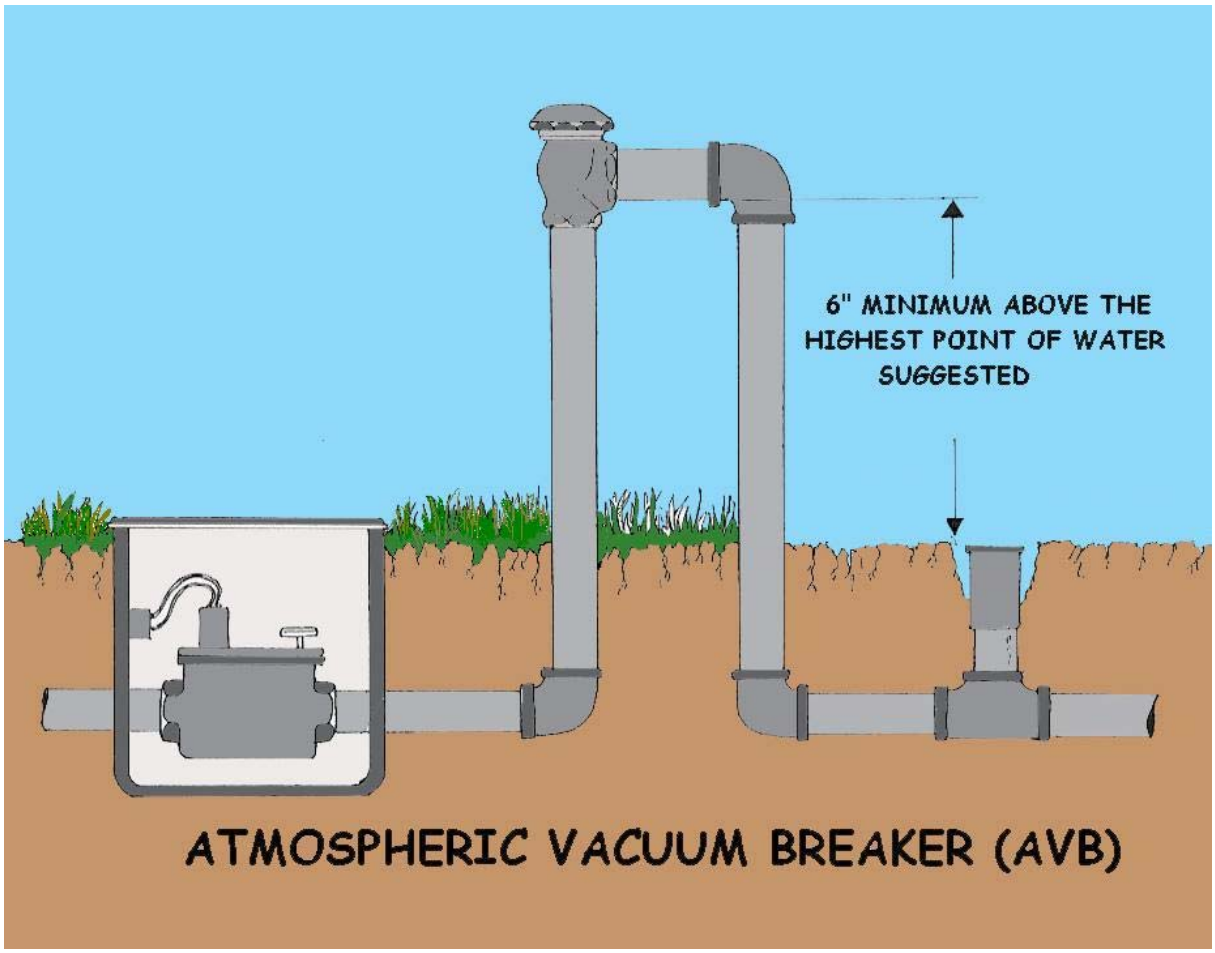
Approved Air Gap Separation (AG)
An approved air gap is a physical separation between the free flowing discharge end of a potable water supply pipeline, and the overflow rim of an open or non-pressure receiving vessel. These separations must be vertically orientated a distance of at least twice the inside diameter of the inlet pipe, but never less than one inch.

An obstruction around or near an air gap may restrict the flow of air into the outlet pipe and nullify the effectiveness of the air gap to prevent backsiphonage. When the air flow is restricted, such as in the case of an air gap located near a wall, the air gap separation must be increased. Also, within a building where the air pressure is artificially increased above atmospheric, such as a sports stadium with a flexible roof kept in place by air blowers, the air gap separation must be increased.

Air gap or vacuum breaker: What should a potable water line be equipped with when connected to a chemical feeder for fluoride?

Air Gap Separation: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.





Atmospheric Vacuum Breaker (AVB)

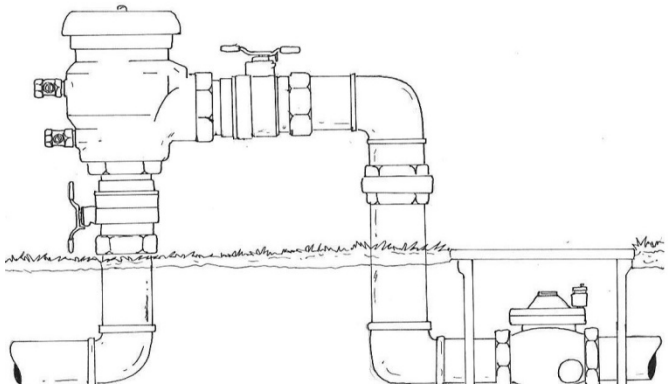
The Atmospheric Vacuum Breaker contains a float check (poppet), a check seat, and an air inlet port. The device allows air to enter the water line when the line pressure is reduced to a gauge pressure of zero or below. The air inlet valve is not internally loaded. To prevent the air inlet from sticking closed, the device must not be installed on the pressure side of a shutoff valve, or wherever it may be under constant pressure more than 12 hours during a 24 hour period. Atmospheric vacuum breakers are designed only to prevent backflow caused by backsiphonage from low health hazards.

Atmospheric Vacuum Breaker Uses: Irrigation systems, commercial dishwasher and laundry equipment, chemical tanks and laboratory sinks (backsiphonage only, non-pressurized connections). (Note: hazard relates to the water purveyor's risk assessment; plumbing codes may allow AVB for high hazard fixture isolation).

Pressure Vacuum Breaker Assembly (PVB)

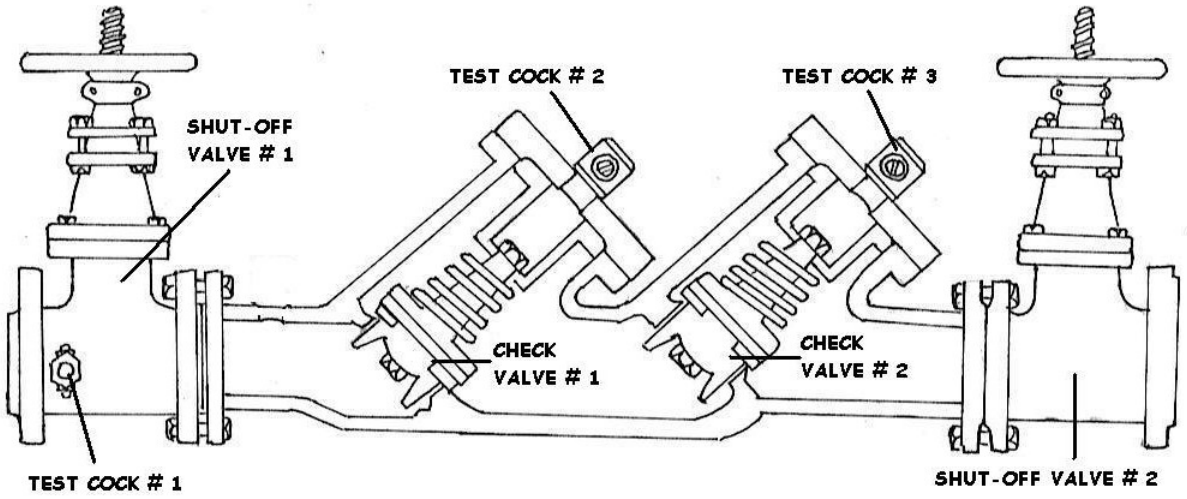
The Pressure Vacuum Breaker Assembly consists of a spring-loaded check valve, an independently operating air inlet valve, two resilient seated shutoff valves, and two properly located resilient seated test cocks. It shall be installed as a unit as shipped by the manufacturer. The air inlet valve is internally loaded to the open position, normally by means of a spring, allowing installation of the assembly on the pressure side of a shutoff valve.

PRESSSURE VACUUM BREAKER ASSEMBLY



Double Check Valve Assembly (DC)

The Double Check Valve Assembly consists of two internally loaded check valves, either spring loaded or internally weighted, two resilient seated full ported shutoff valves, and four properly located resilient seated test cocks. This assembly shall be installed as a unit as shipped by the manufacturer. The double check valve assembly is designed to prevent backflow caused by backpressure and backsiphonage from low health hazards.

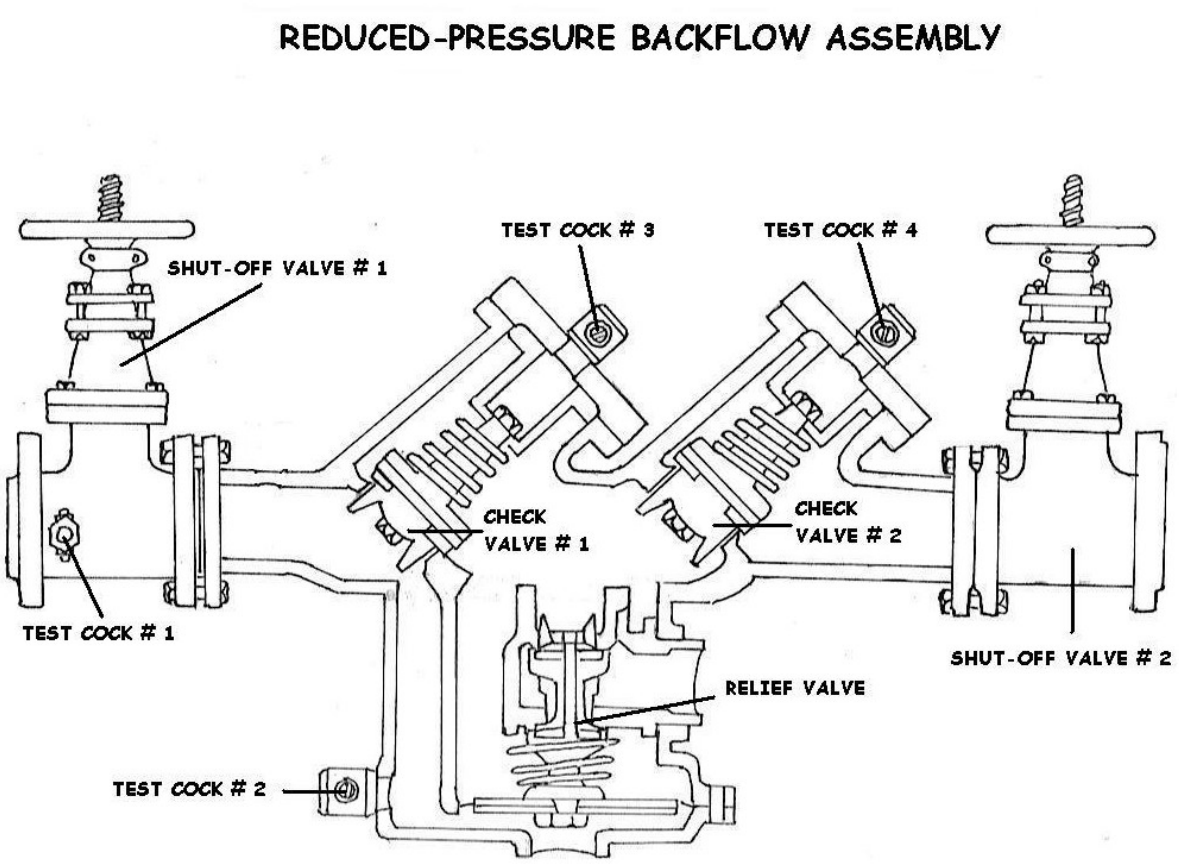


DOUBLE-CHECK BACKFLOW ASSEMBLY

Reduced Pressure Backflow Assembly (RP)

The reduced pressure backflow assembly consists of two independently acting spring loaded check valves separated by a spring loaded differential pressure relief valve, two resilient seated full ported shutoff valves, and four properly located resilient seated test cocks. This assembly shall be installed as a unit shipped by the manufacturer.

During normal operation, the pressure between the two check valves, referred to as the zone of reduced pressure, is maintained at a lower pressure than the supply pressure. If either check valve leaks, the differential pressure relief valve maintains a differential pressure of at least two (2) psi between the supply pressure, and the zone between the two check valves, by discharging water to atmosphere. The reduced pressure backflow assembly is designed to prevent backflow caused by backpressure and backsiphonage from low to high health hazards.



Various examples of RPs and these are easy to find around most water treatment facilities. Incredibly, these devices can be found installed incorrectly, or even installed backwards with the guts removed.

Why do Backflow Preventers Have to be Tested Periodically?

Mechanical backflow preventers have internal seals, springs, and moving parts that are subject to fouling, wear, or fatigue. Also, mechanical backflow preventers and air gaps can be bypassed. Therefore, all backflow preventers have to be tested periodically to ensure that they are functioning properly. A visual check of air gaps is sufficient, but mechanical backflow preventers have to be tested with properly calibrated gauge equipment.

Backflow prevention devices must be tested annually to ensure that they work properly. It is usually the responsibility of the property owner to have this test done and to make sure that a copy of the test report is sent to the Public Works Department or Water Purveyor.

If a device is not tested annually, Public Works or the Water Purveyor will normally notify the property owner, asking them to comply. If the property owner does not voluntarily test their device, the Water provider may be forced to turn off water service to that property. State law may require the Water provider to discontinue water service until testing is complete.

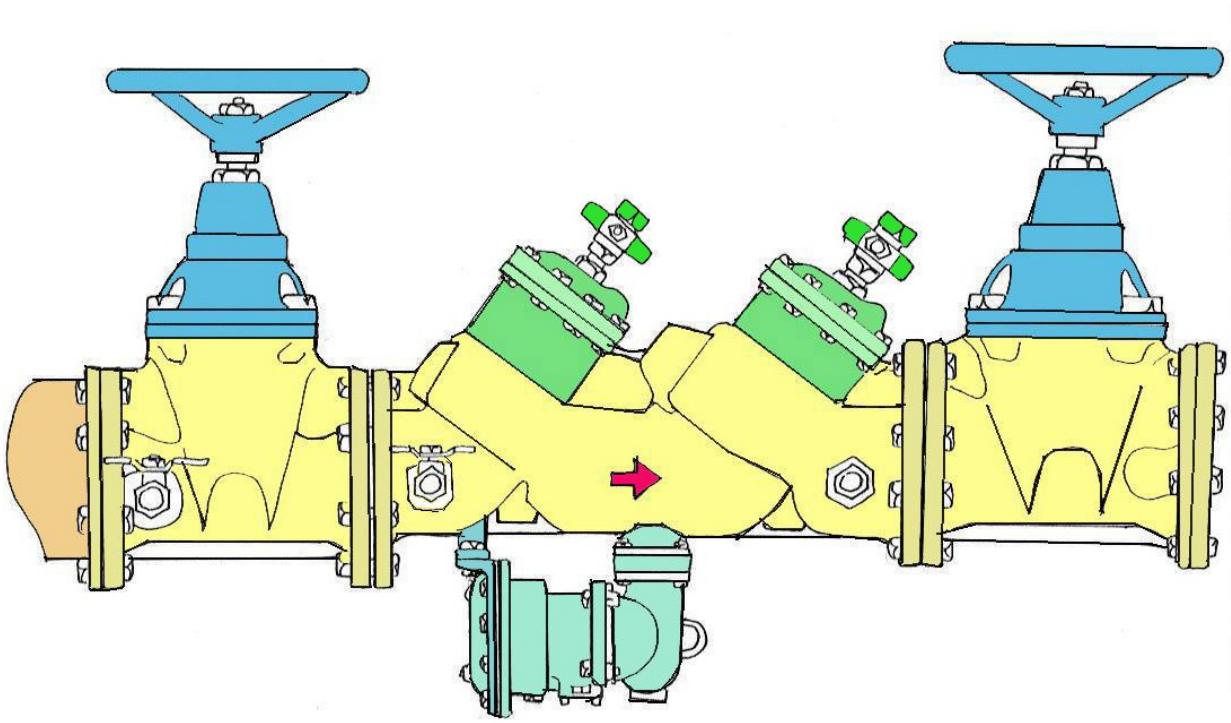
Troubleshooting Table for Cross Connection Problem
1. Sudsy or soapy water.
3. Positive Coliform.
3. Coloring in the water (unusual colors such as bright blue).
4. Organic odors.

Possible Causes
1A. Hose connected to an unprotected hose bib with the other end in a bucket or sink of soapy water.
2A. Hose connected to an unprotected hose bib with the other end lying on the floor of the pump house, on the ground in the car wash area, in the wading or swimming pool or other nonpotable liquid.
2B. Unprotected potable water line feeding a lawn irrigation system.
2C. Submerged inlet, e.g. faucet submerged.
3A. Backflow from toilet.
4A. Handheld pesticide/herbicide applicator attached to unprotected hose.

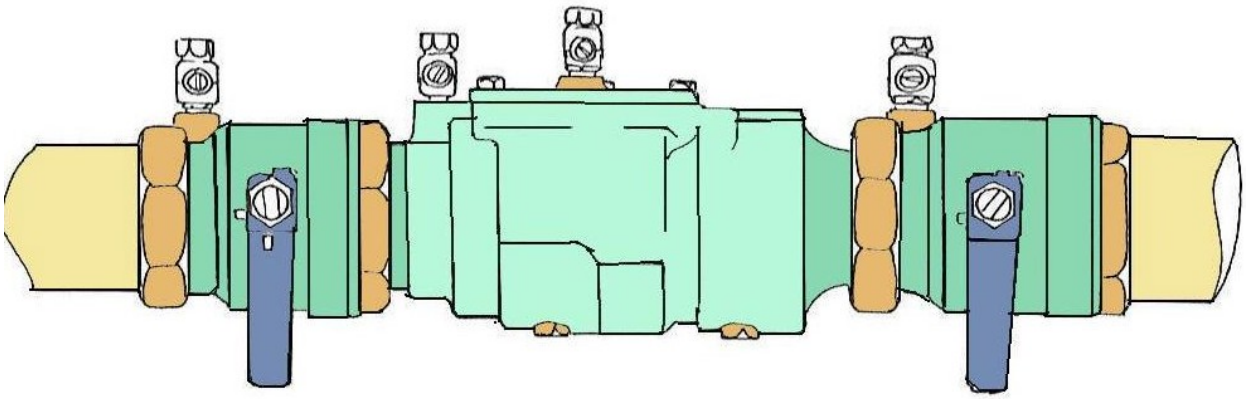
Possible Solutions
1A. Equip all hose bibs with an AVB.
2A. Equip all hose bibs with an AVB.
2B. Install a backflow preventer on the potable water line feeding the irrigation system.
2C. Relocate faucet above flood level.
3A. Get help. Bring in someone who understands cross connections to evaluate the system.
4A. Don't use these devices



This PVB is not 12 inches above the ground nor the highest downstream outlet.



REDUCED PRESSURE BACKFLOW ASSEMBLY



DOUBLE CHECK VALVE ASSEMBLY



Competent Person Duties and Responsibilities

- Performs daily inspections of the protective equipment, trench conditions, safety equipment and adjacent areas.
- Inspections shall be made prior to the start of work and as needed throughout the shift.
- Inspections shall be made after every rainstorm or other hazard occurrence.
- Knowledge of emergency contact methods, telephone or radio dispatch.
- Removes employees and all other personnel from hazardous conditions and makes all changes necessary to ensure their safety.
- Insures all employees have proper protective equipment, hard-hats, reflective vests, steel-toed boots, harnesses, eye protection, hearing protection and drinking water.
- Categorize soil conditions and conduct visual and manual tests.
- Determine the appropriate protection system to be used.
- Maintain on-site records of inspections and protective systems used.
- Maintain on site a Hazard Communication program, Safety Data Sheets (SDS)s and a Risk Management Plan if necessary.
- Maintain current First Aid and CPR certifications. Maintain current Confined Space certification training.

Water Distribution Valves

Water distribution valves are provided in the design of the water systems to allow for the isolation and shut-off of water when emergency conditions occur. It is important to recognize that these valves are a critical link in the management of emergencies that occur in the distribution system. Additionally, these valves are usually operated infrequently therefore, the establishment of an annual valve exercising program is essential to the viability of an utility emergency operations plan.

Emergency operations of water valves presumes that the system operators are familiar with the exact locations of many key water valves within the water system. Equal in importance is the knowledge that when these valves need to be operated in order to isolate a section of the distribution system, they will operate and close effectively in order to prevent a large loss of the water recourse and excessive property damage.

Routine valve inspections should be conducted on the water system valves and the following tasks are accomplished:

- The accuracy of all valves and valve boxes is verified against existing records. If inconsistencies are found, the records are updated to reflect accurate information.
- An inspection is performed on each valve stem and nut to determine if any damage exists.
- The valve is fully closed and the number of turns necessary to accomplish a full closing is recorded.
- The valve is re-opened, and the system flows are re-established.
- The valve box and cover is cleaned, inspected for damaged and painted blue.

Exercising of all valves should be accomplished at the same time as the valve inspection. The exercising program assures that the valve operates and loosens any encrustation from valve seats and gates. Many valve manufacturers recommend that the valve stem be completely opened and then backed off by one complete turn.



Portable valve exercising machine.

Distribution System Design

System design depends on the area where you live. You may be a flatlander, like in Texas, and the services could be spread out for miles. You may live in the Rocky Mountain area and have many fluctuating elevations. Some areas may only serve residents on a part time basis and water will sit for long periods of time, while other areas may have a combination of peaks and valleys with short and long distances of service. Before you design the system, you need to ask yourself some basic questions.

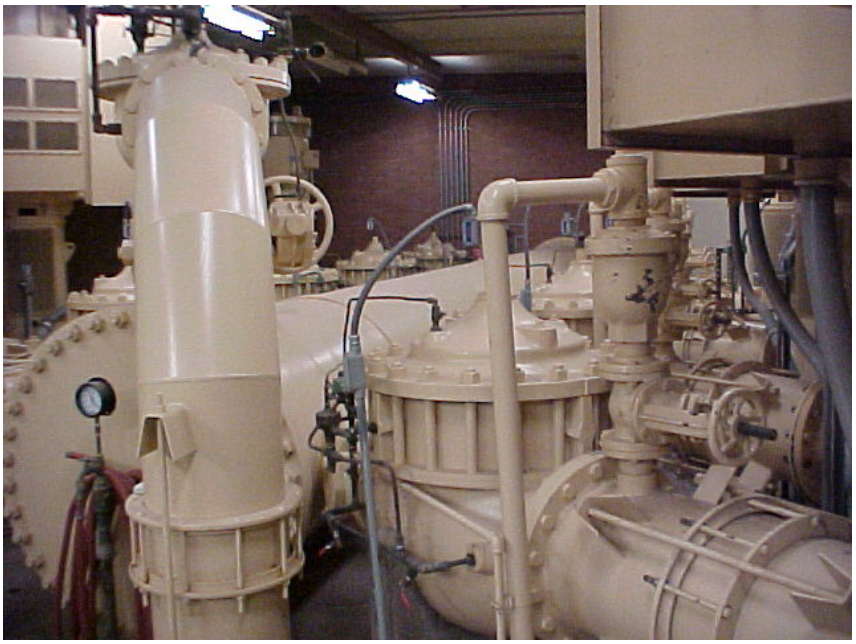
1. ***What is the source of water?***
2. ***What is the population?***
3. ***What kind of storage will I need for high demand and emergencies?***
4. ***How will the pressure be maintained?***

System Elements
The elements of a water distribution system include: distribution mains, arterial mains, storage reservoirs, and system accessories. These elements and accessories are described as follows:

Distribution Mains Distribution mains are the pipelines that make up the distribution system. Their function is to carry water from the water source or treatment works to users.

Arterial Mains Arterial mains are distribution mains of large size. They are interconnected with smaller distribution mains to form a complete gridiron system.

Storage Reservoirs Storage reservoirs are structures used to store water. They also equalize the supply or pressure in the distribution system. A common example of a storage reservoir is an aboveground water storage tank.

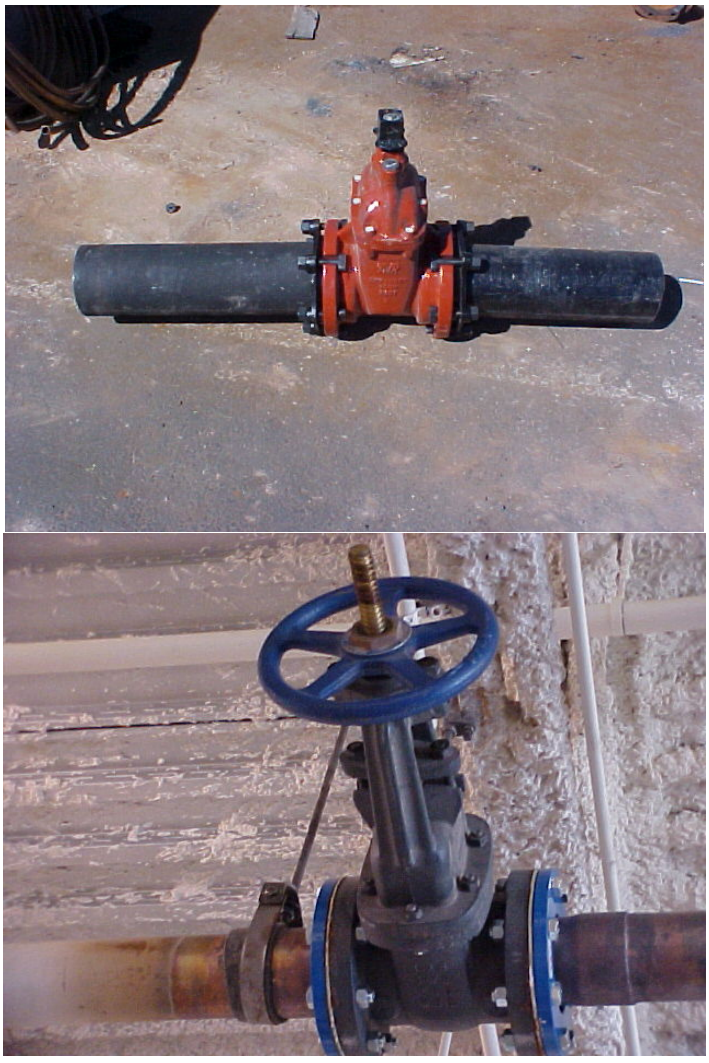


Inside a giant booster pump station.

System Accessories Include the Following

Booster stations are used to increase water pressure from storage tanks for low-pressure mains.

Valves control the flow of water in the distribution system by isolating areas for repair or by regulating system flow or pressure.



Different types of Gate Valves. (Linear)

Top photograph is valve ready for a valve re-placement. It has a Mechanical Type Joint. Bottom photograph is OS&Y commonly found on fire lines. This is a Flange type joint. (Outside Screw and Yoke) As the gate is lifted or opened, the stem will rise.

Gate valves should be used in the distribution system for main line isolation only. Gate Valve is a linear type of valve. Gate valves should be stored upright with the gate down.

Distribution Valves

The purpose of installing shutoff valves in water mains at various locations within the distribution system is to allow sections of the system to be taken out of service for repairs or maintenance, without significantly curtailing service over large areas.

Valves should be installed at intervals not greater than 5,000 feet in long supply lines, and 1,500 feet in main distribution loops or feeders. All branch mains connecting to feeder mains or feeder loops should have valves installed as close to the feeders as practical. In this way, branch mains can be taken out of service without interrupting the supply to other locations. In the areas of greatest water demand, or when the dependability of the distribution system is particularly important, valve spacing of 500 feet may be appropriate.

At intersections of distribution mains, the number of valves required is normally one less than the number of radiating mains. The valve omitted from the line is usually the one that principally supplies flow to the intersection. Shutoff valves should be installed in standardized locations (that is, the northeast comer of intersections or a certain distance from the center line of streets), so they can be easily found in emergencies. All buried small- and medium-sized valves should be installed in valve boxes. For large shutoff valves (about 30 inches in diameter and larger), it may be necessary to surround the valve operator or entire valve within a vault or manhole to allow repair or replacement.

Gate Valves
Gate valves are used when a straight-line flow of fluid and minimum flow restriction are needed. Gate valves are so-named because the part that either stops or allows flow through the valve acts somewhat like a gate.

The gate is usually wedge-shaped. When the valve is wide open, the gate is fully drawn up into the valve bonnet. This leaves an opening for flow through the valve the same size as the pipe in which the valve is installed. Therefore, there is little pressure drop or flow restriction through the valve. Gate valves are not suitable for throttling purposes. The control of flow is difficult because of the valve's design, and the flow of fluid slapping against a partially open gate can cause extensive damage to the valve. Except as specifically authorized, gate valves should not be used for throttling.

Ball Valves
Most ball valves are the quick-acting type. They require only a 90-degree turn to either completely open or close the valve. However, many are operated by planetary gears. This type of gearing allows the use of a relatively small handwheel and operating force to operate a fairly large valve. The gearing does, however, increase the operating time for the valve. Some ball valves also contain a swing check located within the ball to give the valve a check valve feature. Ball valves should be either fully-on or fully-off.

Valve Exercising
Valve exercising should be done once per year (especially main line valves) to detect malfunctioning valves and to prevent valves from becoming inoperable due to freezing or build-up of rust or corrosion. A valve inspection should include drawing valve location maps to show distances (ties) to the valves from specific reference points (telephone poles, stonelines, etc.).

Hydrants are designed to allow water from the distribution system to be used for fire-fighting purposes.



Bottom of a dry barrel fire hydrant; there is a drainage hole on the back of this hydrant, sometimes referred to as a "weep hole".



Notice the corrosion inside this cast iron main.

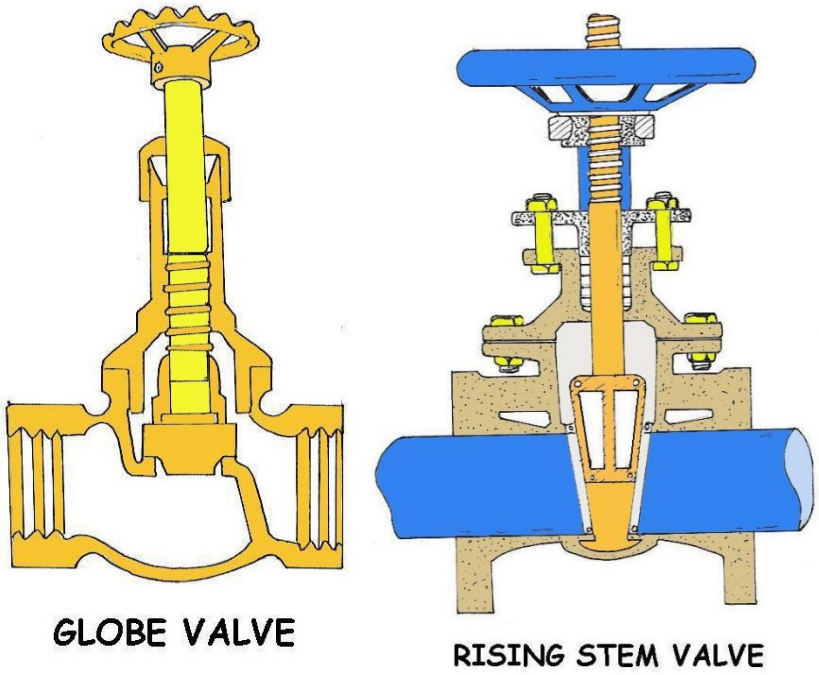
This corrosion is caused by chemical changes produced by electricity or electrolysis. We call this type of corrosion tuberculation. It is a protective crust of corrosion products that have built up over a pit caused by the loss of metal due to corrosion or electrolysis. This type of corrosion will decrease the C-Factor and the carrying capacity in a pipe. Crenothrix bacteria or Red-Iron bacteria will live in the bioslime in this type of tuberculation.

Common Rotary Valves

Globe Valve *Rotary Valve*

Primarily used for flow regulation, and works similar to a faucet. They are rare to find in most distribution systems, but can be found at treatment plants. Always follow standard safety procedures when working on a valve. Most Globes have compact OS & Y type, bolted bonnet, rising stems with renewable seat rings. The disc results with most advanced design features provide the ultimate in dependable, economical flow control.

Globe valves should usually be installed with the inlet below the valve seat. For severe throttling service, the valve may be installed so that the flow enters over the top of the seat and goes down through it. Note that in this arrangement, the packings will be constantly pressurized. If the valve is to be installed near throttling service, verify with an outside contractor or a skilled valve technician. Globe valves, per se, are not suitable for throttling service.



The valve should be welded onto the line with the disc in the fully closed position. Leaving it even partially open can cause distortion and leaking. Allow time for the weld to cool before operating the valve the first time in the pipeline. The preferred orientation of a globe valve is upright. The valve may be installed in other orientations, but any deviation from vertical is a compromise. Installation upside down is not recommended because it can cause dirt to accumulate in the bonnet.

Globe Valve Problems and Solutions

If the valve stem is improperly lubricated or damaged--Disassemble the valve and inspect the stem. Acceptable deviation from theoretical centerline created by joining center points of the ends of the stem is 0.005"/ft of stem. Inspect the threads for any visible signs of damage.

Small grooves less than 0.005" can be polished with an Emory cloth. Contact specialized services or an outside contractor if run-out is unacceptable or large grooves are discovered on the surface of the stem.

If the valve packing compression is too tight--Verify the packing bolt torque and adjust if necessary.

Foreign debris is trapped on threads and/or in the packing area.--This is a common problem when valves are installed outdoors in sandy areas and the areas not cleaned before operating.

Always inspect threads and packing area for particle obstructions; even seemingly small amounts of sand trapped on the drive can completely stop large valves from cycling. The valve may stop abruptly when a cycle is attempted. With the line pressure removed from the valve, disconnect the actuator, gear operator or handwheel and inspect the drive nut, stem, bearings and yoke bushing. Contaminated parts should be cleaned with a lint-free cloth using alcohol, varsol or equivalent. All parts should be re-lubricated before re-assembled. If the valves are installed outdoors in a sandy area, it may be desirable to cover the valves with jackets.

If the valve components are faulty or damaged--contact specialized services or an outside contractor.

If the valve's handwheel is too small--Increasing the size of the handwheel will reduce the amount of torque required to operate the valve. If a larger handwheel is installed, the person operating the valve must be careful not to over-torque the valve when closing it.



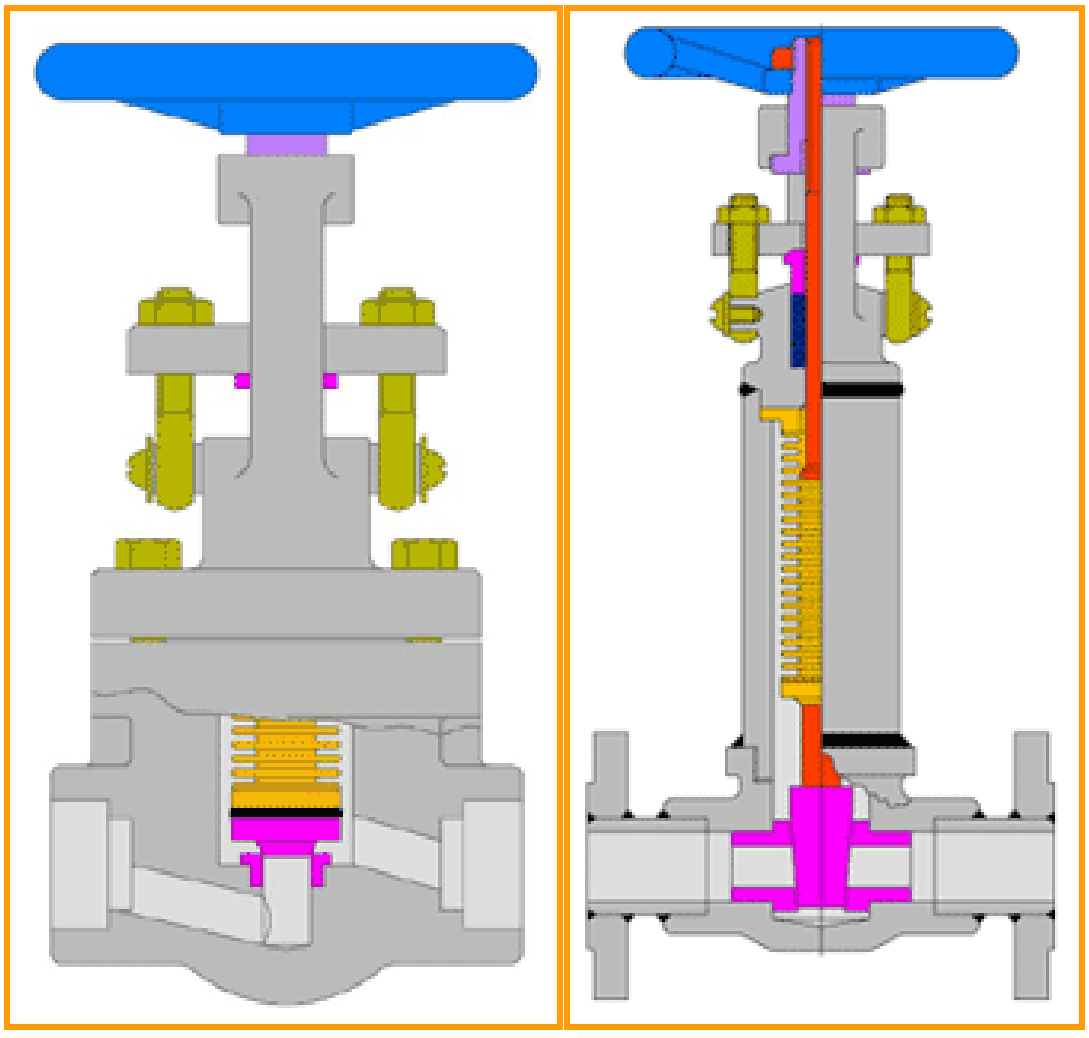
Bellow Seal Valve

Always follow standard safety procedures when working on a valve.

Bellows seal valves provide a complete hermetic seal of the working fluid. They are used in applications where zero leakage of the working fluid into the environment is permitted.

Bellows seal valves are specially modified versions of the standard valves. The installation information that applies to gate and globe valves will apply to bellows seal valves.

A packing leak signifies that the bellows has ruptured or the bellows-assembly weld has a crack. Professor Rusty does not recommend repairing or reusing a damaged bellows. Instead, Professor Rusty suggests replacing the entire bonnet assembly including bellows and stem.



Bellow's style Globe valve on left, Gate valve on right.

Pressure Sustaining Valve
Pressure sustaining valves are used to sustain the system pressure to a predetermined maximum level. The applications balance the pressure distribution throughout the whole system by maintaining the minimum pressure for high altitude users. Pressure sustaining valves are also used to prevent discharging of the pipe system when any user starts to operate. More in a few more pages.

Pressure Reducing Valve
Pressure reducing valves maintain a predetermined outlet pressure which remains steady and unaffected by either changing of inlet pressure and/or various demands. Pressure Reducing Valves are self-contained control valves which do not require external power. More in a few more pages.

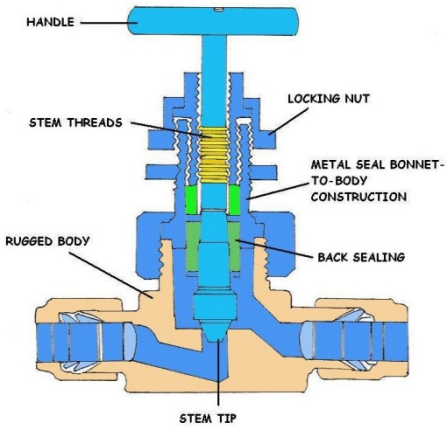
Insertion Valves *Rotary Valve*
Sometimes you have to obtain a shut down and you have only two choices. Do it hot or cut in an insertion or inserting valve. An Insertion valve is normally a Gate Valve that is made to be installed on a hot water main. A few years ago, this was a serious feat. First, you had to pour ten yards of mud or cement and come back and cut the valve in. No longer. The Insertion valve machine and tap works like a tapping sleeve. The only difference is that the tap points up and not to the side. I recommend that any major system budget money to purchase this equipment. It will pay for itself on the first job. Otherwise, contract the work out. You can see in the photograph a manually operated tapping machine. I prefer the electric. Note: see the sweet shoring shield set-up. It is rare to see a nice shoring job.



Hydro Stop valve insertion machine

Needle Valves *Rotary Valve*

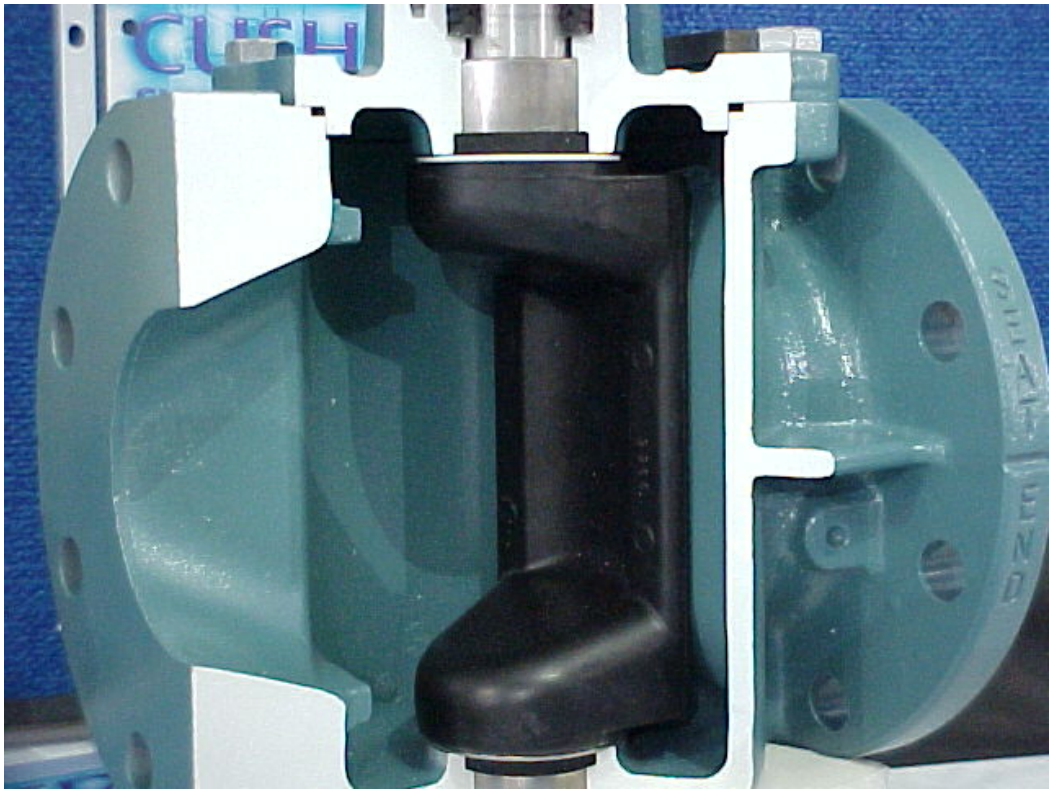
A needle valve, as shown on the right, is used to make relatively fine adjustments in the amount of fluid flow. The distinguishing characteristic of a needle valve is the long, tapered, needle- like point on the end of the valve stem. This "needle" acts as a disk. The longer part of the needle is smaller than the orifice in the valve seat and passes through the orifice before the needle seats. This arrangement permits a very gradual increase or decrease in the size of the opening. Needle valves are often used as component parts of other, more complicated valves. For example, they are used in some types of reducing valves.



NEEDLE VALVE

Plug Valves *Rotary Valve*

Plug valves are extremely versatile valves that are found widely in low-pressure sanitary and industrial applications, especially petroleum pipelines, chemical processing and related fields, and power plants. They are high capacity valves that can be used for directional flow control, even in moderate vacuum systems. They can safely and efficiently handle gas and liquid fuel, and extreme temperature flow, such as boiler feed water, condensate, and similar elements. They can also be used to regulate the flow of liquids containing suspended solids (slurries).



Cut-away of a Plug Valve.

Ball or Corporation Stop *Rotary Valve* ***Small Valves 2 inches and smaller***

Most commonly found on customer or water meters. All small backflow assemblies will have two Ball valves. It is the valve that is either fully on or fully off; and the one that you use to test the abilities of a water service rookie. The best trick is to remove the ball from the Ball valve and have a rookie *Jump a Stop*. The Corp is usually found at the water main on a saddle. Some people say that the purpose of the Corp is to regulate the service. I don't like that explanation. No one likes to dig up the street to regulate the service and Ball valves are only to be used fully on or fully off.



Most ball valves are the quick-acting type. They require only a 90-degree turn to either completely open or close the valve. However, many are operated by planetary gears. This type of gearing allows the use of a relatively small handwheel and operating force to operate a fairly large valve. Always follow standard safety procedures when working on a valve.



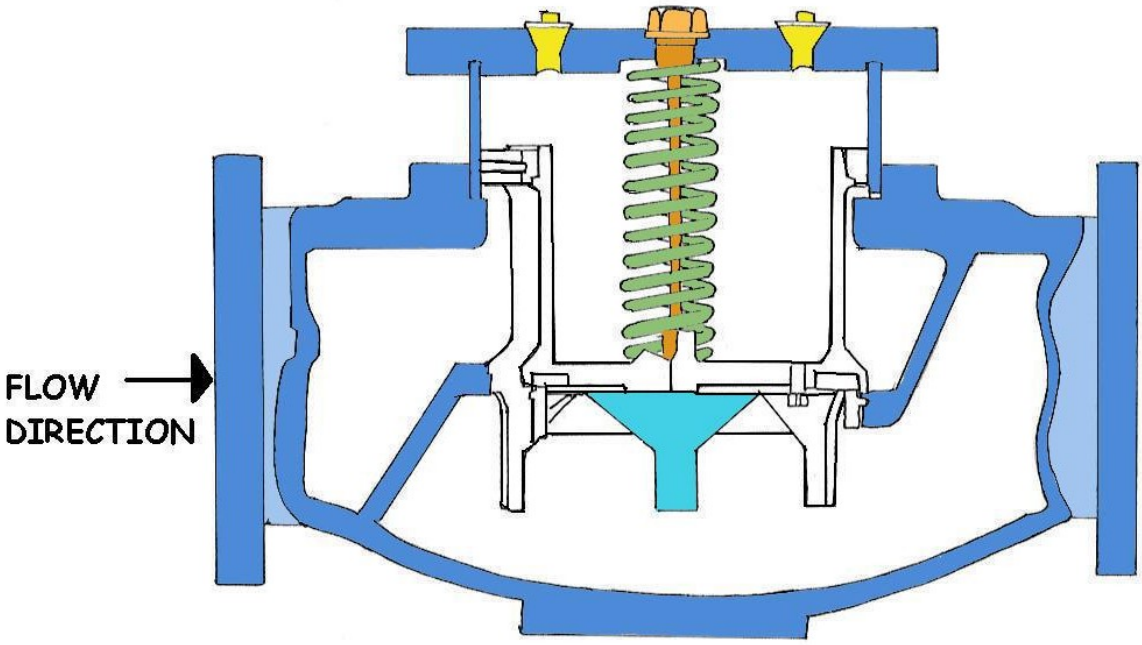
The gearing does, however, increase the operating time for the valve. Some ball valves also contain a swing check located within the ball to give the valve a check valve feature. The brass ball valve is often used for house appliance and industry appliance, the size range is 1/4"-4". Brass or zinc is common for body, brass or iron for stem, brass or iron for ball, aluminum, stainless steel, or iron for handle including a Teflon seal in the ball housing. Flush the pipeline before installing the valve. Debris allowed to remain in the pipeline (such as weld spatters, welding rods, bricks, tools, etc.) can damage the valve. After installation, cycle the valve a minimum of three times and re-torque bolts as required. Ensure that the valve is in the open position and the inside of the body bore of the valve body/body end is coated with a suitable spatter guard.



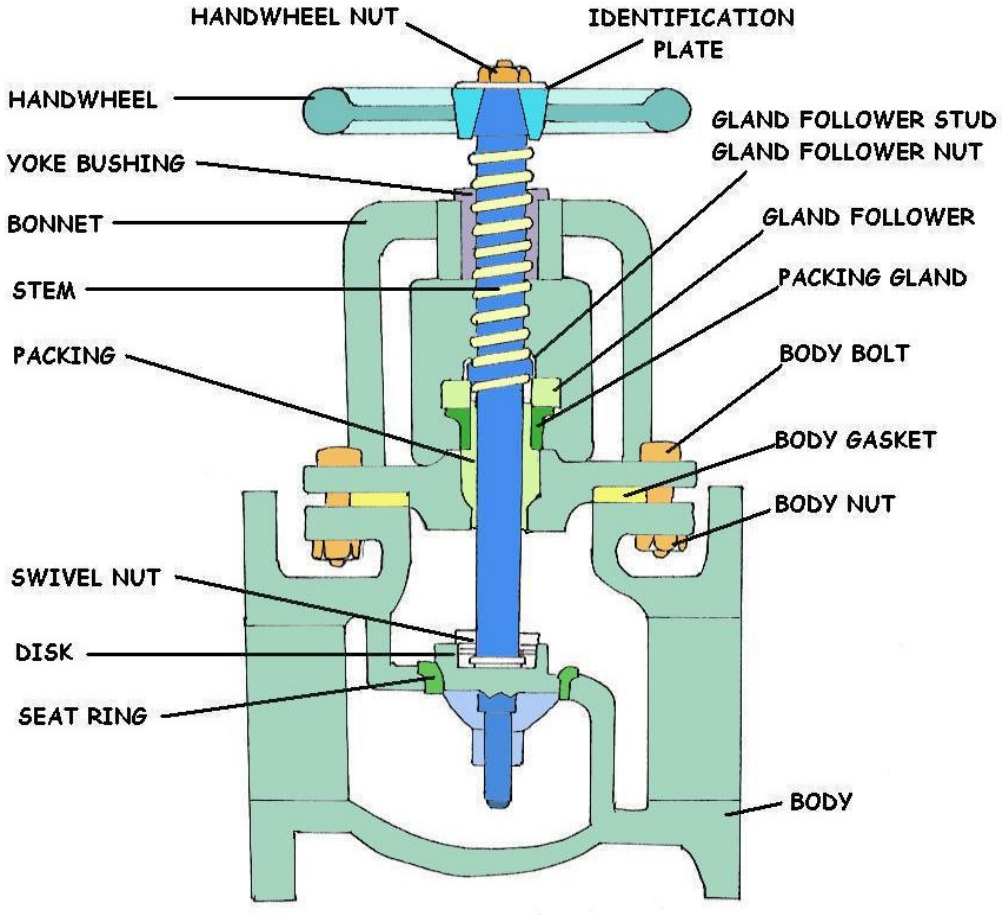
Bird's eye view of the coveted stainless steel ball.



Removing the ball is very difficult. I think they use a robot to tighten the rear nut to keep you from removing it. I recommend that you always use pipe dope or Teflon tape when installing a Stop. I know a lot of you think that brass or bronze will make up the slack, but pipe dope, or Teflon dope or tape makes a nicer job and makes for an easier removal.



FLANGED GLOBE STYLE PRESSURE REDUCING VALVE

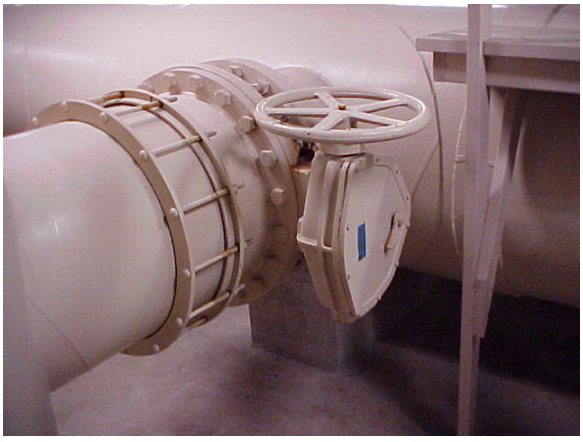


Butterfly Valve *Rotary Valve*

Usually a huge water valve found in both treatment plants and throughout the distribution system. If the valve is not broken, it is relatively easy to operate. It is usually accompanied with a Gate valve used as a by-pass to prevent water hammer. When I was a Valve man, it seemed that every Bypass valve was broken closed when near a Butterfly valve.

These are rotary type of valves usually found on large transmission lines. They may also have an additional valve beside it known as a "*bypass valve*" to prevent a water hammer.

Some of these valves can require 300-600 turns to open or close. Most Valvemen (or the politically correct term "Valve Operators") will use a machine to open or close a Butterfly Valve. The machine will count the turns required to open or close the valve.



Butterfly valves should be installed with the valve shaft horizontal or inclined from vertical. Always follow standard safety procedures when working on a valve.

The valve should be mounted in the preferred direction, with the "HP" marking. Thermal insulation of the valve body is recommended for operating temperatures above 392°F (200°C). The valve should be installed in the closed position to ensure that the laminated seal in the disc is not damaged during installation.

If the pipe is lined, make sure that the valve disc does not contact the pipe lining during the opening stroke. Contact with lining can damage the valve disc.



54 inch Butterfly valve on a huge transmission line. Nice job but no shoring, no ladder or valve blocking.

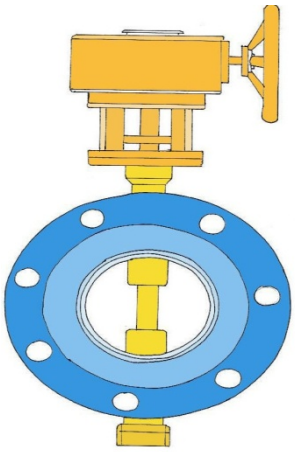
Butterfly Valve Problems

A butterfly valve may have jerky operation for the following reasons:

If the packing is too tight--Loosen the packing torque until it is only hand tight. Tighten to the required level and then cycle the valve. Re-tighten, if required. CAUTION: Always follow safety instructions when operating on valve.

If the shaft seals are dirty or worn out--Clean or replace components, as per assembly-disassembly procedure. CAUTION: Always follow safety instructions when operating on a valve.

If the shaft is bent or warped--The shaft must be replaced. Remove valve from service and contact an outside contractor or your expert fix-it person.



BUTTERFLY VALVE

If the valve has a pneumatic actuator, the air supply may be inadequate--Increase the air supply pressure to standard operating level. Any combination of the following may prevent the valve shaft from rotating:

If the actuator is not working--Replace or repair the actuator as required. Please contact specialized services or an outside contractor for assistance.

If the valve is packed with debris--Cycle the valve and then flush to remove debris. A full cleaning may be required if flushing the valve does not improve valve shaft rotation. Flush or clean valve to remove the debris.



A broken 54 inch Butterfly and a worker inside the water main preparing the interior surface. Notice, this is a Permit Required Confined Space. Hot work permit is also required. Side note, there is a plastic version of the 54 and 60 inch Butterfly valve.

Actuators and Control Devices

Directional control valves route the fluid to the desired actuator. They usually consist of a spool inside a cast iron or steel housing. The spool slides to different positions in the housing, and intersecting grooves and channels route the fluid based on the spool's position.

The spool has a central (neutral) position maintained with springs; in this position the supply fluid is blocked, or returned to tank. Sliding the spool to one side routes the hydraulic fluid to an actuator and provides a return path from the actuator to the tank. When the spool is moved to the opposite direction the supply and return paths are switched. When the spool is allowed to return to the neutral (center) position the actuator fluid paths are blocked, locking it in position.

Directional control valves are usually designed to be stackable, with one valve for each hydraulic cylinder, and one fluid input supplying all the valves in the stack.

Tolerances are very tight in order to handle the high pressure and avoid leaking, spools typically have a clearance with the housing of less than a thousandth of an inch. The valve block will be mounted to the machine's frame with a three point pattern to avoid distorting the valve block and jamming the valve's sensitive components.

The spool position may be actuated by mechanical levers, hydraulic pilot pressure, or solenoids which push the spool left or right. A seal allows part of the spool to protrude outside the housing, where it is accessible to the actuator.

The main valve block is usually a stack of off the shelf directional control valves chosen by flow capacity and performance. Some valves are designed to be proportional (flow rate proportional to valve position), while others may be simply on-off. The control valve is one of the most expensive and sensitive parts of a hydraulic circuit.

Pressure reducing valves reduce the supply pressure as needed for various circuits. Pressure relief valves are used in several places in hydraulic machinery: on the return circuit to maintain a small amount of pressure for brakes, pilot lines, etc; on hydraulic cylinders, to prevent overloading and hydraulic line/seal rupture; on the hydraulic reservoir, to maintain a small positive pressure which excludes moisture and contamination.

Sequence valves control the sequence of hydraulic circuits; to insure that one hydraulic cylinder is fully extended before another starts its stroke, for example. Shuttle valves provide a logical function.

Check valves are one way valves, allowing an accumulator to charge and maintain its pressure after the machine is turned off, for example. Pilot controlled Check valves are one way valves that can be opened (for both directions) by a foreign pressure signal. For instance, if the load should not be held by the check valve anymore. Often the foreign pressure comes from the other pipe that is connected to the motor or cylinder.

Counterbalance valves. A counterbalance valve is, in fact, a special type of pilot controlled check valve. Whereas the check valve is open or closed, the counterbalance valve acts a bit like a pilot controlled flow control.

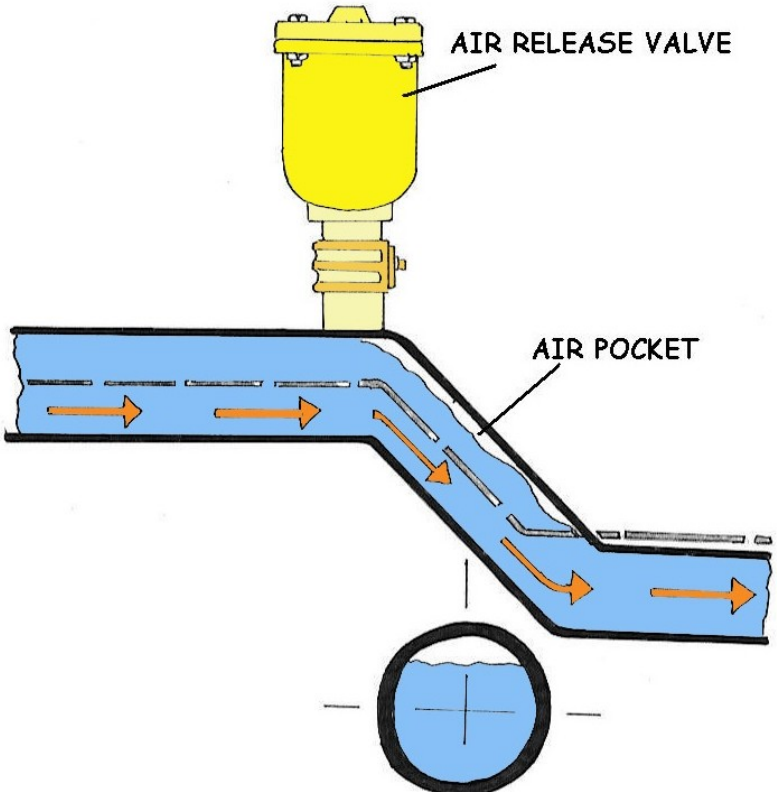
Cartridge valves are in fact the inner part of a check valve; they are off the shelf components with a standardized envelope, making them easy to populate a proprietary valve block. They are available in many configurations: on/off, proportional, pressure relief, etc. They generally screw into a valve block and are electrically controlled to provide logic and automated functions.

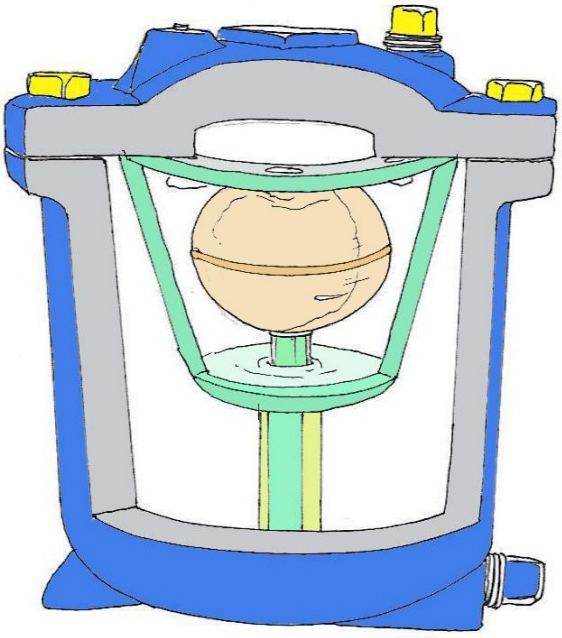
Hydraulic fuses are in-line safety devices designed to automatically seal off a hydraulic line if pressure becomes too low, or safely vent fluid if pressure becomes too high.

Auxiliary valves. Complex hydraulic systems will usually have auxiliary valve blocks to handle various duties unseen to the operator, such as accumulator charging, cooling fan operation, air conditioning power, etc... They are usually custom valves designed for a particular machine, and may consist of a metal block drilled with ports and channels. Cartridge valves are threaded into the ports and may be electrically controlled by switches or a microprocessor to route fluid power as needed.

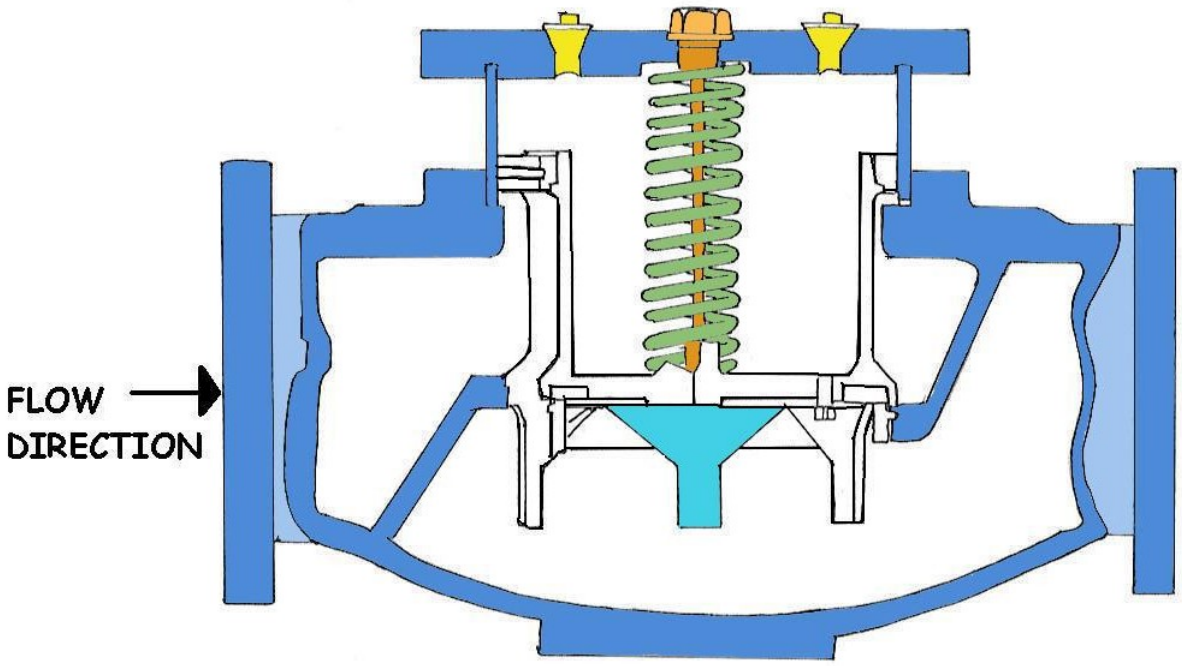


We can see both valve actuators control devices and Butterfly valves as well.

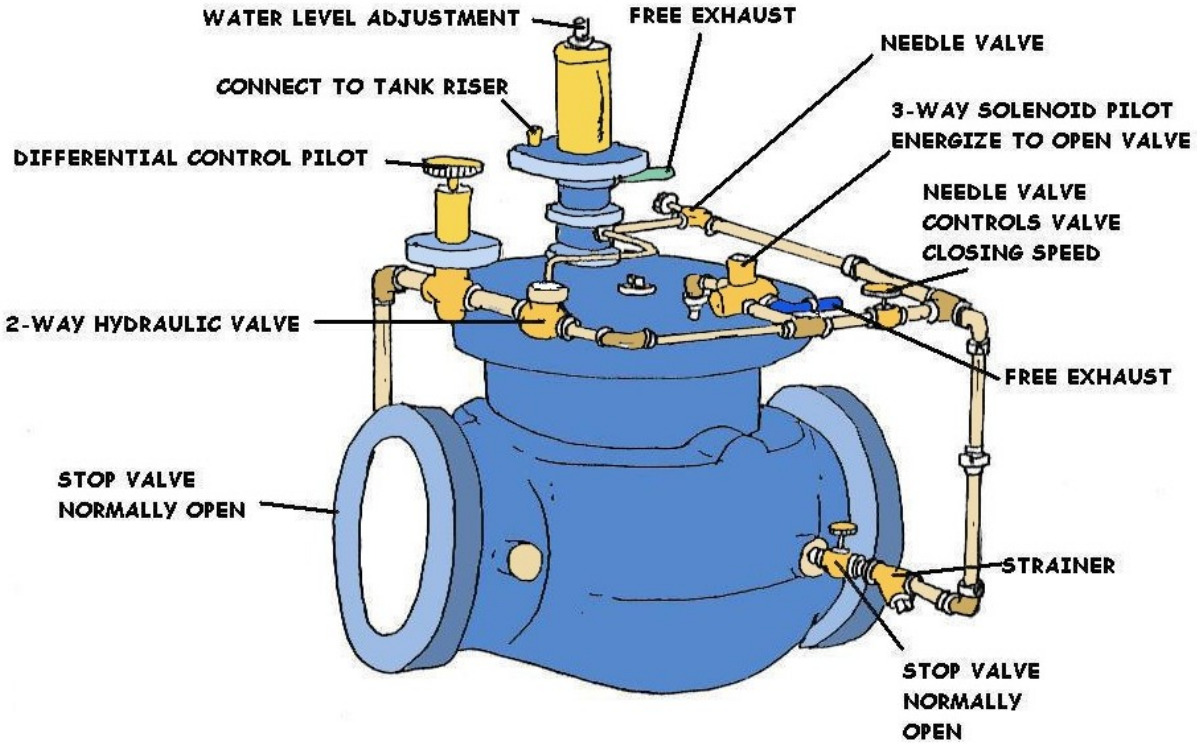




INTERNAL VIEW OF COMBINATION AIR VALVE



FLANGED GLOBE STYLE PRESSURE REDUCING VALVE



ALTITUDE CONTROL VALVE

Pressure Reducing Valves *Rotary Valve*

Pressure Relief Valve

Pressure relief valves are used to release excess pressure that may develop as a result of a sudden change in the velocity of the water flowing in the pipe.

PRVs assist in a variety of functions, from keeping system pressures safely below a desired upper limit to maintaining a set pressure in part of a circuit. Types include relief, reducing, sequence, counterbalance, and unloading. All of these are normally closed valves, except for reducing valves, which are normally open. For most of these valves, a restriction is necessary to produce the required pressure control. One exception is the externally piloted unloading valve, which depends on an external signal for its actuation.

The most practical components for maintaining secondary, lower pressure in a hydraulic system are pressure-reducing valves. Pressure-reducing valves are normally open, 2-way valves that close when subjected to sufficient downstream pressure. There are two types: direct acting and pilot operated.

Direct acting - A pressure-reducing valve limits the maximum pressure available in the secondary circuit regardless of pressure changes in the main circuit, as long as the work load generates no back flow into the reducing valve port, in which case the valve will close.

The pressure-sensing signal comes from the downstream side (secondary circuit). This valve, in effect, operates in reverse fashion from a relief valve (which senses pressure from the inlet and is normally closed). As pressure rises in the secondary circuit, hydraulic force acts on area A of the valve, closing it partly. Spring force opposes the hydraulic force, so that only enough oil flows past the valve to supply the secondary circuit at the desired pressure. The spring setting is adjustable.

When outlet pressure reaches that of the valve setting, the valve closes except for a small quantity of oil that bleeds from the low-pressure side of the valve, usually through an orifice in the spool, through the spring chamber, to the reservoir. Should the valve close fully, leakage past the spool could cause pressure build-up in the secondary circuit. To avoid this, a bleed passage to the reservoir keeps it slightly open, preventing a rise in downstream pressure above the valve setting. The drain passage returns leakage flow to reservoir. (Valves with built-in relieving capability also are available to eliminate the need for this orifice.)

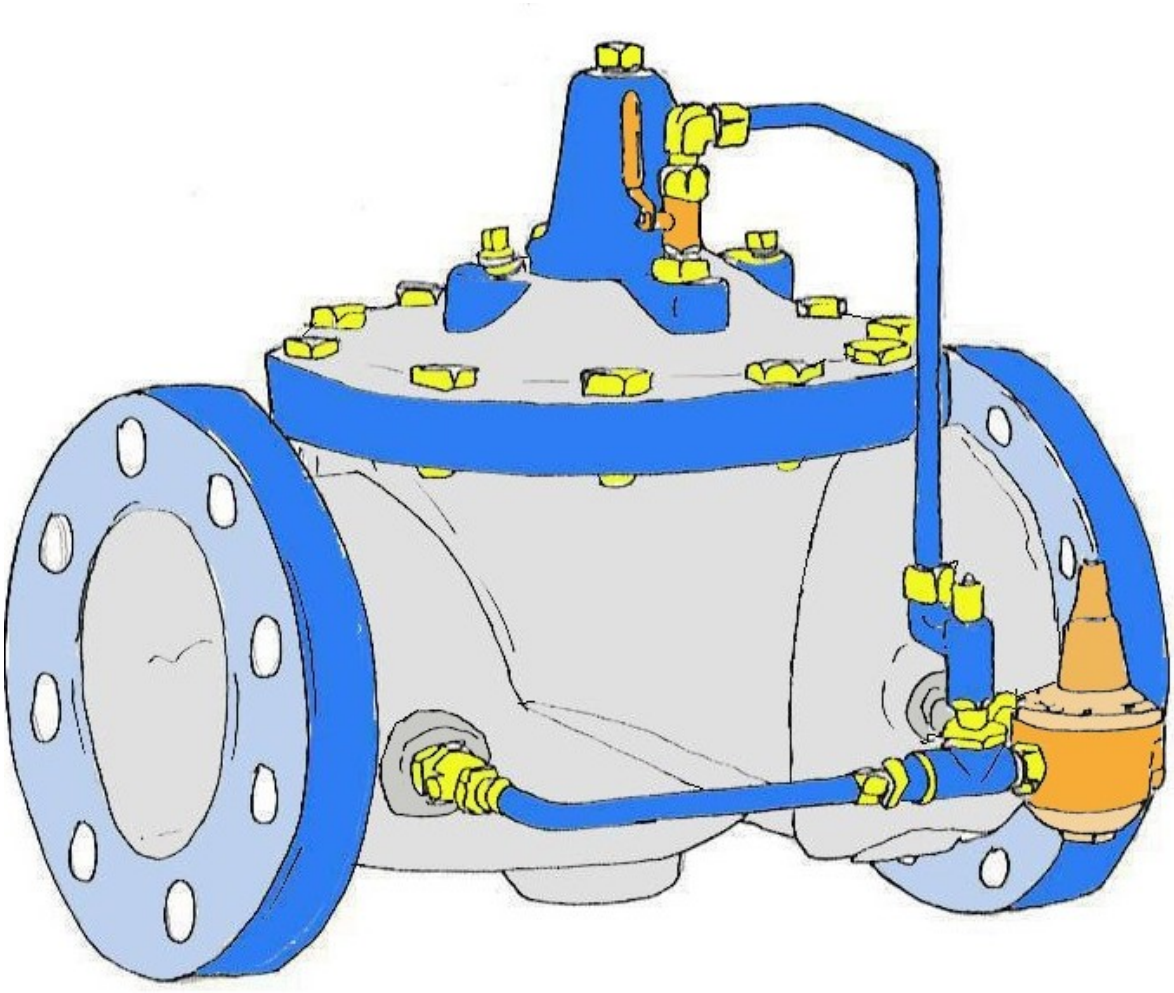
Constant and Fixed Pressure Reduction

Constant-pressure-reducing valves supply a preset pressure, regardless of main circuit pressure, as long as pressure in the main circuit is higher than that in the secondary. These valves balance secondary-circuit pressure against the force exerted by an adjustable spring which tries to open the valve. When pressure in the secondary circuit drops, spring force opens the valve enough to increase pressure and keep a constant reduced pressure in the secondary circuit. Fixed pressure reducing valves supply a fixed amount of pressure reduction regardless of the pressure in the main circuit. For instance, assume a valve is set to provide reduction of 250 psi. If main system pressure is 2,750 psi, reduced pressure will be 2,500 psi; if main pressure is 2,000 psi, reduced pressure will be 1,750 psi.

This valve operates by balancing the force exerted by the pressure in the main circuit against the sum of the forces exerted by secondary circuit pressure and the spring. Because the pressurized areas on both sides of the poppet are equal, the fixed reduction is that exerted by the spring.

How do Pressure Relief Valves Operate?

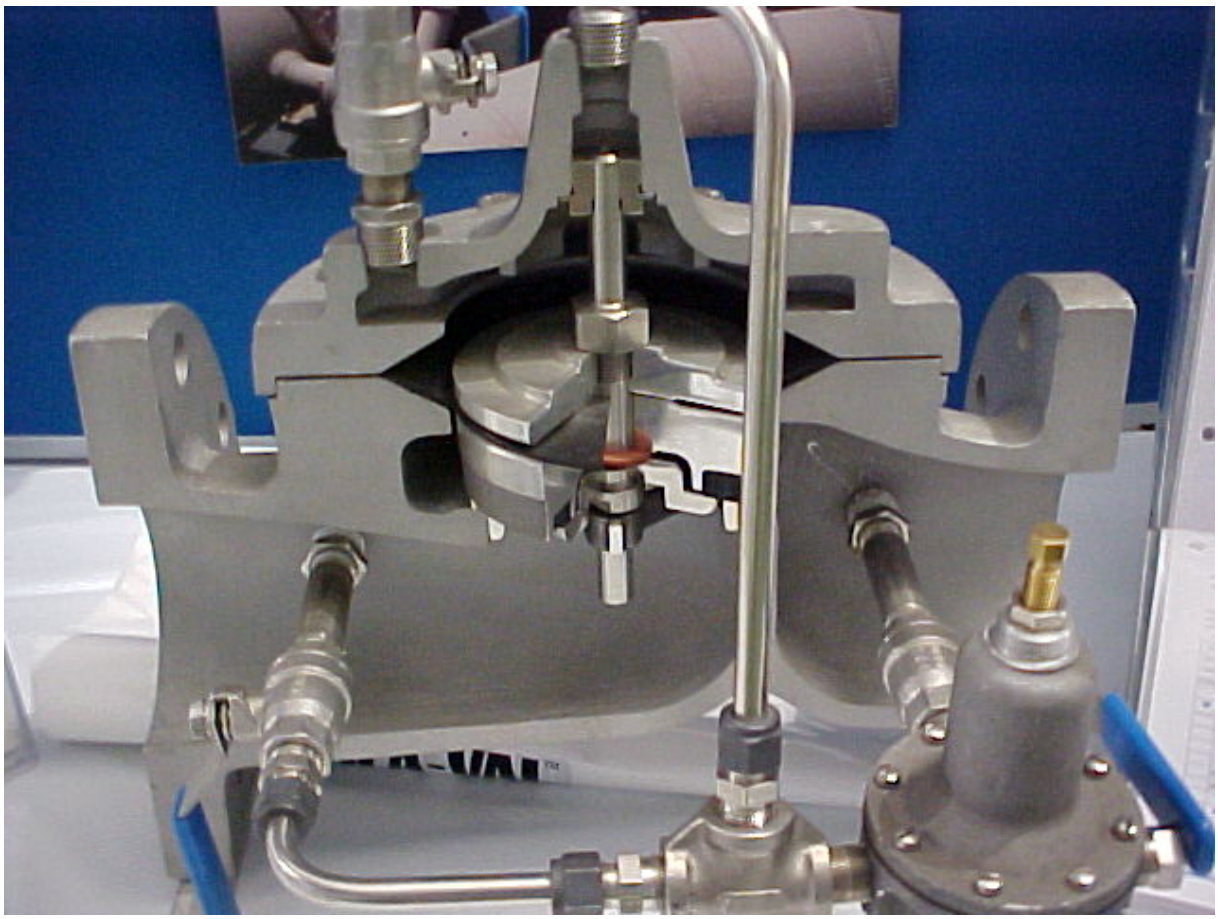
Most pressure relief valves consist of a main valve and pilot control system. The basic main Cla-Val valve is called a Hytrol Valve.



PRESSURE REDUCING VALVE

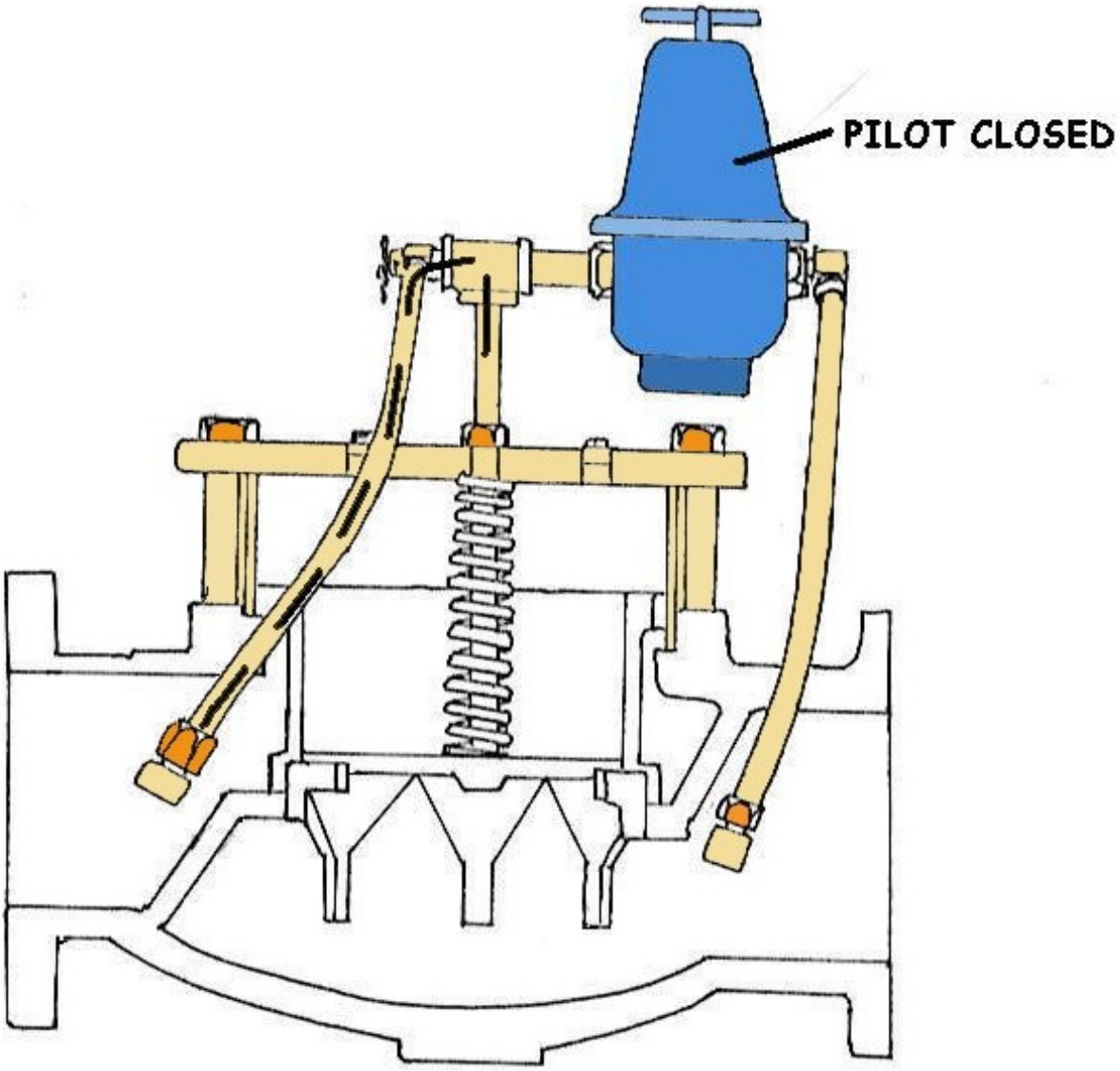
When no pressure is in the valve, the spring and the weight of the diaphragm assembly holds the valve closed.

Often a small box can be connected to an existing pilot PRV valve to control the main Pressure Reducing Valve on the pipe network. This single box contains both the control electronics and an integral data logger to save the cost and space of having both a controller and a separate data logger. There are basically two types of PRV controllers, either time-based (to reduce the pipe pressure at low demand times, e.g. at night) or flow modulated controllers which can realize leakage savings throughout the day and night (by adjusting the pressure according to the demand to prevent excessive pressure at any time of the day or night).



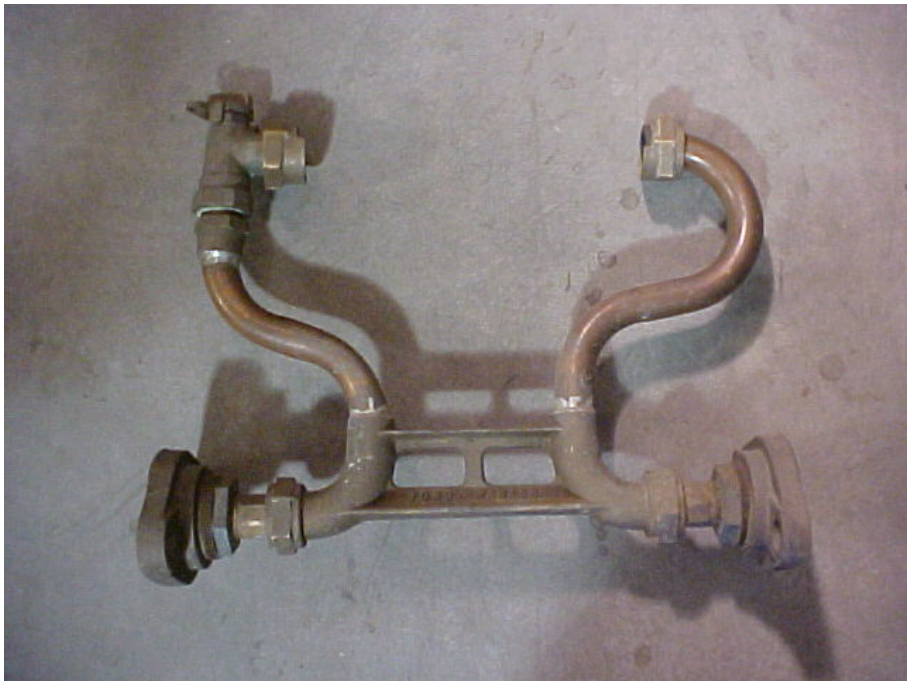
Municipal water distribution systems often have widely varying flow rates ranging from 7:00 am peak demand (or even fire-flow) to minimal 2:00am demand. One valve size cannot accurately control the wide range of flows. A low flow bypass pressure reducing valve is often used to control pressure at the low flow conditions. Both valves are open at maximum flow demand. The small valve is set at a slightly higher pressure than the larger valve.

REDUCED PRESSURE VALVE OPERATION
(VALVE CLOSED)



Service Connections

Service connections are used to connect individual buildings or other plumbing systems to the distribution system mains.



Water Meter Re-setter, riser or sometimes referred to as a copper yoke.



Common distribution repair fittings. Single check valve, Poly Pig, 1-inch repair clamp, 4-inch full circle clamp, T- Bolt and a corp. and saddle.



System Layouts

There are three general ways systems are laid out to deliver water (photograph your quarter section layouts). They include:



A. Tree systems

B. Loop or Grid systems

C. Dead-end systems: *Undesirable, taste and odor problems.*

Tree System

Older water systems frequently were expanded without planning and developed into a treelike system. This consists of a single main that decreases in size as it leaves the source and progresses through the area originally served. Smaller pipelines branch off the main and divide again, much like the trunk and branches of a tree.

A treelike system is not desirable because the size of the old main limits the expansion of the system needed to meet increasing demands. In addition, there are many dead ends in the system where water remains for long periods, causing undesirable tastes and odors in nearby service lines. The most reliable means to provide water for firefighting is by designing redundancy into the system. There are several advantages gained by laying out water mains in a loop or grid, with feeder and distributor mains interconnecting at roadway intersections and other regular intervals.

Friction Loss

Water will still be distributed through the system if a single section fails. The damaged section can be isolated and the remainder of the system will still carry water. Water supplied to fire hydrants will feed from multiple directions. Thus, during periods of peak fire flow demand, there will be less impact from "***friction loss***" in water mains as the velocity within any given section of main will be less since several mains will be sharing the supply.

The system shall be designed to maintain a minimum positive pressure of 25 psi. in all parts of the system at all times, 35 psi. is desirable.. Water pipe shall conform to applicable specifications and standards for the type of pipe to be used. The following shall govern the separation of water lines from possible sources of pollution:

1. Whenever possible, a water line shall be laid at least 10 feet horizontally from any existing or proposed sewer line.

2. Whenever water lines must cross sewers, the water line shall be laid at such an elevation that the bottom of the water line is 18 inches above the top of the sewer. This vertical separation shall be maintained for that portion of the water line located within 10 feet horizontally of any sewer or drain it crosses, said 10 feet to be measured as the normal distance from the water line to the drain or sewer. The sewer shall be constructed of cast iron pipe, type K copper, or

Drain, Waste and Vent (**DWV**) plastic pipe (Schedule 40) with water-tight joints for a distance of 10 feet from each side of the water line. All crossings shall be made at right angles.

3. Where conditions prevent the minimum horizontal and/or vertical separation specified above, special consultation shall be obtained from the Department to determine other routes of water piping.

4. No water line shall pass through, or come into contact with, any part of a sewer manhole.

5. There shall be no physical connection between a community water system and a non-community or private water system, unless the non-community or private water system conforms to community water system requirements.

6. Lines for potable water shall be laid at least 25 feet horizontally from any underground sewage seepage field.

Plumbing Fixture Backflow Protection
The water supply lines shall have no physical connection with nonpotable water supplies. All plumbing shall be in accord with the Uniform Plumbing Code available from this Department. All plumbing fixtures and other equipment connected to the water system shall be so constructed and installed so as to safeguard the water system from the possibility of contamination through cross-connections or backsiphonage. Laundry units and equipment shall be so constructed and installed so as to prevent the contamination of the contents by the backflow of sewage.



Water main breaks are common and this problem is the primary reason to keep a free chlorine residual of at least 2 mg/l in the distribution system, another reason is backflow.

Disinfection of Repaired Pipeline Sections

You should recognize that the protection of the public health of its water customers is the primary role of a water provider. Accordingly, the disinfection of all repaired water appurtenances is paramount to the return of the water system to its normal operation mode. Prior to initiating the disinfection process, a thorough cleaning of all repaired pipes and or reservoirs must be accomplished. The following table indicates the amount of Sodium Hypochlorite and Calcium Hypochlorite that is necessary to disinfect 100,000 gallons of water.

Disinfection Table
For 100,000 Gallons Of Water

Desired Chlorine Dose in MG/L	Pounds of Liquid Chlorine Required	Gallons of Sodium Hypo Chlorite Required 5% Available Chlorine	10% Available Chlorine	15% Available Chlorine	Pounds of Calcium Hypo Chlorite Required. 65% Available
2	1.7	3.9	2.0	1.3	2.6
10	8.3	19.4	9.9	12.8	12.8
50	42	97	49.6	64	64

Spare Parts Inventory

You should maintain a complete inventory of spare parts for the maintenance and repair of all water transmission and distribution lines. The water lines in the system range in size between ¾ inch and 16 inches in diameter. Additionally, you should maintain spare motor controls, pump ends, and motors for all wells and booster stations. Water system personnel can repair the entire range of water lines without assistance from outside contractors. Stand-by warehouse personnel should be available twenty four hours per day to assist in the delivery of spare parts in instances requiring emergency repair.

Preventative maintenance can extend the life of any water pipeline. Pipes can deteriorate on the inside as a result of corrosion and on the outside as a result of aggressive soil and moisture. The Water Department should maintain an intense leak detection program to effectively reduce operating costs and provide revenue savings by reducing lost and unaccounted for water. Leaks can originate in joints and fittings or any corroded portion of a pipeline.

Additionally, leaks will undermine the pavement and water soak the area around the leaking section of pipeline. When leaks are discovered, they should be repaired within twenty-four hours after properly locating all underground utilities through the Underground Service Alert or "***Blue Stake*"** procedure.

Distribution Key Words

Solidification/Stabilization: Solidification/stabilization (**S/S**) techniques are akin to locking the contaminants in the soil. It is a process that physically encapsulates the contaminant. This technique can be used alone or combined with other treatment and disposal methods. The most common form of S/S is a cement process. It simply involves the addition of cement or a cement-based mixture, which thereby limits the solubility or mobility of the waste constituents. These techniques are accomplished either in-situ, by injecting a cement based agent into the contaminated materials or ex situ, by excavating the materials, machine-mixing them with a cement-based agent, and depositing the solidified mass in a designated area. The goal of the S/S process is to limit the spread, via leaching of contaminated material. The end product resulting from the solidification process is a monolithic block of waste with high structural integrity. Types of solidifying/stabilizing agents include the following: Portland; gypsum; modified sulfur cement, consisting of elemental sulfur and hydrocarbon polymers; and grout, consisting of cement and other dry materials, such as acceptable fly ash or blast furnace slag. Processes utilizing modified sulfur cement are typically performed ex situ.

Semi-volatile organic compounds: Semi-volatile organic compounds (**SVOCs**) are compounds with higher vapor pressures than VOCs and therefore are released as gas much more slowly from materials. They are as likely to be transferred to humans by contact or by attaching to dust and being ingested.

Whereas VOCs tend to be emitted rapidly in the first few hours or days after installation of a product then taper off over time, SVOCs will be released by products more slowly and over a longer period of time.

Toxicity Characteristic Leaching: Toxicity characteristic leaching procedure (**TCLP**) is a soil sample extraction method for chemical analysis. An analytical method to simulate leaching through a landfill. The leachate is analyzed for appropriate substances.
TCLP comprises four fundamental procedures:

- Sample preparation for leaching
- Sample leaching
- Preparation of leachate for analysis
- Leachate analysis

The TCLP procedure is generally useful for classifying waste material for disposal options. Extremely contaminated material is expensive to dispose. Grading is required to ensure safe disposal and to avoid paying for disposal of 'clean fill'. The main problem is that the TCLP test is based on the assumption that the waste material will be buried in landfill along with organic material. Organic matter is not really buried with other waste anymore (composting usually applies) and other leachate techniques may be more appropriate. The pH of the sample material is first established, and then leached with an acetic acid / sodium hydroxide solution at a 1:20 mix of sample to solvent. The leachate solution is sealed in extraction vessel for general analytes, or possibly pressure sealed as in zero-headspace extractions (ZHE) for volatile organic compounds and tumbled for 18 hours to simulate an extended leaching time in the ground.

Types of Pipes Used in the Distribution Field

Several types of pipe are used in water distribution systems, but only the most common types used by operators will be discussed. These piping materials include copper, plastic, galvanized steel, and cast iron. Some of the main characteristics of pipes made from these materials are presented below.

Plastic Pipe (PVC)

Plastic pipe has seen extensive use in current construction. Available in different lengths and sizes, it is lighter than steel or copper and requires no special tools to install. Plastic pipe has several advantages over metal pipe. It is flexible, it has superior resistance to rupture from freezing, it has complete resistance to corrosion and, in addition, it can be installed above ground or below ground.

One of the most versatile plastic and polyvinyl resin pipes is the polyvinyl chloride (**PVC**). PVC pipes are made of tough, strong thermoplastic material that has an excellent combination of physical and chemical properties. Its chemical resistance and design strength make it an excellent material for application in various mechanical systems.

Sometimes polyvinyl chloride is further chlorinated to obtain a stiffer design, a higher level of impact resistance, and a greater resistance to extremes of temperature. A CPVC pipe (a chlorinated blend of PVC) can be used not only in cold-water systems, but also in hot-water systems with temperatures up to 210°F. Economy and ease of installation make plastic pipe popular for use in either water distribution and supply systems or sewer drainage systems.



Various types and sizes of coupons or tap cut-outs. You will want to date and collect these cut-outs to determine the condition of the pipe or measure the corrosion.

Plastic Pipe (PVC)

This is currently the most common type of pipe used in distribution systems. It is available in diameters of 1/2" and larger, and in lengths of 10', 20', and 40'. A main advantage is its light weight, allowing for easy installation. A disadvantage is its inability to withstand shock loads. Since it is non-metallic, a tracer wire must be installed with the PVC water main so that it can be located after burial.

The National Sanitation Foundation (**NSF**) currently lists most brands of PVC pipe as being acceptable for potable water use. This information should be stamped on the outside of the pipe, along with working pressure and temperature, diameter and pipe manufacturer. PVC pipe will have the highest C Factor of all the above pipes. The higher the C factor, the smoother the pipe.

Cast Iron (CIP)

This is another type of piping material that has been in use for a long time. It is found in diameters from 3" to 48". Advantages of this material are its long life, durability and ability to withstand working pressures up to 350 psi. Disadvantages include the fact that it is heavy, difficult to install and does not withstand shock loading. Although it is not currently the material of choice, there is still a lot of it in the ground.

Ductile Iron Pipe (DIP)

This was developed to overcome the breakage problems associated with cast iron pipe. It can be purchased in 4" to 45" diameters and lengths of 18' to 20'. Its main advantage is that it is nearly indestructible by internal or external pressures. It is manufactured by injecting magnesium into molten cast iron. It is sometimes protected from highly corrosive soils by wrapping the pipe in plastic sheeting prior to installation. This practice can greatly extend the life of this type of pipe.

Steel Pipe

This pipe is often used in water treatment plants and pump stations. It is available in various diameters and in 20' or 21' lengths. Its main advantage is the ability to form it into a variety of shapes. It also exhibits good yielding and shock resistance. It has a smooth interior surface and can withstand pressures up to 250 psi. A disadvantage is that it is easily corroded by both soil and water.



To reduce corrosion problems, steel pipe is usually galvanized or dipped in coal-tar enamel and wrapped with coal-tar impregnated felt. At present, however, coal-tar products are undergoing scrutiny from a health standpoint and it is recommended that the appropriate regulatory agencies be contacted prior to use of this material.

Asbestos Cement Pipe (ACP)

This pipe is manufactured from Portland cement, long fibrous asbestos and silica. It is available in diameters from 3" to 36" and in 13' lengths. Its main advantages are its ability to withstand corrosion and its excellent hydraulic flow characteristics due to its smoothness. A major disadvantage is that it is brittle and is easily broken during construction or by shock loading. There is some concern regarding the possible release of asbestos fibers in corrosive water and there has been much debate over the health effects of ingested asbestos.

Of greater certainty, however, is the danger posed by inhalation of asbestos fibers. Asbestos is considered a hazardous material, and precautionary measures must be taken to protect water utility workers when cutting, tapping or otherwise handling this type of pipe.

Galvanized Pipe

Galvanized pipe is commonly used for the water distributing pipes inside a building to supply hot and cold water to the fixtures. This type of pipe is manufactured in 21-ft lengths. It is **Galvanized** (coated with zinc) both inside and outside at the factory to resist corrosion. Pipe sizes are based on nominal **INSIDE** diameters. Inside diameters vary with the thickness of the pipe. Outside diameters remain constant so that pipe can be threaded for standard fittings.



Copper

Copper is one of the most widely used materials for tubing. This is because it does not rust and is highly resistant to any accumulation of scale particles in the pipe. This tubing is available in four different types: **K, L, and M for water and DWV for sewer applications.**

K has the thickest walls, and M, the thinnest walls, with L's thickness in between the other two. The thin walls of copper tubing are soldered to copper fittings. Soldering allows all the tubing and fittings to be set in place before the joints are finished. Generally, the result will be faster installation.

Type K copper tubing is available as either rigid (hard temper) or flexible (soft temper) and is primarily used for underground service in the water distribution systems.

Soft temper tubing is available in 40- or 60-ft coils, while hard temper tubing comes in 12- and 20-ft straight lengths. Type L copper tubing is also available in either hard or soft temper and either in coils or in straight lengths. The soft temper tubing is often used as replacement plumbing because of the tube's flexibility, which allows easier installation.

Type L copper tubing is widely used in water distribution systems.

Type M copper tubing is made in hard temper only and is available in straight lengths of 12 and 20 ft. It has a thin wall and is used for branch supplies where water pressure is low, but it is ***NOT*** used for mains and risers. It is also used for chilled water systems, for exposed lines in hot-water heating systems, and for drainage piping.

Notice that the pipe has been illegally cut with a power saw blade. Please check with OSHA on details on handling this common water pipe. ACP will not corrode like metal pipe but will become slow and stained by iron over time. It is easily cracked by heavy loads, but easily repaired with a clamp.

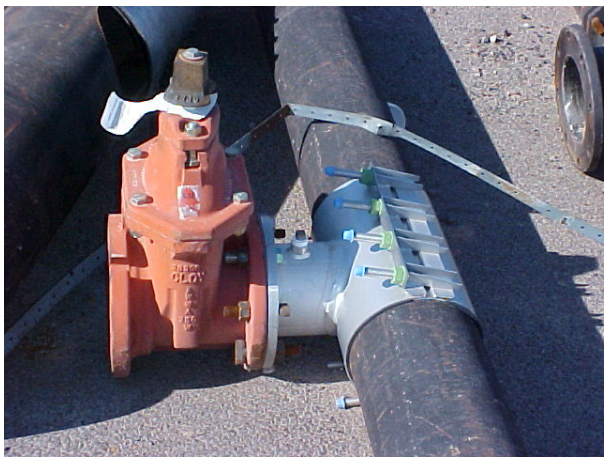


ACP Pipe with illegal power saw cut marks.

Joints and Fittings

Fittings vary according to the type of piping material used. The major types commonly used in water service include elbows, tees, unions, couplings, caps, plugs, nipples, reducers, and adapters.

Besides bell-and-spigot joints, cast-iron water pipes and fittings are made with either flanged, mechanical, or screwed joints. The screwed joints are used only on small-diameter pipe.



Tapping Sleeve

A Gate Valve is used to isolate sections of water mains. Not to be used to throttle or regulate the flow. A Globe valve should be used to regulate the flow. Be sure to chlorinate or disinfect all distribution parts such as valves and piping!

Caps

A pipe cap is a fitting with a female (inside) thread. It is used like a plug, except that the pipe cap screws on the male thread of a pipe or nipple.

Couplings

The three common types of couplings are straight coupling, reducer, and eccentric reducer. The **STRAIGHT COUPLING** is for joining two lengths of pipe in a straight run that do not require additional fittings. A run is that portion of a pipe or fitting continuing in a straight line in the direction of flow.

A **REDUCER** is used to join two pipes of different sizes. The **ECCENTRIC REDUCER** (also called a **BELL REDUCER**) has two female (inside) threads of different sizes with centers so designed that when they are joined, the two pieces of pipe will not be in line with each other, but they can be installed to provide optimum drainage of the line.



Elbows (or ELLS) 90° and 45°

These fittings (fig. 8-5, close to middle of figure) are used to change the direction of the pipe either 90 or 45 degrees. **REGULAR** elbows have female threads at both outlets. **STREET** elbows change the direction of a pipe in a close space where it would be impossible or impractical to use an elbow and nipple.



Both 45 and 90-degree street elbows are available with one female and one male threaded end. The **REDUCING** elbow is similar to the 90-degree elbow except that one opening is smaller than the other is.

Nipples

A nipple is a short length of pipe (12 in. or less) with a male thread on each end. It is used for extension from a fitting. At times, you may use the **DIELECTRIC** or **INSULATING TYPE** of fittings. These fittings connect underground tanks or hot-water tanks. They are also used with pipes of dissimilar metals. These help slow down corrosion that starts inside the pipe and works to the outside of the pipe.

Do not heat or solder dielectric fittings. You may melt the plastic coating on them.

Zinc is a coating on the outside and inside of pipes to slow corrosion. This process is called ***"Galvanization".***

Tees

A tee is used for connecting pipes of different diameters or for changing the direction of pipe runs. A common type of pipe tee is the **STRAIGHT** tee, which has a straight-through portion and a 90-degree takeoff on one side.



Notice the type of pipe connection device.
This is known as a "Restraining Flange".

All three openings of the straight tee are of the same size. Another common type is the **REDUCING** tee, similar to the straight tee just described, except that one of the threaded openings is of a different size than the other.

Water Main Installation

Installation of new or replacement pipe sections should be in accordance with good construction practices. The line must be buried a minimum of 30" below the ground surface to prevent freezing. The line must be bedded and backfilled properly, ensuring protection from weather and surface loadings. Also, thrust blocking (***Kickers***) at all bends, tees, and valves is essential to hold the pipe in place and prevent separation of line sections. Thrust blocking is not necessary if the pipe is welded.



Disinfection of new installations or repaired sections is required prior to placing them in service. This can be accomplished by filling the line with a 25 mg/1 free chlorine solution and allowing it to stand for 24 hours. Valves and fittings used in the waterworks industry are made of cast iron, steel, brass, stainless and fiberglass. Enough gate valves should be placed throughout the system to enable problem areas (leaks, etc.) to be isolated and repaired with minimal service disruption. Air relief valves should be installed at highpoints in the system. Valves should be installed with valve boxes and covers.

Regardless of the type of pipe installed, certain maintenance routines should be performed on the distribution system to maintain water quality and optimal service. These programs should be scheduled and performed on a regular basis.

Flushing at blowoffs on dead end lines and at fire hydrants throughout the system should be done at least twice per year. Flushing is needed to remove stagnant water in dead ends and to remove accumulated sediment that results from turbidity, iron, manganese, etc.

This should also help minimize customer complaints of water quality. Flushing should always be done from the source to the ends of the system. Affected customers should be notified of this process in advance. To do an adequate job of flushing, the flow should reach a velocity of at least 2.5 feet per second, known as the "***minimum cleansing velocity***" of the system (at hydrant locations).

These tests are important to determine the adequacy of the distribution system in transmitting water, particularly during days of peak demand. Also, these tests can help determine if pipe capacity is decreasing over time due to internal corrosion or deposits.

Pressure tests should be done at various locations in the distribution system several times per year. This helps to monitor the performance of the system and alert the operator to problems such as leaks or internal deposits. It is sometimes advantageous to have certain points in the system continuously monitored to provide a constant evaluation of the system.

Troubleshooting Table for Distribution System

Problem

1. Dirty water complaints
2. Red water complaints
3. No or low water pressure
4. Excessive water usage.

Possible Causes

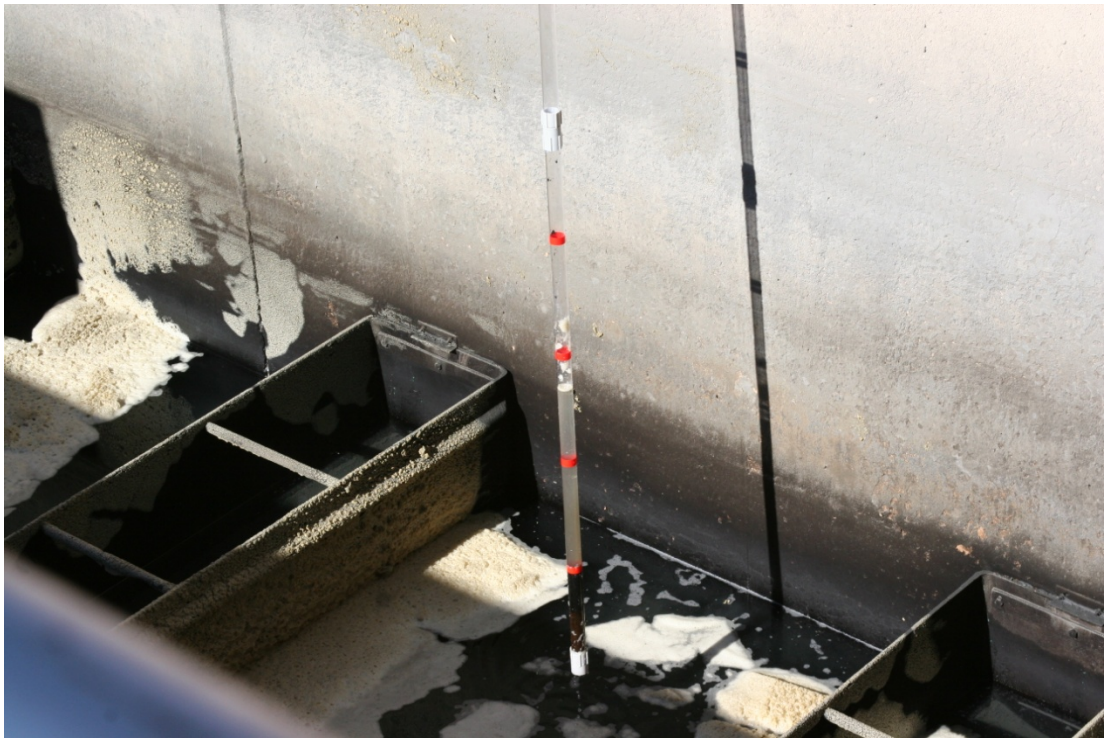
1A. Localized accumulations of debris, solids/particulates in distribution mains.
1B. Cross connection between water system and another system carrying non-potable water.
2A. Iron content of water from source is high. Iron precipitates in mains and accumulates.
2B. Cast iron, ductile iron, or steel mains are corroding causing *"rust*" in the water.
3A. Source of supply, storage or pumping station interrupted.
3B. System cannot supply demands**.**
3C. Service line, meter, or connections shutoff, or clogged with debris.
3D. Broken or leaking distribution pipes.
3E. Valve in system closed or broken.
4A. More connections have been added to the system.
4B. Excessive leakage (>15% of production)is occurring, meters are not installed or not registering properly.
4C. Illegal connections have been made.

Possible Solutions

1A. Collect and preserve samples for analysis if needed. Isolate affected part of main and flush.
1B. Collect and preserve samples for analysis if needed. Conduct survey of system for cross connections. Contact State Drinking Water Agency.
2A. Collect and test water samples from water source and location of complaints for iron. If high at both sites, contact regulatory agency, TA provider, consulting engineer or water conditioning company for assistance with iron removal treatment.
2B. Collect and analyze samples for iron and corrosion parameters. Contact State Drinking Water Agency , TA provider, consulting engineer or water conditioning company for assistance with corrosion control treatment.
3A. Check source, storage and pumping stations. Correct or repair as needed.
3B. Check to see if demands are unusually high. If so, try to reduce demand. Contact State Drinking Water Agency, TA provider or consulting engineer.
3C. Investigate and open or unclog service.
3D. Locate and repair break or leak.
3E. Check and open closed isolation and pressure-reducing valves. Repair or contact contractor if valves are broken.
4A. Compare increase in usage over time with new connections added over same period. If correlation evident take action to curtail demand or increase capacity if needed. Contact State Drinking Water Agency , TA provider or consulting engineer.
4B. Conduct a water audit to determine the cause. If leakage, contact regulatory agency, and consulting engineer or leak detection contractor.
4C. Conduct survey to identify connections.



Filter assessment of filter media loss.



Glossary

ABANDONED WELL: Wells that have been or need to be sealed by an approved method.

ABSENCE OF OXYGEN: The complete absence of oxygen in water described as Anaerobic.

ACCURACY: How closely an instrument measures the true or actual value.

ACID AND BASE ARE MIXED: When an acid and a base are mixed, an explosive reaction occurs and decomposition products are created under certain conditions.

ACID: Slowly add the acid to water while stirring. An operator should not mix acid and water or acid to a strong base.

ACID RAIN: A result of airborne pollutants.

ACTIVATED CHARCOAL (GAC or PAC): Granular Activated Charcoal or Powered Activated Charcoal. Used for taste and odor removal. A treatment technique that is not included in the grading of a water facility.

ACTIVATED CARBON FILTRATION: Can remove organic chemicals that produce off-taste and odor. These compounds are not dangerous to health but can make the water unpleasant to drink. Carbon filtration comes in several forms, from small filters that attach to sink faucets to large tanks that contain removable cartridges. Activated carbon filters require regular maintenance or they can become a health hazard.

ADSORPTION: *Not to be confused with absorption.* Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a film of molecules or atoms (the adsorbate). It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption encompasses both processes, while desorption is the reverse process. Adsorption is present in many natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins, and water purification.

ADSORPTION CLARIFIERS: The concept of the adsorption clarifier package plant was developed in the early 1980s. This technology uses an up-flow clarifier with low-density plastic bead media, usually held in place by a screen. This adsorption media is designed to enhance the sedimentation/clarification process by combining flocculation and sedimentation into one step. In this step, turbidity is reduced by adsorption of the coagulated and flocculated solids onto the adsorption media and onto the solids already adsorbed onto the media. Air scouring cleans adsorption clarifiers followed by water flushing. Cleaning of this type of clarifier is initiated more often than filter backwashing because the clarifier removes more solids. As with the tube-settler type of package plant, the sedimentation/ clarification process is followed by mixed-media filtration and disinfection to complete the water treatment.

AIR GAP SEPARATION: A physical separation space that is present between the discharge vessel and the receiving vessel; for an example, a kitchen faucet.

AIR HAMMER: A pneumatic cylindrical hammering device containing a piston used on air rotary rigs. The air hammer's heavy piston moves up and down by the introduction of compressed air creating a hammering action on the bit.

AIR HOOD: The most suitable protection when working with a chemical that produces dangerous fumes.

AIR ENTRAINMENT: The dissolution or inclusion of air bubbles into water.

AIRLIFT: The lifting of water and/or cuttings to the surface by the injection of high pressure bursts of air. Airlift occurs continuously when drilling with air rotary and can be used for well development with a surging technique.

AIR PUMPING: Continuous airlifting to remove water from the well.

AIR ROTARY: A method of rotary well drilling that utilizes compressed air as the primary drilling fluid.

AGGLOMERATION: A jumbled cluster or mass of varied parts. The act or process of agglomerating.

ALKALINITY: Alkalinity or AT is a measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. Alkalinity is closely related to the acid neutralizing capacity (ANC) of a solution and ANC is often incorrectly used to refer to alkalinity. However, the acid neutralizing capacity refers to the combination of the solution and solids present (e.g., suspended matter, or aquifer solids), and the contribution of solids can dominate the ANC (see carbonate minerals below).

ALTERNATIVE DISINFECTANTS: Disinfectants - other than chlorination (halogens) - used to treat water, e.g. ozone, ultraviolet radiation, chlorine dioxide, and chloramine. There is limited experience and scientific knowledge about the by-products and risks associated with the use of alternatives.

ALGAE: Microscopic plants that are free-living and usually live in water. They occur as single cells floating in water, or as multicellular plants like seaweed or strands of algae that attach to rocks.

ALPHA AND BETA RADIOACTIVITY: Represent two common forms of radioactive decay. Radioactive elements have atomic nuclei so heavy that the nucleus will break apart, or disintegrate spontaneously. When decay occurs, high-energy particles are released. These high-energy particles are called radioactivity. Although radioactivity from refined radioactive elements can be dangerous, it is rare to find dangerous levels of radioactivity in natural waters. An alpha particle is a doubly-charged helium nucleus comprised of two protons, two neutrons, and no electrons. A beta particle is a high-speed electron. Alpha particles do not penetrate matter easily, and are stopped by a piece of paper. Beta particles are much more penetrating and can pass through a millimeter of lead.

ALUMINUM SULFATE: The chemical name for Alum. The molecular formula of Alum is $Al_2(SO_4)3{\sim}14H_2O$. It is a cationic polymer.

AMOEBA: Amoeba (sometimes amœba or ameba, plural amoebae) is a genus of protozoa that moves by means of pseudopods, and is well-known as a representative unicellular organism. The word amoeba or ameba is variously used to refer to it and its close relatives, now grouped as the Amoebozoa, or to all protozoa that move using pseudopods, otherwise termed amoeboids.

AMMONIA: NH_3 A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water. Most ammonia in water is present as the ammonium ion rather than as ammonia.

AMMONIATOR: A control device which meters gaseous ammonia directly into water under positive pressure.

ANAEROBIC: An abnormal condition in which color and odor problems are most likely to occur.

ANAEROBIC CONDITIONS: When anaerobic conditions exist in either the metalimnion or hypolimnion of a stratified lake or reservoir, water quality problems may make the water unappealing for domestic use without costly water treatment procedures. Most of these problems are associated with Reduction in the stratified waters.

ANEROID: Using no fluid, as in aneroid barometer.

ASEPTIC: Free from the living germs of disease, fermentation, or putrefaction.

ANNULAR SPACE: The space between the borehole wall and either drill piping or casing within a well.

ANNULUS: See Annular Space.

AMMONIA: A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water.

AQUICLUDE: A layer or layers of soils or formations which water cannot pass through (ex - solid bedrock or very stiff clay). The opposite of aquifer.

AQUIFER: A saturated layer or layers of soils or formations which water can pass through and be provided in usable quantities to supply wells or springs (ex – saturated semi consolidated sediment or saturated fractured bedrock.) An underground geologic formation capable of storing significant amounts of water.

AQUIFER PARAMETERS: Referring to such attributes as specific capacity, aquifer storage, transmissivity, hydraulic conductivity, gradient, and water levels. Refers to all of the components of Darcy's Law and related parameters.

ARTESIAN AQUIFER: A confined aquifer in which the pressure head results in a water elevation higher than the land surface.

ARTESIAN WELL: A well constructed within an artesian aquifer. When an artesian well is opened it will flow naturally.

As: The chemical symbol of Arsenic.

AS NITROGEN: An expression that tells how the concentration of a chemical is expressed mathematically. The chemical formula for the nitrate ion is NO_3 , with a mass of 62. The concentration of nitrate can be expressed either in terms of the nitrate ion or in terms of the principal element, nitrogen. The mass of the nitrogen atom is 14. The ratio of the nitrate ion mass to the nitrogen atom mass is 4.43. Thus a concentration of 10 mg/L nitrate expressed as nitrogen would be equivalent to a concentration of 44.3 mg/L nitrate expressed as nitrate ion. When dealing with nitrate numbers it is very important to know how numeric values are expressed.

ASYNCHRONOUS: Not occurring at the same time.

AUGER RIG: A drilling rig, which drives a rotating spiral flange to drill into the earth.

ATOM: The general definition of an ion is an atom with a positive or negative charge. Electron is the name of a negatively charged atomic particle.

BACKFLOW PREVENTION: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquid, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

BACKFLOW: To reverse the natural and normal directional flow of a liquid, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

BACKSIPHONAGE: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point.

BACTERIA: Small, one-celled animals too small to be seen by the naked eye. Bacteria are found everywhere, including on and in the human body. Humans would be unable to live without the bacteria that inhabit the intestines and assist in digesting food. Only a small percentage of bacteria cause disease in normal, healthy humans. Other bacteria can cause infections if they get into a cut or wound. Bacteria are the principal concern in evaluating the microbiological quality of drinking water, because some of the bacteria-caused diseases that can be transmitted by drinking water are potentially life-threatening.

BACTERIOPHAGE: Any of a group of viruses that infect specific bacteria, usually causing their disintegration or dissolution. A bacteriophage (from 'bacteria' and Greek phagein, 'to eat') is any one of a number of viruses that infect bacteria. The term is commonly used in its shortened form, phage. Typically, bacteriophages consist of an outer protein hull enclosing genetic material. The genetic material can be ssRNA (single stranded RNA), dsRNA, ssDNA, or dsDNA between 5 and 500 kilo base pairs long with either circular or linear arrangement. Bacteriophages are much smaller than the bacteria they destroy - usually between 20 and 200 nm in size.

BAILER: A device used to withdrawal water or sediment from a well utilizing a check valve type mechanism.

BARITE: Processed barium sulfate, often used to increase drilling fluid densities in mud rotary.

BATTERY: A source of direct current (**DC**) may be used for standby lighting in a water treatment facility. The electrical current used in a DC system may come from a battery.

BENTONITE: High quality clay composed primarily of montmorillonite. Used to thicken drilling mud in mud rotary drilling and used to form seals in well construction or abandonment.

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE (BAT): A level of technology based on the best existing control and treatment measures that are economically achievable within the given industrial category or subcategory.

BEST MANAGEMENT PRACTICES (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the U.S. BMPs also include treatment requirements, operating procedures and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE (BPT): A level of technology represented by the average of the best existing wastewater treatment performance levels within an industrial category or subcategory.

BEST PROFESSIONAL JUDGMENT (BPJ): The method used by a permit writer to develop technology-based limitations on a case-by-case basis using all reasonably available and relevant data.

BIT: The primary cutting edge of a drill string.

BLANK CASING: A section of well casing that is solid.

BLOWDOWN: The discharge of water with high concentrations of accumulated solids from boilers to prevent plugging of the boiler tubes and/or steam lines. In cooling towers, blowdown is discharged to reduce the concentration of dissolved salts in the recirculating cooling water.

BOREHOLE DEVIATION: A boreholes' orientation deviates from vertical while drilling.

BOREHOLE GEOPHYSICS: A surveying technique of utilizing specialized tools to measure various physical parameters of the aquifer, formation, and well.

BOREHOLE: The hole that is formed when drilling into the earth.

BOULDER: An individual rock or solid mass of rock larger than 10 inches in diameter.

BREAK POINT CHLORINATION: The process of chlorinating the water with significant quantities of chlorine to oxidize all contaminants and organic wastes and leave all remaining chlorine as free chlorine.

BRIDGING: The tendency of sediment, filter, or seal media to create an obstruction if installed in too small an annulus or to rapidly. Also can occur within filter packs requiring development.

BROMINE: Chemical disinfectant (HALOGEN) that kills bacteria and algae. This chemical disinfectant has been used only on a very limited scale for water treatment because of its handling difficulties. This chemical causes skin burns on contact, and a residual is difficult to obtain.

BUCKET AUGER: A single cylindrical type of auger flight consisting of offset cutting blades at the bottom. A bucket auger rig rotates the bucket and its blades cut into the earth and fill the bucket with cuttings, which are dumped on the surface as needed.

BUFFER: Chemical that resists pH change, e.g. sodium bicarbonate

BUTTON BIT: A bit that is constructed with raised (typically carbide) buttons that strengthen the bit and aid in crushing and grinding efficiency. A button bit may be of a roller, hammer, or percussion type.

CABLE TOOL: (Also called Percussion Drilling) A method of drilling which utilizes the consecutive lifting and dropping of a heavy drill string via a system of cables.

CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.

Ca: The chemical symbol for calcium.

CADMIUM: A contaminant that is usually not found naturally in water or in very small amounts.

CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.

CALCIUM ION: Is divalent because it has a valence of +2.

CALCIUM, MAGNESIUM AND IRON: The three elements that cause hardness in water.

$CaOCl_2.4H_2O$: The molecular formula of Calcium hypochlorite.

CAPILLARY ACTION: The occurrence of an upward movement of fluid into previously unsaturated soil due to adhesion and surface tension which develops between the fluid and soil particles.

CAPILLARY FRINGE: The uppermost portion of an aquifer where the vadose zone ends. The capillary action of soils permits moisture to extend upwards into the vadose zone within the capillary fringe.

CARBON DIOXIDE GAS: The pH will decrease and alkalinity will change as measured by the Langelier index after pumping carbon dioxide gas into water.

CARBONATE HARDNESS: Carbonate hardness is the measure of Calcium and Magnesium and other hard ions associated with carbonate (CO_32^-) and bicarbonate (HCO_3^-) ions contained in a solution, usually water. It is usually expressed either as parts per million (ppm or mg/L), or in degrees (KH - from the German "Karbonathärte"). One German degree of carbonate hardness is equivalent to about 17.8575 mg/L. Both measurements (mg/L or KH) are usually expressed "as $CaCO_3$" – meaning the amount of hardness expressed as if calcium carbonate was the sole source of hardness. Every bicarbonate ion only counts for half as much carbonate hardness as a carbonate ion does. If a solution contained 1 liter of water and 50 mg $NaHCO_3$ (baking soda), it would have a carbonate hardness of about 18 mg/L as $CaCO_3$. If you had a liter of water containing 50 mg of Na_2CO_3, it would have a carbonate hardness of about 29 mg/L as $CaCO_3$.

CARBONATE, BICARBONATE AND HYDROXIDE: Chemicals that are responsible for the alkalinity of water.

CARBONATE ROCK: Rock that is composed primarily of calcium carbonate.

CASING DRIVER: A percussion or hammering device used to force casing into the subsurface.

CASING: A column of specially designed pipe of metal or plastic material installed in wells in order to keep a borehole open to permit serviceability of and/or construction and completion of a well within it.

CATHEAD: A specially designed auxiliary reel that normally utilizes heavy rope rather than steel cable. Often used on cable tool or percussion drilling rigs for the operation of drive blocks.

CATHODIC PROTECTION: An operator should protect against corrosion of the anode and/or the cathode by painting the copper cathode. Cathodic protection interrupts corrosion by supplying an electrical current to overcome the corrosion-producing mechanism. Guards against stray current corrosion.

CAUSTIC: NaOH (also called Sodium Hydroxide) is a strong chemical used in the treatment process to neutralize acidity, increase alkalinity or raise the pH value.

CAUSTIC SODA: Also known as sodium hydroxide and is used to raise pH.

CAVERN: Large open spaces (>5ft.) encountered while drilling. More often associated with limestone formations in a karst environment.

CEILING AREA: The specific gravity of ammonia gas is 0.60. If released, this gas will accumulate first at the ceiling area. Cl_2 gas will settle on the floor.

CEMENT GROUT: Cement of fine consistency, capable of being pumped. Used to seal in and around wells.

CENTRALIZER: Stand offs attached to well casing and screen to maintain annular space. In drilling, it has the same meaning as stabilizer or drill collar.

CENTRIFUGAL FORCE: That force when a ball is whirled on a string that pulls the ball outward. On a centrifugal pump, it is that force which throws water from a spinning impeller.

CENTRIFUGAL PUMP: A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

CESIUM (also Caesium)**:** Symbol Cs- A soft, silvery-white ductile metal, liquid at room temperature, the most electropositive and alkaline of the elements, used in photoelectric cells and to catalyze hydrogenation of some organic compounds.

CHAIN OF CUSTODY (COC): A record of each person involved in the possession of a sample from the person who collects the sample to the person who analyzes the sample in the laboratory.

CHAIN OF CUSTODY (COC): A record of each person involved in the possession of a sample from the person who collects the sample to the person who analyzes the sample in the laboratory.

CHECK VALVE: Allows water to flow in only one direction.

CHELATION: A chemical process used to control scale formation in which a chelating agent "captures" scale-causing ions and holds them in solution.

CHEMICAL FEED RATE: Chemicals are added to the water in order to improve the subsequent treatment processes. These may include pH adjusters and coagulants. Coagulants are chemicals, such as alum, that neutralize positive or negative charges on small particles, allowing them to stick together and form larger particles that are more easily removed by sedimentation (settling) or filtration. A variety of devices, such as baffles, static mixers, impellers and in-line sprays, can be used to mix the water and distribute the chemicals evenly.

CHEMICAL OXIDIZER: KMnO4 or Potassium Permanganate is used for taste and odor control because it is a strong oxidizer which eliminates many organic compounds.

CHEMICAL REATION RATE: In general, when the temperature decreases, the chemical reaction rate also decreases. The opposite is true for when the temperature increases.

CHEMISORPTION: (or chemical adsorption) Is adsorption in which the forces involved are valence forces of the same kind as those operating in the formation of chemical compounds.

CHLORAMINATION: Treating drinking water by applying chlorine before or after ammonia. This creates a persistent disinfectant residual called chloramines.

CHLORAMINES: A group of chlorine ammonia compounds formed when chlorine combines with organic wastes in the water. Chloramines are not effective as disinfectants and are responsible for eye and skin irritation as well as strong chlorine odors.

CHLORINATION: The process in water treatment of adding chlorine (gas or solid hypochlorite) for purposes of disinfection.

CHLORINE: A chemical used to disinfect water. Chlorine is extremely reactive, and when it comes in contact with microorganisms in water it kills them. Chlorine is added to swimming pools to keep the water safe for swimming. Chlorine is available as solid tablets for swimming pools. Some public water system's drinking water treatment plants use chlorine in a gas form because of the large volumes required. Chlorine is very effective against algae, bacteria and viruses. Protozoa are resistant to chlorine because they have thick coats; protozoa are removed from drinking water by filtration.

CHLORINE DEMAND: Amount of chlorine required to react on various water impurities before a residual is obtained. Also, means the amount of chlorine required to produce a free chlorine residual of 0.1 mg/l after a contact time of fifteen minutes as measured by iodmetic method of a sample at a temperature of twenty degrees in conformance with Standard methods.

CHLORINE FEED: Chlorine may be delivered by vacuum-controlled solution feed chlorinators. The chlorine gas is controlled, metered, introduced into a stream of injector water and then conducted as a solution to the point of application.

CHLORINE, FREE: Chlorine available to kill bacteria or algae. The amount of chlorine available for sanitization after the chlorine demand has been met. Also known as chlorine residual.

CIRCULATION: The continual flow of drilling fluid from injection to recovery and recirculation at the surface.

CLEAR WELL: A large underground storage facility sometimes made of concrete. A clear well or a plant storage reservoir is usually filled when demand is low. The final step in the conventional filtration process, the clearwell provides temporary storage for the treated water. The two main purposes for this storage are to have filtered water available for backwashing the filter and to provide detention time (or contact time) for the chlorine (or other disinfectant) to kill any microorganisms that may remain in the water.

ClO_2: The molecular formula of Chlorine dioxide.

COAGULATION: The best pH range for coagulation is between 5 and 7. Mixing is an important part of the coagulation process you want to complete the coagulation process as quickly as possible.

COBBLES: A rock smaller than a boulder but larger than a pebble. A cobble is greater than 2.5 inches in diameter and smaller than 10 inches in diameter.

COLIFORM: Bacteria normally found in the intestines of warm-blooded animals. Coliform bacteria are present in high numbers in animal feces. They are an indicator of potential contamination of water. Adequate and appropriate disinfection effectively destroys coliform bacteria. Public water systems are required to deliver safe and reliable drinking water to their customers 24 hours a day, 365 days a year. If the water supply becomes contaminated, consumers can become seriously ill. Fortunately, public water systems take many steps to ensure that the public has safe, reliable drinking water. One of the most important steps is to regularly test the water for coliform bacteria. Coliform bacteria are organisms that are present in the environment and in the feces of all warm-blooded animals and humans. Coliform bacteria will not likely cause illness. However, their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies come from the feces of humans or animals. Testing drinking water for all possible pathogens is complex, time-consuming, and expensive. It is relatively easy and inexpensive to test for coliform bacteria. If coliform bacteria are found in a water sample, water system operators work to find the source of contamination and restore safe drinking water. There are three different groups of coliform bacteria; each has a different level of risk.

COLIFORM TESTING: The effectiveness of disinfection is usually determined by Coliform bacteria testing. A positive sample is a bad thing and indicates that you have bacteria contamination.

COLLOIDAL SUSPENSIONS: Because both iron and manganese react with dissolved oxygen to form insoluble compounds, they are not found in high concentrations in waters containing dissolved oxygen except as colloidal suspensions of the oxide.

COLORIMETRIC MEASUREMENT: A means of measuring an unknown chemical concentration in water by measuring a sample's color intensity.

COMMUTATOR: A device for reversing the direction of a current. (in a DC motor or generator) a cylindrical ring or disk assembly of conducting members, individually insulated in a supporting structure with an exposed surface for contact with current-collecting brushes and mounted on the armature shaft, for changing the frequency or direction of the current in the armature windings.

CHRONIC: A stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of an organism. The measurement of chronic effect can be reduced growth, reduced reproduction, etc., in addition to lethality.

COMBINED CHLORINE: The reaction product of chlorine with ammonia or other pollutants, also known as chloramines.

COMMUNITY WATER SYSTEM: A water system which supplies drinking water to 25 or more of the same people year-round in their residences.

COMPLIANCE CYCLE: A 9-calendar year time-frame during which a public water system is required to monitor. Each compliance cycle consists of 3 compliance periods.

COMPLAINCE PERIOD: A 3-calendar year time-frame within a compliance cycle.

COMPLETION (WELL COMPLETION): Refers to the final construction of the well including the installation of pumping equipment.

COMPOSITE SAMPLE: A water sample that is a combination of a group of samples collected at various intervals during the day.

CONDENSATION: The process that changes water vapor to tiny droplets or ice crystals.

CONE OF DEPRESSION: That portion of the water table or potentiometric surface that experiences drawdown from a pumped well.

CONFINED AQUIFER: An aquifer that is isolated by confining layers on both its top and bottom. Pressures within a confined aquifer are normally greater than atmospheric pressure resulting in a potentiometric head.

CONFINING LAYER: An extensive layer of soil or formation that resists the movement of water from an aquifer below or above it. Confining layers isolate aquifers thereby confining them. May or may not be an aquiclude. (ex – Clay or silt rich layer)

CONSOLIDATED: Soil, sediment, or formation that is solidified or cemented together as a unit.

CONTACT TIME, pH and LOW TURBIDITY: Factors which are important in providing good disinfection using chlorine.

CONTACT TIME: If the water temperature decreases from 70°F (21°C) to 40°F (4°C). The operator needs to increase the detention time to maintain good disinfection of the water.

CONTAINS THE ELEMENT CARBON: A simple definition of an organic compound.

CONTAMINANT: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.

CONTAMINATE: tr.v. con·tam·i·nated, con·tam·i·nat·ing, con·tam·i·nates
1. To make impure or unclean by contact or mixture.
2. To expose to or permeate with radioactivity.

CONTAMINATION: A degradation in the quality of groundwater in result of the it's becoming polluted with unnatural or previously non-existent constituents.

CONTINUOUS SLOT SCREEN: A wire wrapped or plastic slotted screen in which the slot openings completely encircle the inner ribs of the screen.

CONTROL TASTE AND ODOR PROBLEMS: $KMnO_4$ Potassium permanganate is a strong oxidizer commonly used to control taste and odor problems.

CONVENTIONAL: A standard or common procedure to a group of more complex methods. (ex – Direct Rotary *conventional* vs. Reverse *non-conventional*)

COPPER: The chemical name for the symbol Cu.

CORROSION: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

CORROSIVITY: The Langelier Index measures corrosivity.

COUPON: A coupon placed to measure corrosion damage in the water mains.

CROSS-CONNECTION: A physical connection between a public water system and any source of water or other substance that may lead to contamination of the water provided by the public water system through backflow. Might be the source of an organic substance causing taste and odor problems in a water distribution system.

CROSS-CONTAMINATION: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.

CUTTING HEAD (CUTTER HEAD): The bit portion of auger flighting that serves as the primary cutting edge of the auger.

CUTTING SHOE: A hardened steel sleeve with a wedged or armored cutting edge that is installed on well casing that is to be driven into the earth.

CUTTINGS: Crushed rock, soil, or formation material generated by the drilling action of a bit.

CRYPTOSPORIDIUM: A disease-causing parasite, resistant to chlorine disinfection. It may be found in fecal matter or contaminated drinking water. Cryptosporidium is a protozoan pathogen of the Phylum Apicomplexa and causes a diarrheal illness called cryptosporidiosis. Other apicomplexan pathogens include the malaria parasite Plasmodium, and Toxoplasma, the causative agent of toxoplasmosis. Unlike Plasmodium, which transmits via a mosquito vector, Cryptosporidium does not utilize an insect vector and is capable of completing its life cycle within a single host, resulting in cyst stages which are excreted in feces and are capable of transmission to a new host.

CYANURIC ACID: White, crystalline, water-soluble solid, $C_3H_3O_3N_3 \cdot 2H_2O$, used chiefly in organic synthesis. Chemical used to prevent the decomposition of chlorine by ultraviolet (UV) light.

CYANOBACTERIA: Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta, is a phylum of bacteria that obtain their energy through photosynthesis. The name "cyanobacteria" comes from the color of the bacteria (Greek: kyanós = blue). They are a significant component of the marine nitrogen cycle and an important primary producer in many areas of the ocean, but are also found on land.

DAILY MAXIMUM LIMITATIONS: The maximum allowable discharge of pollutants during a 24 hour period. Where daily maximum limitations are expressed in units of mass, the daily discharge is the total mass discharged over the course of the day. Where daily maximum limitations are expressed in terms of a concentration, the daily discharge is the arithmetic average measurement of the pollutant concentration derived from all measurements taken that day.

DANGEROUS CHEMICALS: The most suitable protection when working with a chemical that produces dangerous fumes is to work under an air hood or fume hood.

DARCY'S LAW: (Q=KIA) A fundamental equation used in the groundwater sciences to determine aquifer characteristics, where Q=Flux, K=Hydraulic Conductivity (Permeability), I = Hydraulic Gradient (change in head), and A = Cross Sectional Area of flow.

DECIBELS: The unit of measurement for sound.

DECOMPOSE: To decay or rot.

DECOMPOSTION OF ORGANIC MATERIAL: The decomposition of organic material in water produces taste and odors.

DEMINERALIZATION PROCESS: Mineral concentration of the feed water is the most important consideration in the selection of a demineralization process. Acid feed is the most common method of scale control in a membrane demineralization treatment system.

DENTAL CARIES PREVENTION IN CHILDREN: The main reason that fluoride is added to a water supply.

DEPOLARIZATION: The removal of hydrogen from a cathode.

DESICCANT: When shutting down equipment which may be damaged by moisture, the unit may be protected by sealing it in a tight container. This container should contain a desiccant.

DESORPTION: Desorption is a phenomenon whereby a substance is released from or through a surface. The process is the opposite of sorption (that is, adsorption and absorption). This occurs in a system being in the state of sorption equilibrium between bulk phase (fluid, i.e. gas or liquid solution) and an adsorbing surface (solid or boundary separating two fluids). When the concentration (or pressure) of substance in the bulk phase is lowered, some of the sorbed substance changes to the bulk state. In chemistry, especially chromatography, desorption is the ability for a chemical to move with the mobile phase. The more a chemical desorbs, the less likely it will adsorb, thus instead of sticking to the stationary phase, the chemical moves up with the solvent front. In chemical separation processes, stripping is also referred to as desorption as one component of a liquid stream moves by mass transfer into a vapor phase through the liquid-vapor interface.

DEVELOPMENT: The cleaning of the well and bore once construction is complete.

DETENTION LAG: Is the period of time between the moment of change in a chlorinator control system and the moment when the change is sensed by the chlorine residual indicator.

DETENTION LAG TIME: The minimum detention time range recommended for flocculation is 5 – 20 minutes for direct filtration and up to 30 minutes for conventional filtration.

DIATOMACEOUS EARTH: A fine silica material containing the skeletal remains of algae.

DIRECT CURRENT: A source of direct current (**DC**) may be used for standby lighting in a water treatment facility. The electrical current used in a DC system may come from a battery.

DIRECT ROTARY: The conventional method of rotary drilling involving the rotation of a drill string and standard use of drilling fluid to penetrate the earth.

DISCHARGE HEAD: See Total Dynamic Head.

DISINFECT: The application of a chemical to kill most, but not all, microorganisms that may be present. Chlorine is added to public water drinking systems drinking water for disinfection. Depending on your state rule, drinking water must contain a minimum of 0.2 mg/L free chlorine. Disinfection makes drinking water safe to consume from the standpoint of killing pathogenic microorganisms including bacteria and viruses. Disinfection does not remove all bacteria from drinking water, but the bacteria that can survive disinfection with chlorine are not pathogenic bacteria that can cause disease in normal healthy humans.

DISINFECTION: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

DISINFECTION BY-PRODUCTS (DBPs): The products created due to the reaction of chlorine with organic materials (e.g. leaves, soil) present in raw water during the water treatment process. The EPA has determined that these DBPs can cause cancer. Chlorine is added to drinking water to kill or inactivate harmful organisms that cause various diseases. This process is called disinfection. However, chlorine is a very active substance and it reacts with naturally occurring substances to form compounds known as disinfection byproducts (DBPs). The most common DBPs formed when chlorine is used are trihalomethanes (THMs), and haloacetic acids (HAAs).

DISSOLVED OXYGEN: Can be added to zones within a lake or reservoir that would normally become anaerobic during periods of thermal stratification.

DISSOLUTION : The chemical and physical process of dissolving rock. Typically, limestone or carbonate rocks can be dissolved via the percolation or movement of groundwater that, in its infancy, is slightly acidic. As time goes on, the rock may also be physically worn away by the rapid movement of groundwater through the interconnected open spaces created by the initial chemical dissolving process.

DISTILLATION, REVERSE OSMOSIS AND FREEZING: Processes that can be used to remove minerals from the water.

DRAG BIT: A style of drill bit used in rotary drilling when soil or formation conditions are loosely consolidated and are comprised of fine-grained sediments.

DRAWDOWN: The change in water level from static to pumping level.

DRILL COLLAR: A section of the drill string that provides sufficient mass and diameter to maintain vertical borehole alignment and consistent borehole diameter.

DRILL FOAM: Surfactant used in air rotary drilling and well development.

DRILL PIPE: Sections of the drill string that are connected one to another in order to achieve a desired length while also providing a pathway for the circulation of drilling fluid.

DRILL STEM: The complete drill string or, in cable drilling, the equivalent of a drill collar.

DRILL STRING: The complete drilling assembly in rotary drilling including drill pipe, subs, collars, and bit.

DRILLER: A specially trained individual that operates the drilling rig.

DRILLING FLUID: Fluid circulated through the borehole in rotary drilling methods used to lift cuttings to the surface, provide borehole stability, and cool the bit. Drilling Fluid may consist of mud, water, air, foam, or other additives.

DRILLING PERMIT: A certificate of approval to drill and construct a well often required by the state or local regulating authority.

DRILLING PRESSURE: The pressure exerted within the borehole during drilling. The pressure required to circulate drilling fluid to the surface.

DRIVE BLOCK: A heavy collar that attaches over the drill pipe and is dropped successively to advance casing into the earth. Used primarily in cable tool or percussion drilling methods.

DRIVE CLAMP: A fitting that is attached to the top of a drill string or stem serving as a striking surface for driving casing into the earth.

DRIVE UNIT: The portion of a rotary rig that provides the rotation to the drill string. (ex – top drive or table drive unit). Also may be called the drive head.

DRIVING: The installation of a well or casing via forcing of it into the earth by repeated striking.

DRY ACID: A granular chemical used to lower pH and or total alkalinity.

E. COLI, Escherichia coli: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.

EFFECTIVENESS OF CHLORINE: The factors which influence the effectiveness of chlorination the most are pH, turbidity and temperature. Effectiveness of Chlorine decreases occurs during disinfection in source water with excessive turbidity.

ELECTRON: The name of a negatively charged atomic particle.

ELEMENTARY BUSINESS PLAN: Technical Capacity, Managerial Capacity, and Financial Capacity make up the elementary business plan. To become a new public water system, an owner shall file an elementary business plan for review and approval by state environmental agency.

EMERGENCY RESPONSE TEAM: A local team that is thoroughly trained and equipped to deal with emergencies, e.g. chlorine gas leak. In case of a chlorine gas leak, get out of the area and notify your local emergency response team in case of a large uncontrolled chlorine leak.

ENHANCED COAGULATION: The process of joining together particles in water to help remove organic matter.

ENTAMOEBA HISTOLYTICA: Entamoeba histolytica, another water-borne pathogen, can cause diarrhea or a more serious invasive liver abscess. When in contact with human cells, these amoebae are cytotoxic. There is a rapid influx of calcium into the contacted cell, it quickly stops all membrane movement save for some surface blebbing. Internal organization is disrupted, organelles lyse, and the cell dies. The ameba may eat the dead cell or just absorb nutrients released from the cell.

ENTEROVIRUS: A virus whose presence may indicate contaminated water; a virus that may infect the gastrointestinal tract of humans.

EUGLENA: Euglena are common protists, of the class Euglenoidea of the phylum Euglenophyta. Currently, over 1000 species of Euglena have been described. Marin et al. (2003) revised the genus so and including several species without chloroplasts, formerly classified as Astasia and Khawkinea. Euglena sometimes can be considered to have both plant and animal features. Euglena gracilis has a long hair-like thing that stretches from its body. You need a very powerful microscope to see it. This is called a flagellum, and the euglena uses it to swim. It also has a red eyespot. Euglena gracilis uses its eyespot to locate light. Without light, it cannot use its chloroplasts to make itself food.

EVOLUTION: Any process of formation or growth; development: the evolution of a language; the evolution of the airplane. A product of such development; something evolved: The exploration of space is the evolution of decades of research.

Biology. Change in the gene pool of a population from generation to generation by such processes as mutation, natural selection, and genetic drift. A process of gradual, peaceful, progressive change or development, as in social or economic structure or institutions, a motion incomplete in itself, but combining with coordinated motions to produce a single action, as in a machine. A pattern formed by or as if by a series of movements: the evolutions of a figure skater.

F: The chemical symbol of Fluorine.

FAUCET WITH AN AERATOR: When collecting a water sample from a distribution system, a faucet with an aerator should not be used as a sample location.

FAULT: A break in the earth's crust where movement has occurred.

FAULTING: A geological process involving the breaking and displacement of rock or formation through movements within the earth's crust along a fault.

FECAL COLIFORM: A group of bacteria that may indicate the presence of human or animal fecal matter in water. Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.

FILTRATION: The process of passing water through materials with very small holes to strain out particles. Most conventional water treatment plants used filters composed of gravel, sand, and anthracite. These materials settle into a compact mass that forms very small holes. Particles are filtered out as treated water passes through these holes. These holes are small enough to remove microorganisms including algae, bacteria, and protozoans, but not viruses. Viruses are eliminated from drinking water through the process of disinfection using chlorine. A series of processes that physically removes particles from water. A water treatment step used to remove turbidity, dissolved organics, odor, taste and color.

FILTER CLOGGING: An inability to meet demand may occur when filters are clogging.

FILTRATION METHODS: The conventional type of water treatment filtration method includes coagulation, flocculation, sedimentation, and filtration. Direct filtration method is similar to conventional except that the sedimentation step is omitted. Slow sand filtration process does not require pretreatment, has a flow of 0.1 gallons per minute per square foot of filter surface area, and is simple to operate and maintain. The Diatomaceous earth method uses a thin layer of fine siliceous material on a porous plate. This type of filtration medium is only used for water with low turbidity. Sedimentation, adsorption, and biological action treatment methods are filtration processes that involve a number of interrelated removal mechanisms. Demineralization is primarily used to remove total dissolved solids from industrial wastewater, municipal water, and seawater.

FINISHED WATER: Treated drinking water that meets minimum state and federal drinking water regulations.

FLIGHTING: The spiral flanged drill pipe used in auger drilling.

FLOATING SUB: A collapsible section of drill pipe shorter than primary drill pipe. Used to provide a cushion between the drive unit and the drill string.

FLOCCULATION: The process of bringing together destabilized or coagulated particles to form larger masses that can be settled and/or filtered out of the water being treated. Conventional coagulation–flocculation-sedimentation practices are essential pretreatments for many water purification systems—especially filtration treatments. These processes agglomerate suspended solids together into larger bodies so that physical filtration processes can more easily remove them. Particulate removal by these methods makes later filtering processes far more effective. The process is often followed by gravity separation (sedimentation or flotation) and is always followed by filtration. A chemical coagulant, such as iron salts, aluminum salts, or polymers, is added to source water to facilitate bonding among particulates. Coagulants work by creating a chemical reaction and eliminating the negative charges that cause particles to repel each other. The coagulant-source water mixture is then slowly stirred in a process known as flocculation. This water churning induces particles to collide and clump together into larger and more easily removable clots, or “flocs.” The process requires chemical knowledge of source water characteristics to ensure that an effective coagulant mix is employed. Improper coagulants make these treatment methods ineffective. The ultimate effectiveness of coagulation/flocculation is also determined by the efficiency of the filtering process with which it is paired.

FLOCCULANTS: Flocculants, or flocculating agents, are chemicals that promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to improve the sedimentation or filterability of small particles. For example, a flocculant may be used in swimming pool or drinking water filtration to aid removal of microscopic particles which would otherwise cause the water to be cloudy and which would be difficult or impossible to remove by filtration alone. Many flocculants are multivalent cations such as aluminum, iron, calcium or magnesium. These positively charged molecules interact with negatively charged particles and molecules to reduce the barriers to aggregation. In addition, many of these chemicals, under appropriate pH and other conditions such as temperature and salinity, react with water to form insoluble hydroxides which, upon precipitating, link together to form long chains or meshes, physically trapping small particles into the larger floc.

Long-chain polymer flocculants, such as modified polyacrylamides, are manufactured and sold by the flocculant producing business. These can be supplied in dry or liquid form for use in the flocculation process. The most common liquid polyacrylamide is supplied as an emulsion with 10-40 % actives and the rest is a carrier fluid, surfactants and latex. Emulsion polymers require activation to invert the emulsion and allow the electrolyte groups to be exposed.

FLOC SHEARING: Likely to happen to large floc particles when they reach the flocculation process.

FLOCCULATION BASIN: A compartmentalized basin with a reduction of speed in each compartment. This set-up or basin will give the best overall results.

FLOOD RIM: The point of an object where the water would run over the edge of something and begin to cause a flood.

FLOW MUST BE MEASURED: A recorder that measures flow is most likely to be located in a central location.

FLUORIDE: High levels of fluoride may stain the teeth of humans. This is called Mottling. This chemical must not be overfed due to a possible exposure to a high concentration of the chemical. The most important safety considerations to know about fluoride chemicals are that all fluoride chemicals are extremely corrosive**.** These are the substances most commonly used to furnish fluoride ions to water: Sodium fluoride, Sodium silicofluoride and Hydrofluosilicic acid.

FLUORIDE FEEDING: Always review fluoride feeding system designs and specifications to determine whether locations for monitoring readouts and dosage controls are convenient to the operation center and easy to read and correct.

FLUX: The term flux describes the rate of water flow through a semipermeable membrane. When the water flux decreases through a semipermeable membrane, it means that the mineral concentration of the water is increasing.

FORMATION: A series of layers, deposits, or bodies of rock, which are geologically similar and related in depositional environment or origin. A formation can be clearly distinguished relative to bounding deposits or formations due to its particular characteristics and composition.

FORMATION OF TUBERCLES: This condition is of the most concern regarding corrosive water effects on a water system. It is the creation of mounds of rust inside the water lines.

FRACTURE: A discrete break in a rock or formation.

FRACTURED AQUIFER: An aquifer within and otherwise massive block that has been made permeable due to the concentrated presence of fractures typically resultant of faulting or concentrated joints.

FREE CHLORINE: In disinfection, chlorine is used in the form of free chlorine or as hypochlorite ion.

FREE CHLORINE RESIDUAL: Regardless of whether pre-chloration is practiced or not, a free chlorine residual of at least 10 mg/L should be maintained in the clear well or distribution reservoir immediately downstream from the point of post-chlorination. The reason for chlorinating past the breakpoint is to provide protection in case of backflow.

GATE VALVE: The most common type of valve used in isolating a small or medium sized section of a distribution system and is the only linear valve used in water distribution. All the other valves are in the rotary classification.

GIARDIA LAMLIA: Giardia lamblia (synonymous with Lamblia intestinalis and Giardia duodenalis) is a flagellated protozoan parasite that colonizes and reproduces in the small intestine, causing giardiasis. The giardia parasite attaches to the epithelium by a ventral adhesive disc, and reproduces via binary fission. Giardiasis does not spread via the bloodstream, nor does it spread to other parts of the gastro-intestinal tract, but remains confined to the lumen of the small intestine. Giardia trophozoites absorb their nutrients from the lumen of the small intestine, and are anaerobes.

GIARDIASAS, HEPATITIS OR TYHOID: Diseases that may be transmitted through the contamination of a water supply but not AIDS.

GIS – GRAPHIC INFORMATION SYSTEM: Detailed information about the physical locations of structures such as pipes, valves, and manholes within geographic areas with the use of satellites.

GEOTECHNICAL: Characteristics of soil, rock, or formation such as grain size, shear strength, porosity, and compressibility, etc. Of particular concern to a geologist or engineer relative to soil or aquifer characteristics.

GLOBE VAVLVE: The main difference between a globe valve and a gate valve is that a globe valve is designed as a controlling device.

GOOD CONTACT TIME, pH and LOW TURBIDITY: These are factors that are important in providing good disinfection when using chlorine.

GPM: Gallons per minute.

GRAB SAMPLE: A sample which is taken from a water or wastestream on a one-time basis with no regard to the flow of the water or wastestream and without consideration of time. A single grab sample should be taken over a period of time not to exceed 15 minutes.

GRAINSIZE: The dimension of particle classifications such as gravel, sand, silt, and clay. Often based on the unified soil classification system.

GROUNDWATER: Water that percolates through and exists within saturated portions of the earth's crust and is replenished by the hydrologic cycle.

GROUT: A type of cement that is normally fine grained and used to effectively construct well seals and used in well abandonment. Grout may also be used to stabilize otherwise unstable boreholes, permitting continued drilling.

GT: Represents (Detention time) x (mixing intensity) in flocculation.

H_2SO_4: The molecular formula of Sulfuric acid.

HALIDES: A halide is a binary compound, of which one part is a halogen atom and the other part is an element or radical that is less electronegative than the halogen, to make a fluoride, chloride, bromide, iodide, or astatide compound. Many salts are halides. All Group 1 metals form halides with the halogens and they are white solids. A halide ion is a halogen atom bearing a negative charge. The halide anions are fluoride (F), chloride (Cl), bromide (Br), iodide (I) and astatide (At). Such ions are present in all ionic halide salts.

HALL EFFECT: Refers to the potential difference (Hall voltage) on the opposite sides of an electrical conductor through which an electric current is flowing, created by a magnetic field applied perpendicular to the current. Edwin Hall discovered this effect in 1879.

HALOACETIC ACIDS: Haloacetic acids are carboxylic acids in which a halogen atom takes the place of a hydrogen atom in acetic acid. Thus, in a monohaloacetic acid, a single halogen would replace a hydrogen atom. For example, chloroacetic acid would have the structural formula CH_2ClCO_2H. In the same manner, in dichloroacetic acid two chlorine atoms would take the place of two hydrogen atoms ($CHCl_2CO_2H$).

HAMMER BIT: The bit driven by the hammer to cut into rock or formation.

HAMMER: See Air Hammer

HARD ROCK: Consolidated formation or solid rock.

HARD WATER: Hard water causes a buildup of scale in household hot water heaters. Hard water is a type of water that has high mineral content (in contrast with soft water). Hard water primarily consists of calcium (Ca2+), and magnesium (Mg2+) metal cations, and sometimes other dissolved compounds such as bicarbonates and sulfates. Calcium usually enters the water as either calcium carbonate ($CaCO_3$), in the form of limestone and chalk, or calcium sulfate ($CaSO_4$), in the form of other mineral deposits. The predominant source of magnesium is dolomite ($CaMg(CO_3)2$). Hard water is generally not harmful. The simplest way to determine the hardness of water is the lather/froth test: soap or toothpaste, when agitated, lathers easily in soft water but not in hard water. More exact measurements of hardness can be obtained through a wet titration. The total water 'hardness' (including both Ca2+ and Mg2+ ions) is read as parts per million or weight/volume (mg/L) of calcium carbonate (CaCO3) in the water. Although water hardness usually only measures the total concentrations of calcium and magnesium (the two most prevalent, divalent metal ions), iron, aluminum, and manganese may also be present at elevated levels in some geographical locations.

HARDNESS: A measure of the amount of calcium and magnesium salts in water. More calcium and magnesium lead to greater hardness. The term "hardness" comes from the fact that it is hard to get soap suds from soap or detergents in hard water. This happens because calcium and magnesium react strongly with negatively-charged chemicals like soap to form insoluble compounds.

HARTSHORN: The antler of a hart, formerly used as a source of ammonia. Ammonium carbonate.

HAZARDS OF POLYMERS: Slippery and difficult to clean-up are the most common hazards associated with the use of polymers in a water treatment plant.

HEAD: The measure of the pressure of water expressed in feet of height of water. 1 PSI = 2.31 feet of water or 1 foot of head equals about a half a pound of pressure or .433 PSI. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).

HEADWORKS: The facility at the "**head**" of the water source where water is first treated and routed into the distribution system.

HEALTH ADVISORY: An EPA document that provides guidance and information on contaminants that can affect human health and that may occur in drinking water, but which the EPA does not currently regulate in drinking water.

HERTZ: The term used to describe the frequency of cycles in an alternating current (AC) circuit.

HETEROTROPHIC PLATE COUNT: A test performed on drinking water to determine the total number of all types of bacteria in the water.

HF: The molecular formula of Hydrofluoric acid.

HIGH TURBIDITY CAUSING INCREASED CHLORINE DEMAND: May occur or be caused by the inadequate disinfection of water.

HOLLOW STEM (AUGER): An auger form of drilling in which the flighting is hollow.

HOLLOW STEM FLIGHT: The hollow spiral flanged drill pipe used on hollow stem auger rigs.

HOMOPOLAR: Of uniform polarity; not separated or changed into ions; not polar in activity. Electricity. unipolar.

HYDRAULIC CONDUCTIVITY: A primary factor in Darcy's Law, the measure of a soil or formations ability to transmit water, measured in gallons per day (gpd) See also Permeability and Darcy's Law.

HYDRIDES: Hydride is the name given to the negative ion of hydrogen, H. Although this ion does not exist except in extraordinary conditions, the term hydride is widely applied to describe compounds of hydrogen with other elements, particularly those of groups 1–16. The variety of compounds formed by hydrogen is vast, arguably greater than that of any other element. Various metal hydrides are currently being studied for use as a means of hydrogen storage in fuel cell-powered electric cars and batteries. They also have important uses in organic chemistry as powerful reducing agents, and many promising uses in hydrogen economy.

HYDROCHLORIC AND HYPOCHLOROUS ACIDS: HCL and HOCL The compounds that are formed in water when chlorine gas is introduced.

HYDROFLUOSILIC ACID: (H_2SiF_6) a clear, fuming corrosive liquid with a pH ranging from 1 to 1.5. Used in water treatment to fluoridate drinking water.

HYDROGEN SULFIDE OR CHLORINE GAS: These chemicals can cause olfactory fatigue.

HYDROLOGIC CYCLE: (Water Cycle) The continual process of precipitation (rain and snowfall), evaporation (primarily from the oceans), peculation (recharge to groundwater), runoff (surface water), and transpiration (plants) constituting the renew ability and recycling of each component.

HYDROPHOBIC: Does not mix readily with water.

HYGROSCOPIC: Absorbing or attracting moisture from the air.

HYPOCHLORITE (OCL-) AND ORGANIC MATERIALS: Heat and possibly fire may occur when hypochlorite is brought into contact with an organic material.

HYPOLIMNION: The layer of water in a thermally stratified lake that lies below the thermocline, is noncirculating, and remains perpetually cold.

IMPELLERS: The semi-open or closed props or blades of a turbine pump that when rotated generate the pumping force.

IMPERVIOUS: Not allowing, or allowing only with great difficulty, the movement of water.

IN SERIES: Several components being connected one to the other without a bypass, requiring each component to work dependent on the one before it.

INFILTRATION: The percolation of fluid into soil or formation. See also percolation.

INFECTIOUS PATHOGENS/MICROBES/GERMS: Are considered disease-producing bacteria, viruses and other microorganisms.

INFLATABLE PACKER: A rubber or fiber bladder device that is inflated to seal against either casing or borehole walls.

INFORMATION COLLECTION RULE: ICR EPA collected data required by the Information Collection Rule (May 14, 1996) to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts. The rule was intended to provide EPA with information on chemical byproducts that form when disinfectants used for microbial control react with chemicals already present in source water (disinfection byproducts (DBPs)); disease-causing microorganisms (pathogens), including Cryptosporidium; and engineering data to control these contaminants.

INITIAL MONITORING YEAR: An initial monitoring year is the calendar year designated by the Department within a compliance period in which a public water system conducts initial monitoring at a point of entry.

INORGANIC CONTAMINANTS: Mineral-based compounds such as metals, nitrates, and asbestos. These contaminants are naturally-occurring in some water, but can also get into water through farming, chemical manufacturing, and other human activities. EPA has set legal limits on 15 inorganic contaminants.

INORGANIC IONS: Present in all waters. Inorganic ions are essential for human health in small quantities, but in larger quantities they can cause unpleasant taste and odor or even illness. Most community water systems will commonly test for the concentrations of seven inorganic ions: nitrate, nitrite, fluoride, phosphate, sulfate, chloride, and bromide. Nitrate and nitrite can cause an illness in infants called methemoglobinemia. Fluoride is actually added to the drinking water in some public water systems to promote dental health. Phosphate, sulfate, chloride, and bromide have little direct effect on health, but high concentrations of inorganic ions can give water a salty or briny taste.

INSOLUBLE COMPOUNDS: Are types of compounds cannot be dissolved. When iron or manganese reacts with dissolved oxygen (DO) insoluble compound are formed.

INTAKE FACILITIES: One of the more important considerations in the construction of intake facilities is the ease of operation and maintenance over the expected lifetime of the facility. Every intake structure must be constructed with consideration for operator safety and for cathodic protection.

ION EXCHANGE: An effective treatment process used to remove iron and manganese in a water supply. The hardness of the source water affects the amount of water an ion exchange softener may treat before the bed requires regeneration.

IRON: Fe The elements iron and manganese are undesirable in water because they cause stains and promote the growth of iron bacteria.

IRON AND MANGANESE: Fe and Mn In water they can usually be detected by observing the color of the inside walls of filters and the filter media. If the raw water is pre-chlorinated, there will be black stains on the walls below the water level and a black coating over the top portion of the sand filter bed. When significant levels of dissolved oxygen are present, iron and manganese exist in an oxidized state and normally precipitate into the reservoir bottom sediments. The presence of iron and manganese in water promote the growth of Iron bacteria. Only when a water sample has been acidified then you can perform the analysis beyond the 48 hour holding time. Iron and Manganese in water may be detected by observing the color of the of the filter media. Maintaining a free chlorine residual and regular flushing of water mains may control the growth of iron bacteria in a water distribution system.

IRON BACTERIA: Perhaps the most troublesome consequence of iron and manganese in the water is they promote the growth of a group of microorganism known as Iron Bacteria.

IRON FOULING: You should look for an orange color on the resin and backwash water when checking an ion exchange unit for iron fouling

JARS (DRILLING JARS): Metal sections of a drill string that when released provide a jarring force or action to aid in removing drill string. Used primarily in cable tool or percussion drilling methods.

JETTING: The process of injecting high velocity streams of water and/or air through a system of nozzles or jets into the well screen and filter pack for well development.

KARST TOPOGRAPHY: The visual presence of karst on the surface.

KARST: The presence of caverns, voids, sink holes as characteristic features of a weathered limestone or other carbonate formation on or beneath the surface.

KELLY: A multi-faceted section of drill pipe driven by a kelly drive (table or top drive).

KILL = C X T: Where other factors are constant, the disinfecting action may be represented by: Kill=C x T. C= Chlorine T= Contact time.

KINETIC ENERGY: The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

LACRIMATION: The secretion of tears, esp. in abnormal abundance Also, lachrymation, lachrimation.

LANGELIER INDEX: A measurement of Corrosivity. The water is becoming corrosive in the distribution system causing rusty water if the Langelier index indicates that the pH has decreased from the equilibrium point. Mathematically derived factor obtained from the values of calcium hardness, total alkalinity, and pH at a given temperature. A Langelier index of zero indicates perfect water balance (i.e., neither corroding nor scaling). The Langelier Saturation Index (sometimes Langelier Stability Index) is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. Langelier developed a method for predicting the pH at which water is saturated in calcium carbonate (called pHs). The LSI is expressed as the difference between the actual system pH and the saturation pH.
LSI = pH - pHs

LEACHING: A chemical reaction between water and metals that allows for removal of soluble materials.

LEAD AND COPPER: Initial tap water monitoring for lead and copper must be conducted during 2 consecutive 6-month periods.

LIME: Is a chemical that may be added to water to reduce the corrosivity. When an operator adds lime to water, Calcium and magnesium become less soluble.

LIME SODA SOFTENING: In a lime soda softening process, to the pH of the water is raised to 11.0. In a lime softening process, excess lime is frequently added to remove Calcium and Magnesium Bicarbonate. The minimum hardness which can be achieved by the lime-soda ash process is 30 to 40 mg/L as calcium carbonate. The hardness due to noncarbonate hardness is most likely to determine the choice between lime softening and ion exchange to remove hardness.

LIME SOFTENING: Lime softening is primarily used to “soften” water—that is to remove calcium and magnesium mineral salts. But it also removes harmful toxins like radon and arsenic. Though there is no consensus, some studies have even suggested that lime softening is effective at removal of Giardia. Hard water is a common condition responsible for numerous problems. Users often recognize hard water because it prevents their soap from lathering properly. However, it can also cause buildup (“scale”) in hot water heaters, boilers, and hot water pipes. Because of these inconveniences, many treatment facilities use lime softening to soften hard water for consumer use. Before lime softening can be used, managers must determine the softening chemistry required. This is a relatively easy task for groundwater sources, which remain more constant in their composition. Surface waters, however, fluctuate widely in quality and may require frequent changes to the softening chemical mix. In lime softening, lime and sometimes sodium carbonate are added to the water as it enters a combination solids contact clarifier. This raises the pH (i.e., increases alkalinity) and leads to the precipitation of calcium carbonate. Later, the pH of the effluent from the clarifier is reduced again, and the water is then filtered through a granular media filter. The water chemistry requirements of these systems require knowledgeable operators, which may make lime softening an economic challenge for some very small systems.

LINE SHAFT TURBINE: See vertical turbine.

LOGGED (LOGGING): The assessment and documentation of geological and water production data obtained while drilling progresses or following drilling through the use of borehole geophysical logging tools.

L.O.T.O.: Lock Out, Tag Out. If a piece of equipment is locked out, the key to the lock-out device the key should be held by the person who is working on the equipment. The tag is an identification device and the lock is a physical restraint.

M-ENDO BROTH: The coliform group is used as indicators of fecal pollution in water, for assessing the effectiveness of water treatment and disinfection, and for monitoring water quality. m-Endo Broth is used for selectively isolating coliform bacteria from water and other specimens using the membrane filtration technique. m-Endo Broth is prepared according to the formula of Fifield and Schaufus.1 It is recommended by the American Public Health Association in standard total coliform membrane filtration procedure for testing water, wastewater, and foods.2,3 The US EPA specifies using m-Endo Broth in the total coliform methods for testing water using single-step, two-step, and delayed incubation membrane filtration methods.

MAGNESIUM HARDNESS: Measure of the magnesium salts dissolved in water – it is not a factor in water balance.

MAGNETIC STARTER: Is a type of motor starter should be used in an integrated circuit to control flow automatically.

MARBLE AND LANGELIER TESTS: Are used to measure or determine the corrosiveness of a water source.

MAXIMUM CONTAMINANT LEVEL (MCLs): The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL.

MAXIMUM CONTAMINANT LEVEL GOAL (MCLG): The level of a contaminant at which there would be no risk to human health. This goal is not always economically or technologically feasible, and the goal is not legally enforceable.

MCL for TURBIDITY: Turbidity is undesirable because it causes health hazards. An MCL for turbidity was established by the EPA because turbidity does not allow for proper disinfection.

MEASURE CORROSION DAMAGE: A coupon such as a strip of metal and is placed to measure corrosion damage in the distribution system in a water main.

MECHANICAL SEAL: A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them. Held in place with spring pressure.

MEDIUM WATER SYSTEM: More than 3,300 persons and 50,000 or fewer persons.

MEGGER: Is a portable instrument used to measure insulation resistance. The megger consists of a hand-driven DC generator and a direct reading ohm meter. Used to test the insulation resistance on a motor.

M-ENDO BROTH: The media shall be brought to the boiling point when preparing M-Endo broth to be used in the membrane filter test for total coliform.

METALIMNION: Thermocline, middle layer of a thermally stratified lake which is characterized by a rapid decrease in temperature in proportion to depth.

METALLOID: Metalloid is a term used in chemistry when classifying the chemical elements. On the basis of their general physical and chemical properties, nearly every element in the periodic table can be termed either a metal or a nonmetal. A few elements with intermediate properties are, however, referred to as metalloids. (In Greek metallon = metal and eidos = sort)

METHANE: Methane is a chemical compound with the molecular formula CH_4. It is the simplest alkane, and the principal component of natural gas. Methane's bond angles are 109.5 degrees. Burning methane in the presence of oxygen produces carbon dioxide and water. The relative abundance of methane and its clean burning process makes it a very attractive fuel. However, because it is a gas at normal temperature and pressure, methane is difficult to transport from its source. In its natural gas form, it is generally transported in bulk by pipeline or LNG carriers; few countries still transport it by truck.

MILLILITER: One one-thousandth of a liter; A liter is a little more than a quart. A milliliter is about two drops from an eye dropper.

Mg/L: Stands for "**milligrams per liter**." A common unit of chemical concentration. It expresses the mass of a chemical that is present in a given volume of water. A milligram (one one-thousandth of a gram) is equivalent to about 18 grains of table salt. A liter is equivalent to about one quart.

MICROBIOLOGICAL: Is a type of analysis in which a composite sample unacceptable.

MICROBE OR MICROBIAL: Any minute, simple, single-celled form of life, especially one that causes disease.

MICROBIAL CONTAMINANTS: Microscopic organisms present in untreated water that can cause waterborne diseases.

MICROORGANISMS: Very small animals and plants that are too small to be seen by the naked eye and must be observed using a microscope. Microorganisms in water include algae, bacteria, viruses, and protozoa. Algae growing in surface waters can cause off-taste and odor by producing the chemicals MIB and geosmin. Certain types of bacteria, viruses, and protozoa can cause disease in humans. Bacteria are the most common microorganisms found in treated drinking water. The great majority of bacteria are not harmful. In fact, humans would not be able to live without the bacteria that inhabit the intestines. However, certain types of bacteria called coliform bacteria can signal the presence of possible drinking water contamination.

MILLILITER: One one-thousandth of a liter. A liter is a little more than a quart. A milliliter is about two drops from an eye dropper.

MOISTURE: If a material is hygroscopic, it must it be protected from water.

MOISTURE AND POTASSIUM PERMANGANATE: The combination of moisture and potassium permanganate produces heat.

MOLECULAR WEIGHT: The molecular mass (abbreviated Mr) of a substance, formerly also called molecular weight and abbreviated as MW, is the mass of one molecule of that substance, relative to the unified atomic mass unit u (equal to 1/12 the mass of one atom of carbon-12). This is distinct from the relative molecular mass of a molecule, which is the ratio of the mass of that molecule to 1/12 of the mass of carbon 12 and is a dimensionless number. Relative molecular mass is abbreviated to Mr.

MOTTLING: High levels of fluoride may stain the teeth of humans.

M.S.D.S.: Safety Data Sheets (SDS). A safety document must an employer provide to an operator upon request.

MUD BALLS IN FILTER MEDIA: Is a possible result of an ineffective or inadequate filter backwash.

MUD CAKE: A film of mud drilling fluid that builds up on borehole walls adding to borehole stability and limits the groundwater's ability to enter the borehole while drilling.

MUD CAKING: The process of building up the mud cake.

MUD ENGINEER: A specially trained individual who's responsible for maintaining proper drilling fluid densities and viscosity.

MUD PIT: Single or multiple subsurface or surface containment system used for settling cuttings out of drilling fluid and for recirculation of drilling fluid.

MUD PUMP: A specially designed pump that can pass particles of mud and cuttings (drilling fluid) at variable pressures, serving as the primary component in a mud rotary drilling system (similar to a grout or cement pump).

MUD ROTARY: The method of rotary drilling with mud circulation as the drilling fluid.

MURIATIC ACID: An acid used to reduce pH and alkalinity. Also used to remove stain and scale.

MYCOTOXIN: A toxin produced by a fungus.

NaOCl: Is the molecular formula of Sodium hypochlorite.

NaOH: Is the molecular formula of Sodium hydroxide.

NASCENT: Coming into existence; emerging.

NATURAL GRAVEL PACK (NATURALLY PACKED): Refers to a well that has no gravel pack installed but is simply allowed to develop a filter pack composed of the aquifer particles itself. Usually coarse grained and hard rock aquifers are naturally packed.

NH_3: The molecular formula of Ammonia.

NH_4+: The molecular formula of the Ammonium ion.

NITRATES: A dissolved form of nitrogen found in fertilizers and sewage by-products that may leach into groundwater and other water sources. Nitrates may also occur naturally in some waters. Over time, nitrates can accumulate in aquifers and contaminate groundwater.

NITROGEN: Nitrogen is a nonmetal, with an electronegativity of 3.0. It has five electrons in its outer shell and is therefore trivalent in most compounds. The triple bond in molecular nitrogen (N_2) is one of the strongest in nature. The resulting difficulty of converting (N_2) into other compounds, and the ease (and associated high energy release) of converting nitrogen compounds into elemental N_2, have dominated the role of nitrogen in both nature and human economic activities.

NITROGEN AND PHOSPHORUS: Pairs of elements and major plant nutrients that cause algae to grow.

NO_3^-: The molecular formula of the Nitrate ion.

NON-CARBONATE HARDNESS: The portion of the total hardness in excess of the alkalinity.

NON-CARBONATE IONS: Water contains non-carbonate ions if it cannot be softened to a desired level through the use of lime only.

NON-POINT SOURCE POLLUTION: Air pollution may leave contaminants on highway surfaces. This non-point source pollution adversely impacts reservoir water and groundwater quality.

NON-TRANSIENT, NON-COMMUNITY WATER SYSTEM: A water system which supplies water to 25 or more of the same people at least six months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.

NORMALITY: It is the number of equivalent weights of solute per liter of solution. Normality highlights the chemical nature of salts: in solution, salts dissociate into distinct reactive species (ions such as H^+, Fe_3^+, or Cl^-). Normality accounts for any discrepancy between the concentrations of the various ionic species in a solution. For example, in a salt such as $MgCl_2$, there are two moles of Cl^- for every mole of Mg_2^+, so the concentration of Cl- as well as of Mg_2^+ is said to be 2 N (read: "two normal"). Further examples are given below. A normal is one gram equivalent of a solute per liter of solution. The definition of a gram equivalent varies depending on the type of chemical reaction that is discussed - it can refer to acids, bases, redox species, and ions that will precipitate. It is critical to note that normality measures a single ion which takes part in an overall solute. For example, one could determine the normality of hydroxide or sodium in an aqueous solution of sodium hydroxide, but the normality of sodium hydroxide itself has no meaning. Nevertheless it is often used to describe solutions of acids or bases, in those cases it is implied that the normality refers to the H+ or OH- ion. For example, 2 Normal sulfuric acid (H_2SO_4), means that the normality of H+ ions is 2, or that the molarity of the sulfuric acid is 1. Similarly for 1 Molar H_3PO_4 the normality is 3 as it contains three H+ ions.

NTNCWS: Non-transient non-community water system.

NTU (Nephelometric turbidity unit)**:** A measure of the clarity or cloudiness of water.

O_3: The molecular formula of ozone.

OIL TUBE: A tubular enclosure that houses the line shaft and bearings of a vertical turbine pump. Oil is allowed to pass through the oil tube in order to lubricate the pumps drive shaft and bearings.

OLIGOTROPHIC: A reservoir that is nutrient-poor and contains little plant or animal life. An oligotrophic ecosystem or environment is one that offers little to sustain life. The term is commonly utilized to describe bodies of water or soils with very low nutrient levels. It derives etymologically from the Greek oligo (small, little, few) and trophe (nutrients, food). Oligotrophic environments are of special interest for the alternative energy sources and survival strategies upon which life could rely.

ORGANIC PRESURSORS: Natural or man-made compounds with chemical structures based upon carbon that, upon combination with chlorine, leading to trihalomethane formation.

OSMOSIS: Osmosis is the process by which water moves across a semi permeable membrane from a low concentration solute to a high concentration solute to satisfy the pressure differences caused by the solute.

OVERBURDEN: Normally a thin loosely consolidated or unconsolidated sediment overlying competent formation.

OVER-RANGE PROTECTION DEVICES: Mechanical dampers, snubbers and an air cushion chamber are examples of surging and overrange protection devices.

OXIDE: An oxide is a chemical compound containing at least one oxygen atom as well as at least one other element. Most of the Earth's crust consists of oxides. Oxides result when elements are oxidized by oxygen in air. Combustion of hydrocarbons affords the two principal oxides of carbon, carbon monoxide and carbon dioxide. Even materials that are considered to be pure elements often contain a coating of oxides. For example, aluminum foil has a thin skin of Al_2O_3 that protects the foil from further corrosion.

OXIDIZED:
1. to convert (an element) into an oxide; combine with oxygen.
2. to cover with a coating of oxide or rust.
3. to take away hydrogen, as by the action of oxygen; add oxygen or any nonmetal.
4. to remove electrons from (an atom or molecule), thereby increasing the valence. Compare REDUCE (def. 12).

–verb (used without object)

5. to become oxidized.

OXIDIZING: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

OXYGEN DEFICIENT ENVIRONMENT: One of the most dangerous threats to an operator upon entering a manhole.

OZONE: Ozone or trioxygen (O_3) is a triatomic molecule, consisting of three oxygen atoms. It is an allotrope of oxygen that is much less stable than the diatomic O_2. Ground-level ozone is an air pollutant with harmful effects on the respiratory systems of animals. Ozone in the upper atmosphere filters potentially damaging ultraviolet light from reaching the Earth's surface. It is present in low concentrations throughout the Earth's atmosphere. It has many industrial and consumer applications. Ozone, the first allotrope of a chemical element to be recognized by science, was proposed as a distinct chemical compound by Christian Friedrich Schönbein in 1840, who named it after the Greek word for smell (ozein), from the peculiar odor in lightning storms. The formula for ozone, O_3, was not determined until 1865 by Jacques-Louis Soret and confirmed by Schönbein in 1867. Ozone is a powerful oxidizing agent, far better than dioxygen. It is also unstable at high concentrations, decaying to ordinary diatomic oxygen (in about half an hour in atmospheric conditions):

$2\ O_3 = 3\ O_2$

This reaction proceeds more rapidly with increasing temperature and decreasing pressure. Deflagration of ozone can be triggered by a spark, and can occur in ozone concentrations of 10 wt% or higher.

OZONE DOES NOT PROVIDE A RESIDUAL: One of the major drawbacks to using ozone as a disinfectant.

OZONE, CHLORINE DIOXIDE, UV, CHLORAMINES: These chemicals may be used as alternative disinfectants.

PAC: A disadvantage of using PAC is it is very abrasive and requires careful maintenance of equipment. One precaution that should be taken in storing PAC is that bags of carbon should not be stored near bags of HTH. Removes tastes and odors by adsorption only. Powered activated carbon frequently used for taste and odor control because PAC is non-specific and removes a broad range of compounds. Jar tests and threshold odor number testing determines the application rate for powdered activated carbon. Powdered activated carbon, or PAC, commonly used for in a water treatment plant for taste and odor control. Powdered activated carbon may be used with some success in removing the precursors of THMs

PACKING: Material, usually of woven fiber, placed in rings around the shaft of a pump and used to control the leakage from the stuffing box.

PARAMECIUM: Paramecia are a group of unicellular ciliate protozoa formerly known as slipper animalcules from their slipper shape. They are commonly studied as a representative of the ciliate group. Simple cilia cover the body which allows the cell to move with a synchronous motion (like a caterpilla). There is also a deep oral groove containing inconspicuous compound oral cilia (as found in other peniculids) that is used to draw food inside. They generally feed upon bacteria and other small cells. Osmoregulation is carried out by a pair of contractile vacuoles, which actively expel water absorbed by osmosis from their surroundings. Paramecia are widespread in freshwater environments, and are especially common in scums. Paramecia are attracted by acidic conditions. Certain single-celled eukaryotes, such as Paramecium, are examples for exceptions to the universality of the genetic code (translation systems where a few codons differ from the standard ones).

PATHOGENS: Disease-causing pathogens; waterborne pathogens A pathogen may contaminate water and cause waterborne disease.

Pb: The chemical symbol of Lead.

PCE: Perchloroethylene. Known also as perc or tetrachloroethylene, perchloroethylene is a clear, colorless liquid with a distinctive, somewhat ether-like odor. It is non-flammable, having no measurable flashpoint or flammable limits in air. Effective over a wide range of applications, perchloroethylene is supported by closed loop transfer systems, stabilizers and employee exposure monitoring.

PEAK DEMAND: The maximum momentary load placed on a water treatment plant, pumping station or distribution system.

PERCOLATION: The process of fluid penetrating or slowly flowing through soil, rock, or formation. See also infiltration.

PERCUSSION RIG: See Cable Tool.

PERFORATED SCREEN: Well screen that has openings mechanically cut into it.

PERFORMANCE CURVE: A graphical representation of a pumps efficiency relative to gpm and feet of head.

PEPTIDOGLYCAN: A polymer found in the cell walls of prokaryotes that consists of polysaccharide and peptide chains in a strong molecular network. Also called *mucopeptide*, *murein*.

PERMEATE: The term for water which has passed through the membrane of a reverse osmosis unit.

PERMEABILITY: A measure of a soil or formation's capacity to transmit water, typically in volume per time units. Equivalent to Darcy's hydraulic conductivity.

PERMEABLE: Soil or formation of which water can pass through.

pH: A unit of measure which describes the degree of acidity or alkalinity of a solution. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. The term pH is derived from “p”, the mathematical symbol of the negative logarithm, and “H”, the chemical symbol of Hydrogen. The definition of pH is the negative logarithm of the Hydrogen ion activity. $pH=-\log[H^+]$.

pH OF SATURATION: The ideal pH for perfect water balance in relation to a particular total alkalinity level and a particular calcium hardness level, at a particular temperature. The pH where the Langelier Index equals zero.

PHENOLPHTHALEIN/TOTAL ALKALINITY: The relationship between the alkalinity constituent’s bicarbonate, carbonate, and hydroxide can be based on the P and T alkalinity measurement.

PHENOL RED: Chemical reagent used for testing pH in the range of 6.8 - 8.4.

PHOSPHATE, NITRATE AND ORGANIC NITROGEN: Nutrients in a domestic water supply reservoir may cause water quality problems if they occur in moderate or large quantities.

PHYSISORPTION: (Or physical adsorption) Is adsorption in which the forces involved are intermolecular forces (van der Waals forces) of the same kind as those responsible for the imperfection of real gases and the condensation of vapors, and which do not involve a significant change in the electronic orbital patterns of the species involved. The term van der Waals adsorption is synonymous with physical adsorption, but its use is not recommended.

PICOCURIE: A unit of radioactivity. "Pico" is a metric prefix that means one one-millionth of one one-millionth. A picocurie is one one-millionth of one one-millionth of a Curie. A Curie is that quantity of any radioactive substance that undergoes 37 billion nuclear disintegrations per second. Thus a picocurie is that quantity of any radioactive substance that undergoes 0.037 nuclear disintegrations per second.

pCi/L: Picocuries per liter A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

PICOCURIE: A unit of radioactivity. "Pico" is a metric prefix that means one one-millionth of one one-millionth. A picocurie is one one-millionth of one one-millionth of a Curie. A Curie is that quantity of any radioactive substance that undergoes 37 billion nuclear disintegrations per second. Thus a picocurie is that quantity of any radioactive substance that undergoes 0.037 nuclear disintegrations per second.

PIEZOMETRIC SURFACE: See potentiometric surface.

PILOT BIT: A bit used on auger rigs to cut a pilot hole ahead of the cutter head when drilling into more resistant formations.

PIPELINE APPURTENANCE: Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

PITLESS ADAPTER: A fitting installed on a section of column pipe and well casing permitting piping from the well to be installed below grade. (Often requires a special permit for construction)

PLANKTON: The aggregate of passively floating, drifting, or somewhat motile organisms occurring in a body of water, primarily comprising microscopic algae and protozoa.

PLATFORM: The portion of the drilling rig where a driller and crew operate the drill rig.

PLUG: A removable cap installed behind the pilot and cutter bits on hollow stem auger flighting.

POINT OF ENTRY: POE.

POLLUTION: To make something unclean or impure. See Contaminated.

POLYPHOSPHATES: Chemicals that may be added to remove low levels of iron and manganese.

POLYMER: A type of chemical when combined with other types of coagulants aid in binding small suspended particles to larger particles to help in the settling and filtering processes.

PORE SPACE: The interstitial space between sediments and fractures that is capable of storing and transmitting water.

POROSITY: A factor representing a rock, soil, or formations percentage of open space available for the percolation and storage of groundwater.

POST-CHLORINE: Where the water is chlorinated to make sure it holds a residual in the distribution system.

POTABLE: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.

POTENTIAL ENERGY: The energy that a body has by virtue of its position or state enabling it to do work.

POTENTIOMETRIC SURFACE: An imaginary surface representing the height a column of water will reach at any location within a confined aquifer. The measured surface of a confined aquifer related to the aquifer's pressure head.

PPM: Abbreviation for parts per million.

PRE-CHLORINE: Where the raw water is dosed with a large concentration of chlorine.

PRE-CHLORINATION: The addition of chlorine before the filtration process will help:
> Control algae and slime growth
> Control mud ball formation
> Improve coagulation
> Precipate iron
The addition of chlorine to the water prior to any other plant treatment processes.

PERKINESIS: The aggregation resulting from random thermal motion of fluid molecules.

PRESSURE: Pressure is defined as force per unit area. It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. The standard unit for pressure is the Pascal, which is a Newton per square meter. For an object sitting on a surface, the force pressing on the surface is the weight of the object, but in different orientations it might have a different area in contact with the surface and therefore exert a different pressure.

PRESSURE HEAD: The height of a column of water capable of being maintained by pressure. See also Total Head, Total Dynamic Head.

PRESSURE MEASUREMENT: Bourdon tube, Bellows gauge and Diaphragm are commonly used to measure pressure in waterworks systems. A Bellows-type sensor reacts to a change in pressure.

PREVENTION: To take action; stop something before it happens.

PROTON, NEUTRON AND ELECTRON: Are the 3 fundamental particles of an atom.

PRODUCING ZONE: A specific productive interval.

PRODUCTIVE INTERVAL: The portion or portions of an aquifer in which significant water production is obtained within the well.

PROTIST: Any of a group of eukaryotic organisms belonging to the kingdom Protista according to some widely used modern taxonomic systems. The protists include a variety of unicellular, coenocytic, colonial, and multicellular organisms, such as the protozoans, slime molds, brown algae, and red algae. A unicellular protoctist in taxonomic systems in which the protoctists are considered to form a kingdom.

PROTOCTIST: Any of various unicellular eukaryotic organisms and their multicellular, coenocytic, or colonial descendants that belong to the kingdom Protoctista according to some taxonomic systems. The protoctists include the protozoans, slime molds, various algae, and other groups. In many new classification systems, all protoctists are considered to be protists.

PROTOZOA: Microscopic animals that occur as single cells. Some protozoa can cause disease in humans. Protozoa form cysts, which are specialized cells like eggs that are very resistant to chlorine. Cysts can survive the disinfection process, then "hatch" into normal cells that can cause disease. Protozoa must be removed from drinking water by filtration, because they cannot be effectively killed by chlorine.

PUBLIC NOTIFICATION: An advisory that EPA requires a water system to distribute to affected consumers when the system has violated MCLs or other regulations. The notice advises consumers what precautions, if any, they should take to protect their health.

PUBLIC WATER SYSTEM (PWS): Any water system which provides water to at least 25 people for at least 60 days annually. There are more than 170,000 PWSs providing water from wells, rivers and other sources to about 250 million Americans. The others drink water from private wells. There are differing standards for PWSs of different sizes and types.

PUMP SURGING: A process of well development whereby water is pumped nearly to the surface and then is allowed to fall back into the well. The process creates a backwashing action that cleans the well and nearby formation.

PUMPING LIFT: The height to which water must be pumped or lifted to, feet of head.

PWS: 3 types of public water systems. Community water system, non-transient non-community water system, transient non community water system.

RADIOCHEMICALS: (Or radioactive chemicals) Occur in natural waters. Naturally radioactive ores are particularly common in the Southwestern United States, and some streams and wells can have dangerously high levels of radioactivity. Total alpha and beta radioactivity and isotopes of radium and strontium are the major tests performed for radiochemicals. The federal drinking water standard for gross alpha radioactivity is set at 5 picocuries per liter.

RADIUS OF INFLUENCE: The distance away from a pumping well that water levels are affected by a wells cone of depression.

RAWHIDING: See Pump Surging.

RAW TURBIDITY: The turbidity of the water coming to the treatment plant from the raw water source.

RAW WATER: Water that has not been treated in any way; it is generally considered to be unsafe to drink.

REAGENT: A substance used in a chemical reaction to measure, detect, examine, or produce other substances.

REAM: The process of enlarging a borehole.

REAMER BIT: A special bit designed to ream existing boreholes.

RECHARGE: The infiltration component of the hydrologic cycle. Often used in the context of referring to: The infiltration of water back into an aquifer, resulting in the restoration of lost storage and water levels which had been decreased due to pumping and/or natural discharges from the aquifer.

RECIRCULATING SYSTEM: A system of constructed or surface mud pits that settle out cuttings from drilling fluid to be circulated back down the borehole.

RECORDER, FLOW: A flow recorder that measures flow is most likely to be located anywhere in the plant where a flow must be measured and in a central location.

RED WATER AND SLIME: Iron bacteria are undesirable in a water distribution system because of red water and slime complaints.

REDOX POTENTIAL: Reduction potential (also known as redox potential, oxidation / reduction potential or ORP) is the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species' affinity for electrons and tendency to be reduced. In aqueous solutions, the reduction potential is the tendency of the solution to either gain or lose electrons when it is subject to change by introduction of a new species. A solution with a higher (more positive) reduction potential than the new species will have a tendency to gain electrons from the new species (i.e. to be reduced by oxidizing the new species) and a solution with a lower (more negative) reduction potential will have a tendency to lose electrons to the new species (i.e. to be oxidized by reducing the new species).

RELAY LOGIC: The name of a popular method of automatically controlling a pump, valve, chemical feeder, and other devices.

RESERVOIR: An impoundment used to store water.

RESIDUAL DISINFECTION PROTECTION: A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

REVERSE MUD ROTARY: A non-conventional drilling method in which drilling fluid is injected through the borehole annulus downward through the bit and circulated back to the surface through the drill string.

REVERSE OSMOSIS: Forces water through membranes that contain holes so small that even salts cannot pass through. Reverse osmosis removes microorganisms, organic chemicals, and inorganic chemicals, producing very pure water. For some people, drinking highly purified water exclusively can upset the natural balance of salts in the body. Reverse osmosis units require regular maintenance or they can become a health hazard.

RIBBED STABILIZER: A stabilizer or drill collar that has cutting ribs attached to its side. Ribs are normally installed in vertical or spiral arrangements.

ROLLER BIT: A rotary drill bit having rotating cutting heads.

ROTAMETER: The name of transparent tube with a tapered bore containing a ball is often used to measure the rate of flow of a gas or liquid.

ROTARY RIG: A conventional rotary drill rig. Can be either an air or mud rotary rig.

ROTIFER: Rotifers get their name (derived from Greek and meaning "wheel-bearer"; they have also been called wheel animalcules) from the corona, which is composed of several ciliated tufts around the mouth that in motion resemble a wheel. These create a current that sweeps food into the mouth, where it is chewed up by a characteristic pharynx (called the mastax) containing a tiny, calcified, jaw-like structure called the trophi. The cilia also pull the animal, when unattached, through the water. Most free-living forms have pairs of posterior toes to anchor themselves while feeding. Rotifers have bilateral symmetry and a variety of different shapes. There is a well-developed cuticle which may be thick and rigid, giving the animal a box-like shape, or flexible, giving the animal a worm-like shape; such rotifers are respectively called loricate and illoricate.

RUNOFF: Surface water sources such as a river or lake are primarily the result of natural processes of runoff.

SAFE YIELD: A possible consequence when the “safe yield” of a well is exceeded and water continues to be pumped from a well, is land subsidence around the well will occur. Safe yield refers to a long-term balance between the water that is naturally and artificially recharged to an aquifer and the groundwater that is pumped out. When more water is removed than is recharged, the aquifer is described as being out of safe yield. When the water level in the aquifer then drops, we are said to be mining groundwater.

SALTS ARE ABSENT: Is a strange characteristic that is unique to water vapor in the atmosphere.

SAMPLE: The water that is analyzed for the presence of EPA-regulated drinking water contaminants. Depending on the regulation, EPA requires water systems and states to take samples from source water, from water leaving the treatment facility, or from the taps of selected consumers.

SAMPLING LOCATION: A location where soil or cuttings samples may be readily and accurately collected.

SAND, ANTHRACITE AND GARNET: Mixed media filters are composed of these three materials.

SANITARY SURVEY: Persons trained in public health engineering and the epidemiology of waterborne diseases should conduct the sanitary survey. The importance of a detailed sanitary survey of a new water source cannot be overemphasized. An on-site review of the water sources, facilities, equipment, operation, and maintenance of a public water systems for the purpose of evaluating the adequacy of the facilities for producing and distributing safe drinking water. The purpose of a non-regulatory sanitary survey is to identify possible biological and chemical pollutants which might affect a water supply.

SANITIZER: A disinfectant or chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

SATURATION INDEX: See Langelier's Index.

SATURATOR: A device which produces a fluoride solution for the fluoride process. Crystal-grade types of sodium fluoride should be fed with a saturator. Overfeeding must be prevented to protect public health when using a fluoridation system.

SATURATED ZONE: Where an unconfined aquifer becomes saturated beneath the capillary fringe.

SCADA: A remote method of monitoring pumps and equipment. 130 degrees F is the maximum temperature that transmitting equipment is able to with stand. If the level controller may be set with too close a tolerance 45 could be the cause of a control system that is frequently turning a pump on and off.

SCALE: Crust of calcium carbonate, the result of unbalanced water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. The regular use of stain prevention chemicals can prevent scale.

SCHMUTZDECKE: German, "grime or filth cover", sometimes spelt schmutzedecke) is a complex biological layer formed on the surface of a slow sand filter. The schmutzdecke is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. The composition of any particular schmutzdecke varies, but will typically consist of a gelatinous biofilm matrix of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. As a schmutzdecke ages, more algae tend to develop, and larger aquatic organisms may be present including some bryozoa, snails and annelid worms.

SCROLL AND BASKET: The two basic types of centrifuges used in water treatment.

SEAL: For wells: to abandon a well by filling up the well with approved seal material including cementing with grout from a required depth to the land surface.

SECONDARY DRINKING WATER STANDARDS: Non-enforceable federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water.

SECTIONAL MAP: The name of a map that provides detailed drawings of the distribution system's zones. Sometimes we call these quarter-sections.

SEDIMENTATION BASIN: Where the thickest and greatest concentration of sludge will be found. Twice a year sedimentation tanks should be drained and cleaned if the sludge buildup interferes with the treatment process.

SEDIMENTATION: The process of suspended solid particles settling out (going to the bottom of the vessel) in water.

SEDIMENT: Grains of soil, sand, gravel, or rock deposited by and generated by water movement.

SENSOR: A float and cable system are commonly found instruments that may be used as a sensor to control the level of liquid in a tank or basin.

SESSILE: *Botany*. attached by the base, or without any distinct projecting support, as a leaf issuing directly from the stem. *Zoology*. permanently attached; not freely moving.

SETTLED SOLIDS: Solids that have been removed from the raw water by the coagulation and settling processes.

SHAKER: A device used in mud containment systems that vibrates various sized screens as drilling fluid passes through it, thereby separating cuttings from drilling fluid and providing a good sampling location.

SHOCK: Also known as superchlorination or break point chlorination. Ridding a water of organic waste through oxidization by the addition of significant quantities of a halogen.

SHORT-CIRCUITING: Short Circuiting is a condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction or settling times in comparison with the presumed detention times.

SHROUD: A baffle or piece of pipe installed over a pump to force water to pass the pumps motor.

SIEVE ANALYSIS: The process of sifting soil or formation samples through a series of screens to determine percentages of particle sizes.

SINGLE PHASE POWER: The type of power used for lighting systems, small motors, appliances, portable power tools and in homes.

SINUSOID: A curve described by the equation y = a sin x, the ordinate being proportional to the sine of the abscissa.

SINUSOIDAL: Mathematics. Of or pertaining to a sinusoid. Having a magnitude that varies as the sine of an independent variable: a sinusoidal current.

SLUDGE BASINS: After cleaning sludge basins and before returning the tanks into service the tanks should be inspected, repaired if necessary, and disinfected.

SLUDGE REDUCTION: Organic polymers are used to reduce the quantity of sludge. If a plant produces a large volume of sludge, the sludge could be dewatered, thickened, or conditioned to decrease the volume of sludge. Turbidity of source water, dosage, and type of coagulant used are the most important factors which determine the amount of sludge produced in a treatment of water.

SLURRY: A mixture of crushed rock and water.

SMALL WATER SYSTEM: 3,300 or fewer persons.

SOC: Synthetic organic chemical. A common way for a synthetic organic chemical such as dioxin to be introduced to a surface water supply is from an industrial discharge, agricultural drainage, or a spill.

SODA ASH: Chemical used to raise pH and total alkalinity (sodium carbonate)

SODIUM BICARBONATE: Commonly used to increase alkalinity of water and stabilize pH.

SODIUM BISULFATE: Chemical used to lower pH and total alkalinity (dry acid).

SODIUM HYDROXIDE: Also known as caustic soda, a by-product chlorine generation and often used to raise pH.

SOIL MOISTURE: A relative consideration of the degree to which a soil is saturated.

SOFTENING WATER: When the water has a low alkalinity it is advantageous to use soda ash instead of caustic soda for softening water.

SOFTENING: The process that removes the ions which cause hardness in water.

SOLAR DRYING BEDS OR LAGOONS: Are shallow, small-volume storage pond where sludge is concentrated and stored for an extended periods.

SOLAR DRYING BEDS, CENTRIFUGES AND FILTER PRESSES: Are procedures used in the dewatering of sludge.

SOLID, LIQUID AND VAPOR: 3 forms of matter.

SOLDER: A fusible alloy used to join metallic parts.

SOLID STEM (AUGER): An auger that is constructed of solid stem drill flights.

SPADNS: The lab reagent called SPADNS solution is used in performing the Fluoride test.

SPECIFIC CAPACITY (Sc): A measure of a well's pumping performance in gallons per minute per foot of drawdown.

SPIDER: A bearing or flange used in vertical turbine pumps to stabilize the drive shaft or shaft tube and seal column joints.

SPIRAL FLANGE: A continuous blade that wraps spirally around auger flighting.

SPIRIT OF HARTSHORN: A colorless, pungent, suffocating, aqueous solution of about 28.5 percent ammonia gas: used chiefly as a detergent, for removing stains and extracting certain vegetable coloring agents, and in the manufacture of ammonium salts.

SPLIT SPOON: A sampling device that is driven into the earth and operated by a wire line for the retrieval of soil or formation samples.

SPLIT FLOW CONTROL SYSTEM: This type of control system is to control the flow to each filter influent which is divided by a weir.

SPRAY BOTTLE OF AMMONIA: An operator should use ammonia to test for a chlorine leak around a valve or pipe. You will see white smoke if there is a leak.

SPRING PRESSURE: Is what maintains contact between the two surfaces of a mechanical seal.

STABILE: Reference to formation, soil, or sediments of sufficient strength to remain in place under its own weight and existing pressures.

STABILIZE: Actions taken to enhance borehole stability or vertical rotational when drilling.

STABILIZER: The portion of a drill string used to stabilize rotation.

STANDPIPE: A water tank that is taller than it is wide. Should not be found in low point.

STERILIZED GLASSWARE: The only type of glassware that should be used in testing for coliform bacteria.

STORAGE TANKS: Three types of water usage that determine the volume of a storage tank are fire suppression storage, equalization storage, and emergency storage. Equalization storage is the volume of water needed to supply the system for periods when demand exceeds supply. Generally, a water storage tank's interior coating (paint) protects the interior about 3-5 years.

S.T.P.: Standard temperature and pressure standard temperature and pressure the temperature of 0°C and pressure of 1 atmosphere, usually taken as the conditions when stating properties of gases.

STRATIFIED: Layered.

STUFFING BOX: That portion of the pump that houses the packing or mechanical seal.

SUB: A small section of drill pipe used to connect larger sections.

SUBMERSIBLE PUMP: A turbine pump that has the motor attached directly to it and therefore is operated while submerged.

SULFATE: Will readily dissolve in water to form an anion. Sulfate is a substance that occurs naturally in drinking water. Health concerns regarding sulfate in drinking water have been raised because of reports that diarrhea may be associated with the ingestion of water containing high levels of sulfate. Of particular concern are groups within the general population that may be at greater risk from the laxative effects of sulfate when they experience an abrupt change from drinking water with low sulfate concentrations to drinking water with high sulfate concentrations.

Sulfate in drinking water currently has a secondary maximum contaminant level (SMCL) of 250 milligrams per liter (mg/L), based on aesthetic effects (i.e., taste and odor). This regulation is not a federally enforceable standard, but is provided as a guideline for States and public water systems. EPA estimates that about 3% of the public drinking water systems in the country may have sulfate levels of 250 mg/L or greater. The Safe Drinking Water Act (SDWA), as amended in 1996, directs the U.S. Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) to jointly conduct a study to establish a reliable dose-response relationship for the adverse human health effects from exposure to sulfate in drinking water, including the health effects that may be experienced by sensitive subpopulations (infants and travelers). SDWA specifies that the study be based on the best available peer-reviewed science and supporting studies, conducted in consultation with interested States, and completed in February 1999.

SULFIDE: The term sulfide refers to several types of chemical compounds containing sulfur in its lowest oxidation number of -2. Formally, "sulfide" is the dianion, S_2^-, which exists in strongly alkaline aqueous solutions formed from H_2S or alkali metal salts such as Li_2S, Na_2S, and K_2S. Sulfide is exceptionally basic and, with a pKa > 14, it does not exist in appreciable concentrations even in highly alkaline water, being undetectable at pH < ~15 (8 M NaOH). Instead, sulfide combines with electrons in hydrogen to form HS, which is variously called hydrogen sulfide ion, hydrosulfide ion, sulfhydryl ion, or bisulfide ion. At still lower pH's (<7), HS- converts to H_2S, hydrogen sulfide. Thus, the exact sulfur species obtained upon dissolving sulfide salts depends on the pH of the final solution. Aqueous solutions of transition metals cations react with sulfide sources (H_2S, NaSH, Na_2S) to precipitate solid sulfides. Such inorganic sulfides typically have very low solubility in water and many are related to minerals. One famous example is the bright yellow species CdS or "cadmium yellow". The black tarnish formed on sterling silver is Ag_2S. Such species are sometimes referred to as salts. In fact, the bonding in transition metal sulfides is highly covalent, which gives rise to their semiconductor properties, which in turn is related to the practical applications of many sulfide materials.

SUPERNATANT: The liquid layer which forms above the sludge in a settling basin.

SURFACE SEAL: The upper portion of a wells construction where surface contaminants are adequately prevented from entering the well, normally consisting of surface casing and neat cement grout.

SURFACE WATER SOURCES: Surface water sources such as a river or lake are primarily the result of Runoff.

SURFACE WATER: Water that is open to the atmosphere and subject to surface runoff; generally, lakes, streams, rivers.

SURFACTANT: Surfactants reduce the surface tension of water by adsorbing at the liquid-gas interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. Many surfactants can also assemble in the bulk solution into aggregates. Examples of such aggregates are vesicles and micelles. The concentration at which surfactants begin to form micelles is known as the critical micelle concentration or CMC. When micelles form in water, their tails form a core that can encapsulate an oil droplet, and their (ionic/polar) heads form an outer shell that maintains favorable contact with water. When surfactants assemble in oil, the aggregate is referred to as a reverse micelle. In a reverse micelle, the heads are in the core and the tails maintain favorable contact with oil. Surfactants are also often classified into four primary groups; anionic, cationic, non-ionic, and zwitterionic (dual charge).

SUSCEPTIBILITY WAIVER: A waiver that is granted based upon the results of a vulnerability assessment.

SURGE-BLOCK: A disc shaped device that fits tightly into a well and is moved up and down to agitate the water column in order to develop a well.

SURGING: The process of purging a well rapidly for well development.

SWAB: See Surge-block.

SWING ARM: A large moveable arm on a bucket auger rig that pulls the bucket auger out away from the drilling rig for dumping.

SYNCHRONY: Simultaneous occurrence; synchronism.

TABLE DRIVE: A drilling rig that uses a rotating table within the platform to turn a kelly driven drill string.

TABLE: The back portion of a drill rig where the drill pipe is inserted (or driven if a table drive), adjacent to or within the driller's platform.

TAPPING VALVE: The name of the valve that is specifically designed for connecting a new water main to an existing main that is under pressure.

TARGET DEPTH: The proposed construction depth of a well prior to drilling.

TASTE AND ODORS: The primary purpose to use potassium permanganate in water treatment is to control taste and odors. Anaerobic water undesirable for drinking water purposes because of color and odor problems are more likely to occur under these conditions. Taste and odor problems in the water may happen if sludge and other debris are allowed to accumulate in a water treatment plant.

TCE, *trichloroethylene*: A solvent and degreaser used for many purposes; for example dry cleaning, it is a common groundwater contaminant. Trichloroethylene is a colorless liquid which is used as a solvent for cleaning metal parts. Drinking or breathing high levels of trichloroethylene may cause nervous system effects, liver and lung damage, abnormal heartbeat, coma, and possibly death. Trichloroethylene has been found in at least 852 of the 1,430 National Priorities List sites identified by the Environmental Protection Agency (EPA).

TDS-TOTAL DISSOLVED SOLIDS: An expression for the combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that the solids (often abbreviated TDS) must be small enough to survive filtration through a sieve size of two micrometers. Total dissolved solids are normally only discussed for freshwater systems, since salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is generally considered not as a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of presence of a broad array of chemical contaminants. Ion exchange is an effective treatment process used to remove iron and manganese in a water supply. This process is ideal as long as the water does not contain a large amount of TDS. When determining the total dissolved solids, a sample should be filtered before being poured into an

evaporating dish and dried. Demineralization may be necessary in a treatment process if the water has a very high value Total Dissolved Solids.

TELEMETERING: The use of a transmission line with remote signaling to monitor a pumping station or motors. Can be used to accomplish accurate and reliable remote monitoring and control over a long distribution system.

TEMPERATURE SAMPLE: This test should be performed immediately in the field, this is a grab sample.

TELESCOPING KELLY: A kelly with successively smaller sized pipe within itself that drops out as a borehole is drilled. This permits that drilling may proceed without adding drill pipe. Normally found on bucket auger rigs.

TELESCOPING: The successive decrease in borehole size with depth.

THE RATE DECREASES: In general, when the temperature decreases, the chemical reaction rate decreases also.

THICKENING, CONDITIONING AND DEWATERING: Common processes that are utilized to reduce the volume of sludge.

TIME FOR TURBIDITY BREAKTHROUGH AND MAXIMUM HEADLOSS: Are the two factors which determine whether or not a change in filter media size should be made.

TITRATION: A method of testing by adding a reagent of known strength to a water sample until a specific color change indicates the completion of the reaction.

TITRIMETRIC: Chemistry. Using or obtained by titration. Titrimetrically, adverb.

TOP DRIVE: A rotary type drill head that moves freely up and down the rigs mast while driving the drill string.

TOROID: A surface generated by the revolution of any closed plane curve or contour about an axis lying in its plane. The solid enclosed by such a surface.

TOTAL ALKALINITY: A measure of the acid-neutralizing capacity of water which indicates its buffering ability, i.e. measure of its resistance to a change in pH. Generally, the higher the total alkalinity, the greater the resistance to pH change.

TOTAL COLIFORM: Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.

TOTAL DISSOLVED SOLIDS (TDS): The accumulated total of all solids that might be dissolved in water.

TOTAL DYNAMIC HEAD: The pressure (psi) or equivalent feet of water, required for a pump to lift water to its point of storage overcoming elevation head, friction loss, line pressure, drawdown and pumping lift.

TRANSIENT, NON-COMMUNITY WATER SYSTEM: TNCWS A water system which provides water in a place such as a gas station or campground where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants which pose long-term health risks because fewer than 25 people drink the water over a long period. They still must test their water for microbes and several chemicals. A Transient Non-community Water System: Is not required to sample for VOC's.

TREATED WATER: Disinfected and/or filtered water served to water system customers. It must meet or surpass all drinking water standards to be considered safe to drink.

TRIHALOMETHANES (THM): Four separate compounds including chloroform, dichlorobromomethane, dibromochloromethane, and bromoform. The most common class of disinfection by-products created when chemical disinfectants react with organic matter in water during the disinfection process. See Disinfectant Byproducts.

TRICONE BIT: A roller bit with three independent rolling bits with teeth or buttons that intermesh for efficient rock crushing and cutting.

TUBE SETTLERS: This modification of the conventional process contains many metal tubes that are placed in the sedimentation basin, or clarifier. These tubes are approximately 1 inch deep and 36 inches long, split-hexagonal shape and installed at an angle of 60 degrees or less. These tubes provide for a very large surface area upon which particles may settle as the water flows upward. The slope of the tubes facilitates gravity settling of the solids to the bottom of the basin, where they can be collected and removed. The large surface settling area also means that adequate clarification can be obtained with detention times of 15 minutes or less. As with conventional treatment, this sedimentation step is followed by filtration through mixed media.

TUBERCLES: The creation of this condition is of the most concern regarding corrosive water effects on a water system. Tubercles are formed due to joining dissimilar metals, causing electro-chemical reactions. Like iron to copper pipe. We have all seen these little rust mounds inside cast iron pipe.

TURBIDIMETER: Monitoring the filter effluent turbidity on a continuous basis with an in-line instrument is a recommended practice. Turbidimeter is best suited to perform this measurement.

TURBIDITY: A measure of the cloudiness of water caused by suspended particles.

TURBINE PUMP: A pump that utilizes rotating impellers on a shaft that generate centrifugal force for pumping water.

UNCONFINED AQUIFER: An aquifer that exists under atmospheric pressure and is not confined.

UNCONSOLIDATED: Sediment that is not cemented or is loosely arranged.

UNDER-REAM: The process of reaming, from within the borehole, a section of an existing smaller borehole area.

UNSATURATED ZONE: That portion of the subsurface, including the capillary fringe that is not saturated but may contain water in both vapor and liquid form. See also Vadose Zone.

UNSTABLE: Sediment or other material that cannot exit without rapidly decomposing or collapsing in on itself. (ex. unconsolidated sediment)

U.S. ENVIRONMENTAL PROTECTION AGENCY: In the United States, this agency responsible for setting drinking water standards and for ensuring their enforcement. This agency sets federal regulations which all state and local agencies must enforce.

UNDER PRESSURE IN STEEL CONTAINERS: After chlorine gas is manufactured, it is primarily transported in steel containers.

UNIT FILTER RUN VOLUME (UFRV): One of the most popular ways to compare filter runs. This technique is the best way to compare water treatment filter runs.

VADOSE ZONE: A portion of the subsurface above the water table that is not saturated but contains water in both vapor and liquid form. The portion of the subsurface where water percolates through to the saturated zone. See also Unsaturated Zone.

VANE: That portion of an impeller that throws the water toward the volute.

VARIABLE DISPLACEMENT PUMP: A pump that will produce different volumes of water dependent on the pressure head against it.

VELOCITY HEAD: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.

VENTURI: If water flows through a pipeline at a high velocity, the pressure in the pipeline is reduced. Velocities can be increased to a point that a partial vacuum is created.

VERTICAL TURBINE: A type of variable displacement pump in which the motor or drive head is mounted on the wellhead and rotates a drive shaft connected to the pump impellers.

VIRION: A complete viral particle, consisting of RNA or DNA surrounded by a protein shell and constituting the infective form of a virus.

VIRUSES: Very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.

VITRIFICATION: Vitrification is a process of converting a material into a glass-like amorphous solid that is free from any crystalline structure, either by the quick removal or addition of heat, or by mixing with an additive. Solidification of a vitreous solid occurs at the glass transition temperature (which is lower than melting temperature, Tm, due to supercooling). When the starting material is solid, vitrification usually involves heating the substances to very high temperatures. Many ceramics are produced in such a manner. Vitrification may also occur naturally when lightning strikes sand, where the extreme and immediate heat can create hollow, branching rootlike structures of glass, called fulgurite. When applied to whiteware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime. The microstructure of whiteware ceramics frequently contain both amorphous and crystalline phases.

VOC WAIVER: The longest term VOC waiver that a public water system using groundwater could receive is 9 years.

VOLATILE ORGANIC COMPOUNDS: (**VOCs**) Solvents used as degreasers or cleaning agents. Improper disposal of VOCs can lead to contamination of natural waters. VOCs tend to evaporate very easily. This characteristic gives VOCs very distinct chemical odors like gasoline, kerosene, lighter fluid, or dry cleaning fluid. Some VOCs are suspected cancer-causing agents. Volatile organic compounds (VOCs) are organic chemical compounds that have high enough vapor pressures under normal conditions to significantly vaporize and enter the atmosphere. A wide range of carbon-based molecules, such as aldehydes, ketones, and other light hydrocarbons are VOCs. The term often is used in a legal or regulatory context and in such cases the precise definition is a matter of law. These definitions can be contradictory and may contain "loopholes"; e.g. exceptions, exemptions, and exclusions. The United States Environmental Protection Agency defines a VOC as any organic compound that participates in a photoreaction; others believe this definition is very broad and vague as organics that are not volatile in the sense that they vaporize under normal conditions can be considered volatile by this EPA definition. The term may refer both to well characterized organic compounds and to mixtures of variable composition.

VOID: An opening, gap, or space within rock or sedimentary formations formed at the time of origin or deposition.

VOLTAGE: Voltage (sometimes also called electric or electrical tension) is the difference of electrical potential between two points of an electrical or electronic circuit, expressed in volts. It measures the potential energy of an electric field to cause an electric current in an electrical conductor. Depending on the difference of electrical potential it is called extra low voltage, low voltage, high voltage or extra high voltage. Specifically Voltage is equal to energy per unit charge.

VOLUTE: The spiral-shaped casing surrounding a pump impeller that collects the liquid discharge by the impeller.

VORTEX: The helical swirling of water moving towards a pump.

VIRUSES: Are very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.

VOLATILE ORGANIC COMPOUNDS: (**VOCs**) Solvents used as degreasers or cleaning agents. Improper disposal of VOCs can lead to contamination of natural waters. VOCs tend to evaporate very easily. This characteristic gives VOCs very distinct chemical odors like gasoline, kerosene, lighter fluid, or dry cleaning fluid. Some VOCs are suspected cancer-causing agents.

VULNERABILITY ASSESSMENT: An evaluation of drinking water source quality and its vulnerability to contamination by pathogens and toxic chemicals.

WAIVERS: Monitoring waivers for nitrate and nitrite are prohibited.

WASHOUT: The rapid erosion of aquifer material from the borehole walls while a well is being drilled, which often results in a loss of circulation.

WATER COURSE: An opening within a cable tool drill string that allows fluid to flow in and out of the drill string thereby minimizing friction loss to the slurry.

WATER HAMMER: A surge in a pipeline resulting from the rapid increase or decrease in water flow. Water hammer exerts tremendous force on a system and can be highly destructive.

WATER PURVEYOR: The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

WATER QUALITY: The 4 broad categories of water quality are: Physical, chemical, biological, radiological. Pathogens are disease causing organisms such as bacteria and viruses. A positive bacteriological sample indicates the presence of bacteriological contamination. Source water monitoring for lead and copper be performed when a public water system exceeds an action level for lead of copper.

WATER QUALITY CRITERIA: Comprised of both numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or States for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal.

WATER QUALITY STANDARD: A statute or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

WATER TABLE: The measured water level surface of an unconfined aquifer.

WATER VAPOR: A characteristic that is unique to water vapor in the atmosphere is that water does not contain any salts.

WATERBORNE DISEASE: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

WATERSHED: An area that drains all of its water to a particular water course or body of water. The land area from which water drains into a stream, river, or reservoir.

WEATHERED: The existence of rock or formation in a chemically or physically broken down or decomposed state. Weathered material is in an unstable state.

WELL ABANDONMENT: The process of sealing a well by approved means. The filling of a well to the surface with cement grout.

WELL HEAD: The upper portion of the well that is constructed on the land surface, including the well manifold. Also a term used to refer to the area near the well that is subject to wellhead protection.

WELL HEAD PROTECTION: Programs designed to maintain the quality of groundwater used as public drinking water sources, by managing the land uses around the well field. A government program that encourages the limitation and elimination of activities, near and within a wells recharge area, which present a potential risk to the wells water supply.

WELL MANIFOLD: The piping, valves, and metering equipment used to connect the well to the distribution system, installed on the wellhead.

WELL SCREEN: A section of well casing that contains openings which permit water to enter the well but limit or prevent sediment from entering the well while pumping.

WELL SEAL: The watertight cap or seal installed within and between the well casing and pumping equipment. The metal or plastic plug or seal, which the pumping column rests on the top of casing.

WHOLE EFFLUENT TOXICITY: The total toxic effect of an effluent measured directly with a toxicity test.

YIELD: The volume of water measured in flow rates that are produced from the well.

ZONE OF AERATION: See Saturated Zone or Vadose Zone.

ZONE OF SATURATION: See Saturated Zone.



Top- Pre-sedimentation basin

Common Water Treatment and Distribution Chemicals

Chemical Name	Common Name	Chemical Formula
Aluminum hydroxide		$Al(OH)_3$
Aluminum sulfate	Alum, liquid	$AL_2(SO_4)3 . 14(H_2O)$
Ammonia		NH_3
Ammonium		NH_4
Bentonitic clay	Bentonite	
Calcium bicarbonate		$Ca(HCO_3)2$
Calcium carbonate	Limestone	$CaCO_3$
Calcium chloride		$CaCl_2$
Calcium Hypochlorite	HTH	$Ca(OCl)_2 . 4H_2O$
Calcium hydroxide	Slaked Lime	$Ca(OH)_2$
Calcium oxide	Unslaked (Quicklime)	CaO
Calcium sulfate	Gypsum	$CaSO_4$
Carbon	Activated Carbon	C
Carbon dioxide		CO_2
Carbonic acid		$H2CO_3$
Chlorine gas		Cl_2
Chlorine Dioxide		ClO_2
Copper sulfate	Blue vitriol	$CuSO_4 . 5H_2O$
Dichloramine		$NHCl_2$
Ferric chloride	Iron chloride	$FeCl_3$
Ferric hydroxide		$Fe(OH)_3$
Ferric sulfate	Iron sulfate	$Fe_2(SO_4)_3$
Ferrous bicarbonate		$Fe(HCO_3)_2$
Ferrous hydroxide		$Fe(OH)_3$
Ferrous sulfate	Copperas	$FeSO_4.7H_20$
Hydrofluorsilicic acid		H_2SiF_6
Hydrochloric acid	Muriatic acid	HCl
Hydrogen sulfide		H_2S
Hypochlorus acid		HOCL
Magnesium bicarbonate		$Mg(HCO_3)2$
Magnesium carbonate		$MgCO_3$
Magnesium chloride		$MgCl_2$
Magnesium hydroxide		$Mg(OH)_2$
Magnesium dioxide		MgO_2
Manganous bicarbonate		$Mn(HCO_3)2$
Manganous sulfate		$MnSO_4$
Monochloramine		NH_2Cl
Potassium bicarbonate		$KHCO_3$
Potassium permanganate		$KMnO_4$

Chemical Name	Common Name	Chemical Formula
Sodium carbonate	Soda ash	Na_2CO_3
Sodium chloride	Salt	NaCl
Sodium chlorite		$NaClO_2$
Sodium fluoride		NaF
Sodium fluorsilicate		Na_2SiF_6
Sodium hydroxide	Lye	NaOH
Sodium hypochlorite		NaOCl
Sodium Metaphosphate	Hexametaphosphate	$NaPO_3$
Sodium phosphate	Disodium phosphate	Na_3PO_4
Sodium sulfate		Na_2SO_4
Sulfuric acid		H_2SO_4



Fluoride. Many communities add fluoride to their drinking water to promote dental health. Each community makes its own decision about whether or not to add fluoride. The EPA has set an enforceable drinking water standard for fluoride of 4 mg/L (some people who drink water containing fluoride in excess of this level over many years could develop bone disease, including pain and tenderness of the bones). The EPA has also set a secondary fluoride standard of 2 mg/L to protect against dental fluorosis.

Microorganism Appendix



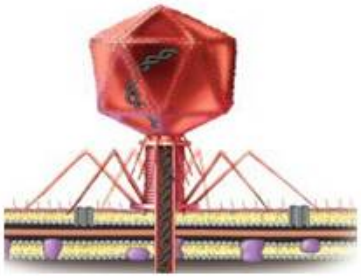
COCCI
(SPHERICAL)



SPIRILLI
(SPIRAL)

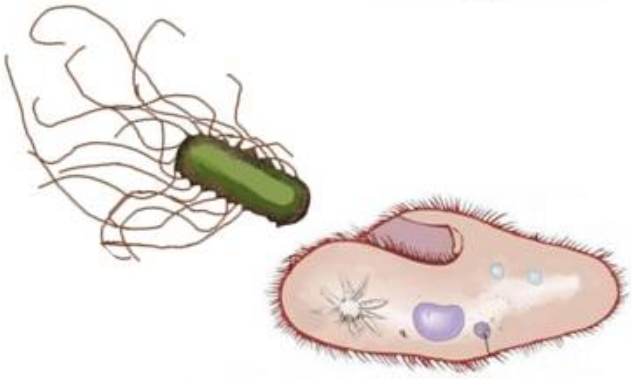


BACILLI
(ROD-SHAPED)

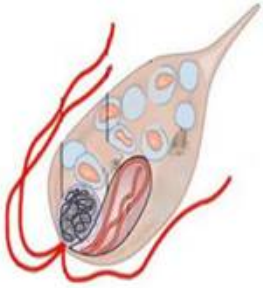




VIRUSES



BACTERIA

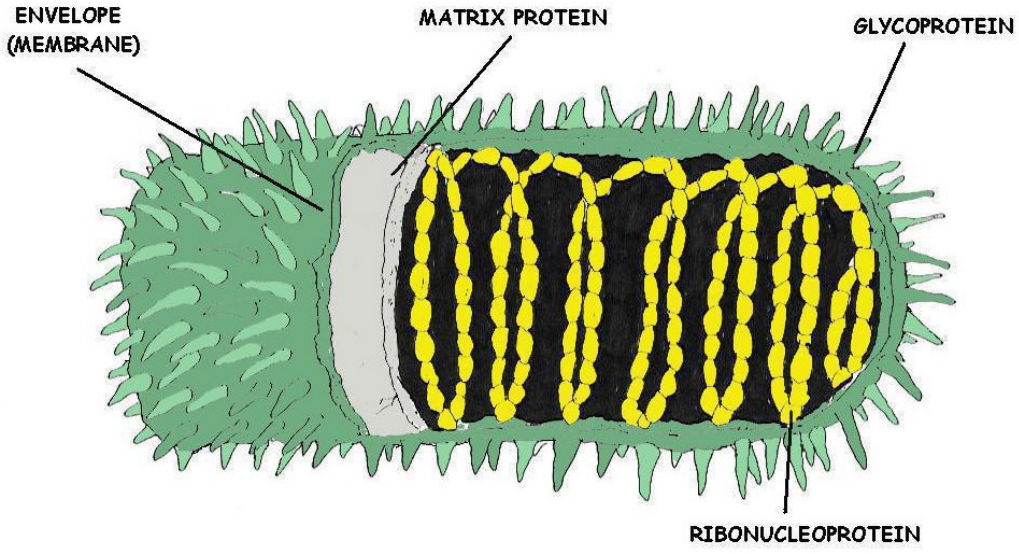


PROTOZOA

BACTERIA TYPES

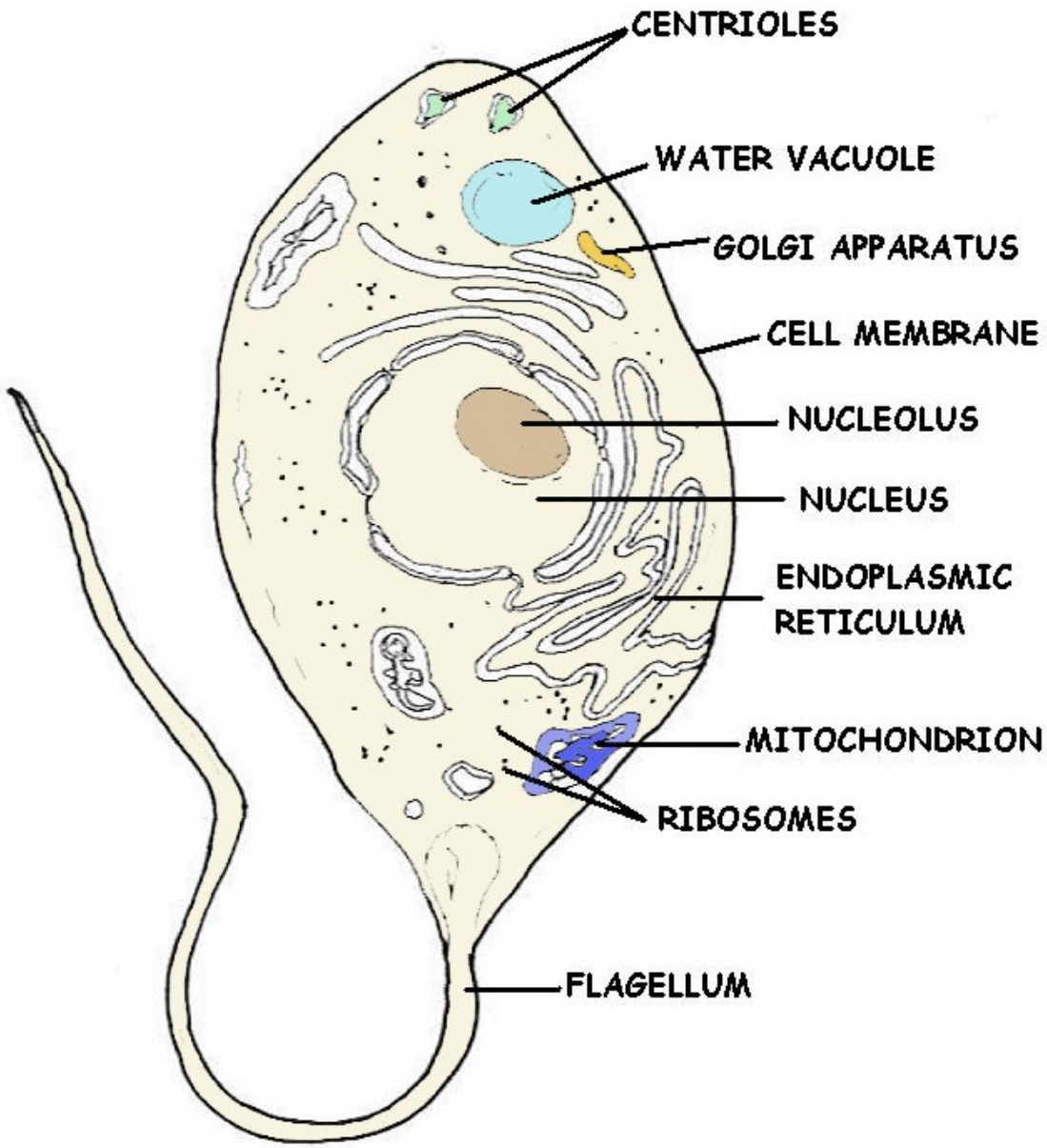


This section will give a close-up and short explanation of the major microorganisms found in water and in wastewater.



VIRUS

Protozoa



PROTOZOAN CELL

Protozoa are around 10–50 micrometer, but can grow up to 1 mm and can easily be seen under a microscope. Protozoa exist throughout aqueous environments and soil. Protozoa occupy a range of trophic levels. As predators, they prey upon unicellular or filamentous algae, bacteria, and microfungi.

Protozoa play a role both as herbivores and as consumers in the decomposer link of the food chain. Protozoa also play a vital role in controlling bacteria populations and biomass. As components of the micro- and meiofauna, protozoa are an important food source for microinvertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important. Protozoa such as the malaria parasites (Plasmodium spp.), trypanosomes and leishmania are also important as parasites and symbionts of multicellular animals.

Most protozoa exist in 5 stages of life which are in the form of trophozoites and cysts. As cysts, protozoa can survive harsh conditions, such as exposure to extreme temperatures and harmful chemicals, or long periods without access to nutrients, water, or oxygen for a period of time. Being a cyst enables parasitic species to survive outside of the host, and allows their transmission from one host to another. When protozoa are in the form of trophozoites (Greek, tropho=to nourish), they actively feed and grow. The process by which the protozoa takes its cyst form is called encystation, while the process of transforming back into trophozoite is called excystation.

Protozoa can reproduce by binary fission or multiple fission. Some protozoa reproduce sexually, some asexually, and some both (e.g. Coccidia). An individual protozoan is hermaphroditic.

Classification
Protozoa were commonly grouped in the kingdom of Protista together with the plant-like algae and fungus-like water molds and slime molds. In the 21st-century systematics, protozoans, along with ciliates, mastigophorans, and apicomplexans, are arranged as animal-like protists. However, protozoans are neither Animalia nor Metazoa (with the possible exception of the enigmatic, moldy Myxozoa).

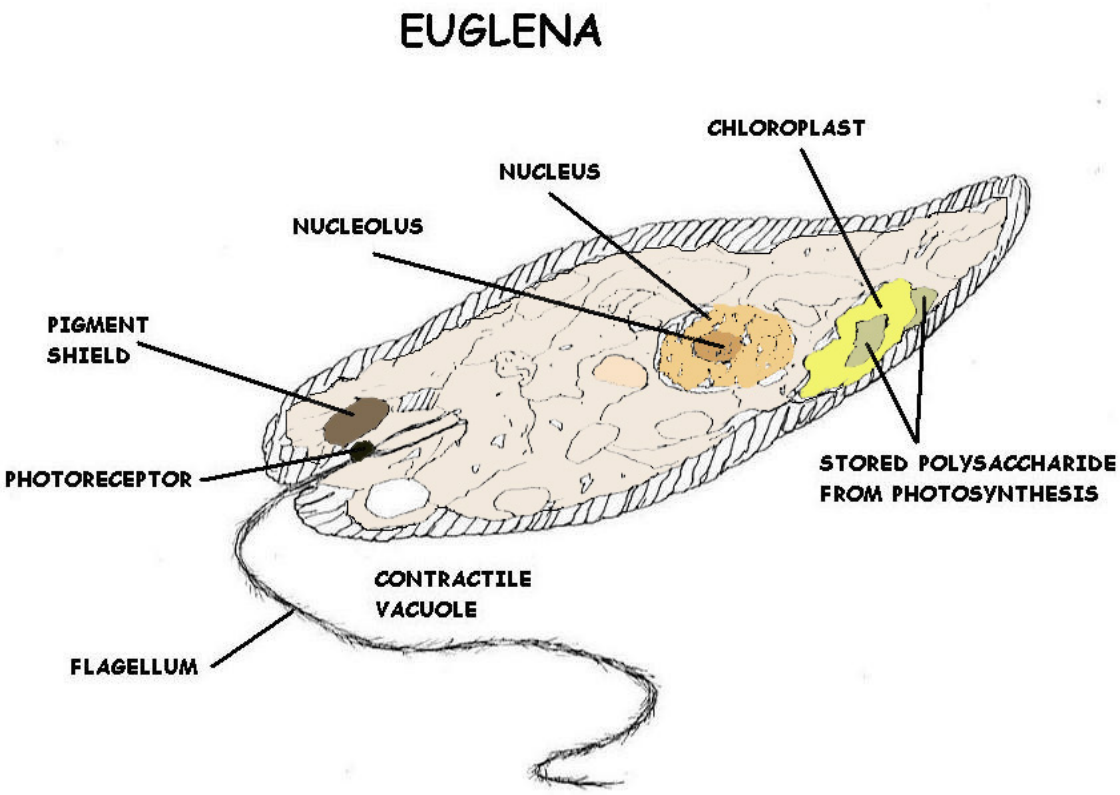
Sub-groups
Protozoa have traditionally been divided on the basis of their means of locomotion, although this is no longer believed to represent genuine relationships:
* Flagellates (e.g. Giardia lambia)
* Amoeboids (e.g. Entamoeba histolytica)
* Sporozoans (e.g. Plasmodium knowlesi)
* Apicomplexa
* Myxozoa
* Microsporidia
* Ciliates (e.g. Balantidium coli)

There are many ways that infectious diseases can spread. Pathogens usually have specific routes by which they are transmitted, and these routes may depend on the type of cells and tissue that a particular agent targets. For example, because cold viruses infect the respiratory tract, they are dispersed into the air via coughing and sneezing.

Once in the air, the viruses can infect another person who is unlucky enough to inhale air containing the virus particles.

Agents vary greatly in their stability in the environment. Some viruses may survive for only a few minutes outside of a host, while some spore-forming bacteria are extremely durable and may survive in a dormant state for a decade or more.

Protozoa Section



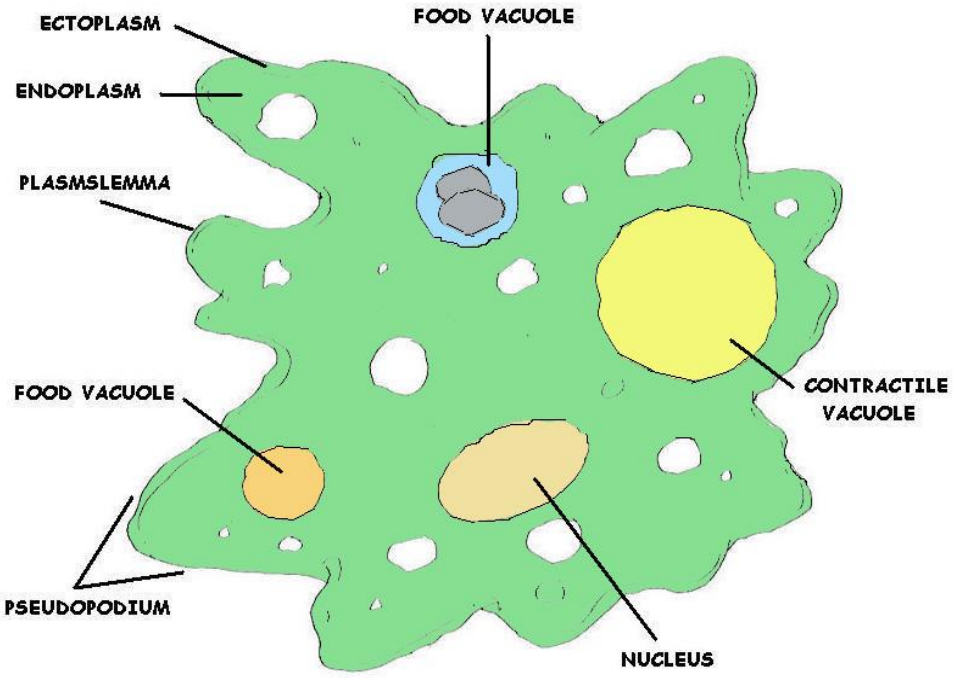
The diverse assemblage of organisms that carry out all of their life functions within the confines of a single, complex eukaryotic cell are called protozoa.

Paramecium, Euglena, and Amoeba are well-known examples of these major groups of organisms. Some protozoa are more closely related to animals, others to plants, and still others are relatively unique. Although it is not appropriate to group them together into a single taxonomic category, the research tools used to study any unicellular organism are usually the same, and the field of protozoology has been created to carry out this research. The unicellular photosynthetic protozoa are sometimes also called algae and are addressed elsewhere. This report considers the status of our knowledge of heterotrophic protozoa (protozoa that cannot produce their own food).

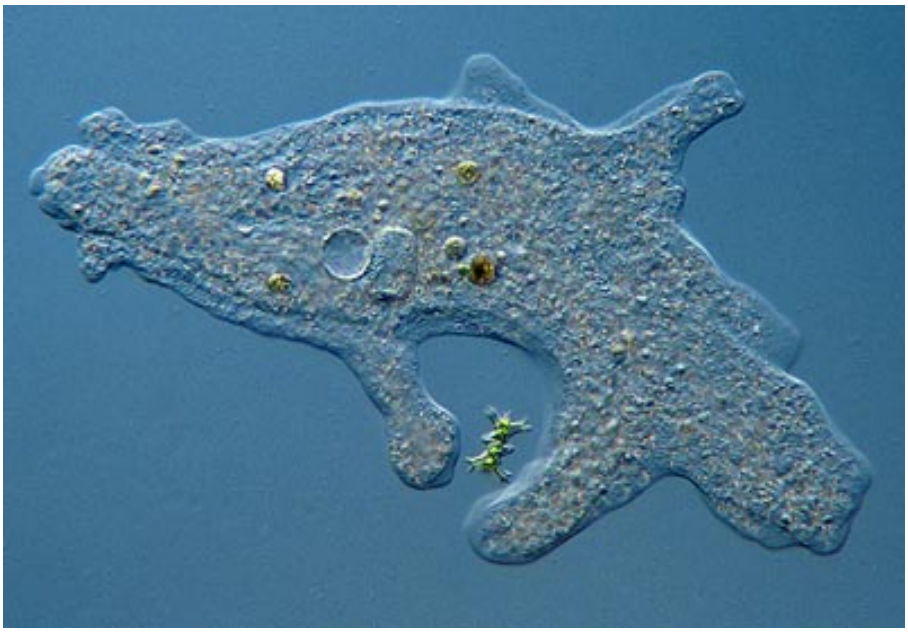
Free-living Protozoa

Protozoans are found in all moist habitats within the United States, but we know little about their specific geographic distribution. Because of their small size, production of resistant cysts, and ease of distribution from one place to another, many species appear to be cosmopolitan and may be collected in similar microhabitats worldwide (Cairns and Ruthven 1972). Other species may have relatively narrow limits to their distribution.

Marine ciliates inhabit interstices of sediment and beach sands, surfaces, deep sea and cold Antarctic environments, planktonic habitats, and the algal mats and detritus of estuaries and wetlands.



AMOEBA



Amoeba proteus*, pseudopods slowly engulf the small desmid *Staurastrum.

Amoebas

Amoebas (Phylum Rhizopoda) are unicellular protists that are able to change their shape constantly. Each species has its own distinct repertoire of shapes.

How does an amoeba locomote?
Amoebas locomote by way of cytoplasmic movement. (cytoplasm is the cell content around the nucleus of the cell) The amoeba forms pseudopods (false feet) with which they 'flow' over a surface. The cytoplasma not only flows, it also changes from a fluid into a solid state.

These pseudopods are also used to capture prey, they simply engulf the food. They can detect the kind of prey and use different 'engulfing tactics'.

The image from the last page shows several cell organelles. Left from the center we can see aspherical water expelling vesicle and just right of it, the single nucleus of this species can be seen. Other species may have many nuclei. The cell is full of brown food vacuoles and also contains small crystals.

Protozoa Information
Our actual knowledge of salinity, temperature, and oxygen requirements of marine protozoa is poor (although some groups, such as the foraminifera, are better studied than others), and even the broadest outlines of their biogeographic ranges are usually a mystery. In general, freshwater protozoan communities are similar to marine communities except the specialized interstitial fauna of the sand is largely missing. In freshwater habitats, the foraminifera and radiolaria common in marine environments are absent or low in numbers while testate amoebae exist in greater numbers. Relative abundance of species in the marine versus freshwater habitat is unknown.

Soil-dwelling protozoa have been documented from almost every type of soil and in every kind of environment, from the peat-rich soil of bogs to the dry sands of deserts. In general, protozoa are found in greatest abundance near the soil surface, especially in the upper 15 cm (6 in), but occasional isolates can be obtained at depths of a meter (yard) or more.

Protozoa do not constitute a major part of soil biomass, but in some highly productive regions such as forest litter, the protozoa are a significant food source for the microinvertebrates, with a biomass that may reach 20 g/m2 of soil surface area there.

Environmental Quality Indicators
Polluted waters often have a rich and characteristic protozoan fauna. The relative abundance and diversity of protozoa are used as indicators of organic and toxic pollution (Cairns et al. 1972; Foissner 1987; Niederlehner et al. 1990; Curds 1992). Bick (1972), for example, provided a guide to ciliates that are useful as indicators of environmental quality of European freshwater systems, along with their ecological distribution with respect to parameters such as amount of organic material and oxygen levels.

Foissner (1988) clarified the taxonomy of European ciliates as part of a system for classifying the state of aquatic habitats according to their faunas.

Symbiotic Protozoa

Parasites

Protozoa are infamous for their role in causing disease, and parasitic species are among the best-known protozoa. Nevertheless, our knowledge has large gaps, especially of normally free-living protozoa that may become pathogenic in immunocompromised individuals. For example, microsporidia comprise a unique group of obligate, intracellular parasitic protozoa. Microsporidia are amazingly diverse organisms with more than 700 species and 80 genera that are capable of infecting a variety of plant, animal, and even other protist hosts.

They are found worldwide and have the ability to thrive in many ecological conditions. Until the past few years, their ubiquity did not cause a threat to human health, and few systematists worked to describe and classify the species. Since 1985, however, physicians have documented an unusual rise in worldwide infections in AIDS patients caused by four different genera of microsporidia (Encephalitozoon, Nosema, Pleistophora, and Enterocytozoon). According to the Centers for Disease Control in the United States, difficulties in identifying microsporidian species are impeding diagnosis and effective treatment of AIDS patients.

Protozoan Reservoirs of Disease

The presence of bacteria in the cytoplasm of protozoa is well known, whereas that of viruses is less frequently reported. Most of these reports simply record the presence of bacteria or viruses and assume some sort of symbiotic relationship between them and the protozoa. Recently, however, certain human pathogens were shown to not only survive but also to multiply in the cytoplasm of free-living, nonpathogenic protozoa. Indeed, it is now believed that protozoa are the natural habitat for certain pathogenic bacteria. To date, the main focus of attention has been on the bacterium Legionella pneumophila, the causative organism of Legionnaires' disease; these bacteria live and reproduce in the cytoplasm of some free-living amoebae (Curds 1992). More on this subject in the following pages.

Symbionts

Some protozoa are harmless or even beneficial symbionts. A bewildering array of ciliates, for example, inhabit the rumen and reticulum of ruminates and the cecum and colon of equids. Little is known about the relationship of the ciliates to their host, but a few may aid the animal in digesting cellulose.

Data on Protozoa

While our knowledge of recent and fossil foraminifera in the U.S. coastal waterways is systematically growing, other free-living protozoa are poorly known. There are some regional guides and, while some are excellent, many are limited in scope, vague on specifics, or difficult to use. Largely because of these problems, most ecologists who include protozoa in their studies of aquatic habitats do not identify them, even if they do count and measure them for biomass estimates (Taylor and Sanders 1991).

Parasitic protozoa of humans, domestic animals, and wildlife are better known although no attempt has been made to compile this information into a single source. Large gaps in our knowledge exist, especially for haemogregarines, microsporidians, and myxosporidians (see Kreier and Baker 1987).

Museum Specimens
For many plant and animal taxa, museums represent a massive information resource. This is not true for protozoa. In the United States, only the National Natural History Museum (Smithsonian Institution) has a reference collection preserved on microscope slides, but it does not have a protozoologist curator and cannot provide species' identification or verification services. The American Type Culture Collection has some protozoa in culture, but its collection includes relatively few kinds of protozoa.

Ecological Role of Protozoa
Although protozoa are frequently overlooked, they play an important role in many communities where they occupy a range of trophic levels. As predators upon unicellular or filamentous algae, bacteria, and microfungi, protozoa play a role both as herbivores and as consumers in the decomposer link of the food chain. As components of the micro- and meiofauna, protozoa are an important food source for microinvertebrates. Thus, the ecological role of protozoa in the transfer of bacterial and algal production to successive trophic levels is important.

Factors Affecting Growth and Distribution
Most free-living protozoa reproduce by cell division (exchange of genetic material is a separate process and is not involved in reproduction in protozoa). The relative importance for population growth of biotic versus chemical-physical components of the environment is difficult to ascertain from the existing survey data. Protozoa are found living actively in nutrient-poor to organically rich waters and in fresh water varying between 0°C (32°F) and 50°C (122°F). Nonetheless, it appears that rates of population growth increase when food is not constrained and temperature is increased (Lee and Fenchel 1972; Fenchel 1974; Montagnes et al. 1988).

Comparisons of oxygen consumption in various taxonomic groups show wide variation (Laybourn and Finlay 1976), with some aerobic forms able to function at extremely low oxygen tensions and to thereby avoid competition and predation.

Many parasitic and a few free-living species are obligatory anaerobes (grow without atmospheric oxygen). Of the free-living forms, the best known are the plagiopylid ciliates that live in the anaerobic sulfide-rich sediments of marine wetlands (Fenchel et al. 1977). The importance of plagiopylids in recycling nutrients to aerobic zones of wetlands is potentially great.

Because of the small size of protozoa, their short generation time, and (for some species) ease of maintaining them in the laboratory, ecologists have used protozoan populations and communities to investigate competition and predation.

The result has been an extensive literature on a few species studied primarily under laboratory conditions. Few studies have been extended to natural habitats with the result that we know relatively little about most protozoa and their roles in natural communities. Intraspecific competition for common resources often results in cannibalism, sometimes with dramatic changes in morphology of the cannibals (Giese 1973). Field studies of interspecific competition are few and most evidence for such species interactions is indirect (Cairns and Yongue 1977).

Contractile Vacuoles

Many protozoa have contractile vacuoles, which collect and expel excess water, and extrusomes, which expel material used to deflect predators or capture prey. In multicellular organisms, hormones are often produced in vesicles. In higher plants, most of a cell's volume is taken up by a central vacuole or tonoplast, which maintains its osmotic pressure. Many eukaryotes have slender motile projections, usually called flagella when long and cilia when short. These are variously involved in movement, feeding, and sensation. These are entirely distinct from prokaryotic flagella. They are supported by a bundle of microtubules arising from a basal body, also called a kinetosome or centriole, characteristically arranged as nine doublets surrounding two singlets. Flagella also may have hairs or mastigonemes, scales, connecting membranes, and internal rods. Their interior is continuous with the cell's cytoplasm.

Centrioles

Centrioles are often present even in cells and groups that do not have flagella. They generally occur in groups of one or two, called kinetids that give rise to various microtubular roots. These form a primary component of the cytoskeletal structure, and are often assembled over the course of several cell divisions, with one flagellum retained from the parent and the other derived from it. Centrioles may also be associated in the formation of a spindle during nuclear division. Some protists have various other microtubule-supported organelles. These include the radiolaria and heliozoa, which produce axopodia used in flotation or to capture prey, and the haptophytes, which have a peculiar flagellum-like organelle called the haptonema.

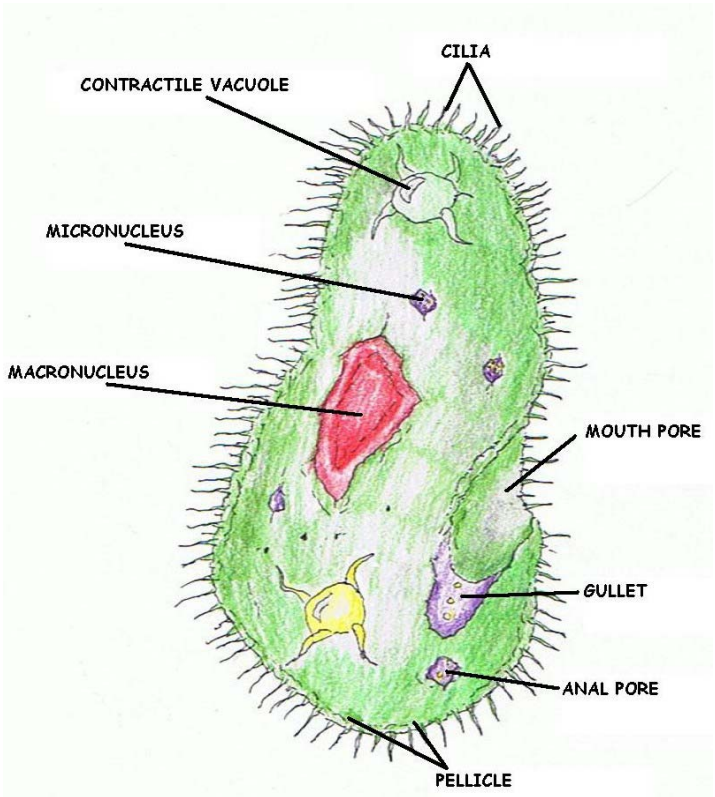
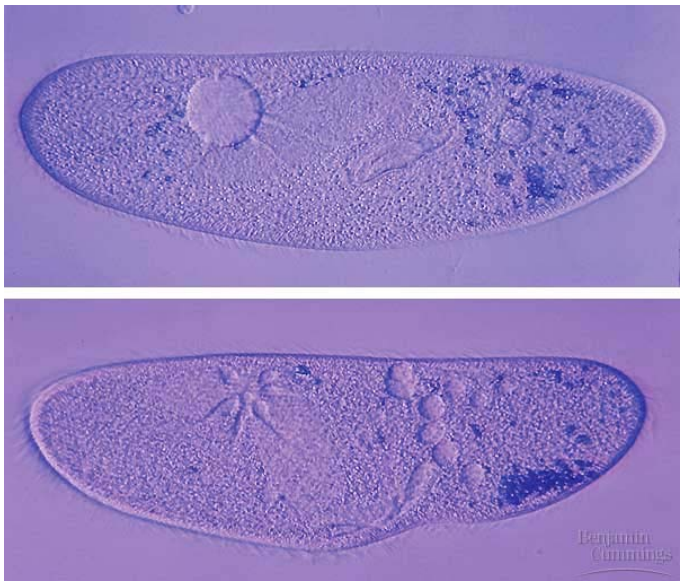


Figure 1. A diagram of *Paramecium* sp. with major organelles indicated.



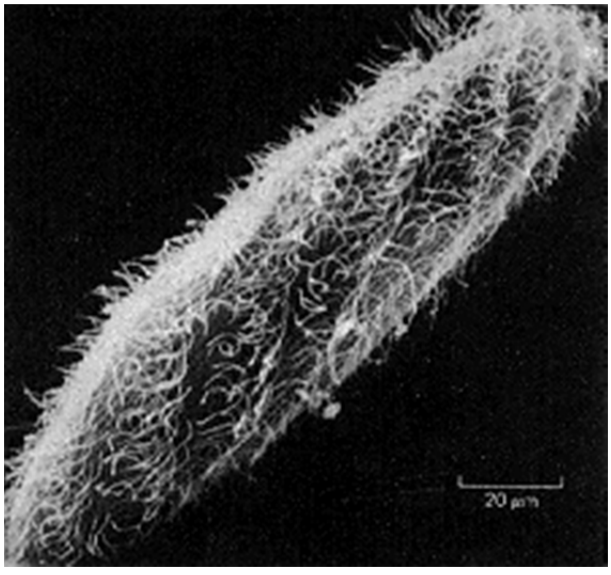
Contractile Vacuoles

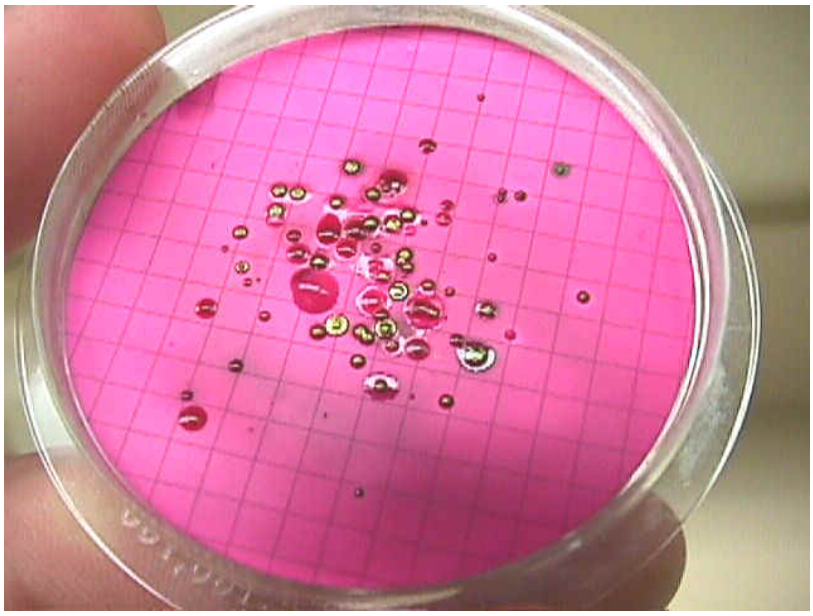
Figure 2. The contractile vacuole when full (top) and after contraction (bottom).

Paramecium

Members of the genus *Paramecium* are single-celled, freshwater organisms in the kingdom Protista. They exist in an environment in which the osmotic concentration in their external environment is much lower than that in their cytoplasm. More specifically, the habitat in which they live is **hypotonic** to their cytoplasm. As a result of this, *Paramecium* is subjected to a continuous influx of water, as water diffuses inward to a region of higher osmotic concentration.

If *Paramecium* is to maintain homeostasis, water must be continually pumped out of the cell (against the osmotic gradient) at the same rate at which it moves in. This process, known as **osmoregulation**, is carried out by two organelles in *Paramecium* known as **contractile vacuoles** (Figures 1 and 2).





Coliform Bacteria on a Petri Dish. Bottom photo, SimPlate for HPC counts. IDEXX's SimPlate for HPC method is used for the quantification of heterotrophic plate count (HPC) in water. It is based on the Multiple Enzyme Technology which detects viable bacteria in water by testing for the presence of key enzymes known to be present in these little organisms. This technique uses enzyme substrates that produce a blue fluorescence when metabolized by waterborne bacteria. The sample and media are added to a SimPlate Plate, incubated and then examined for fluorescing wells. The number of wells corresponds to a Most Probable Number (MPN) of total bacteria in the original sample. The MPN values generated by the SimPlate for HPC method correlate with the Pour Plate method using the Total Plate Count Agar incubated at 35^{o}C for 48 hours as described in *Standard Methods for the Examination of Water and Wastewater, 19th Edition.*



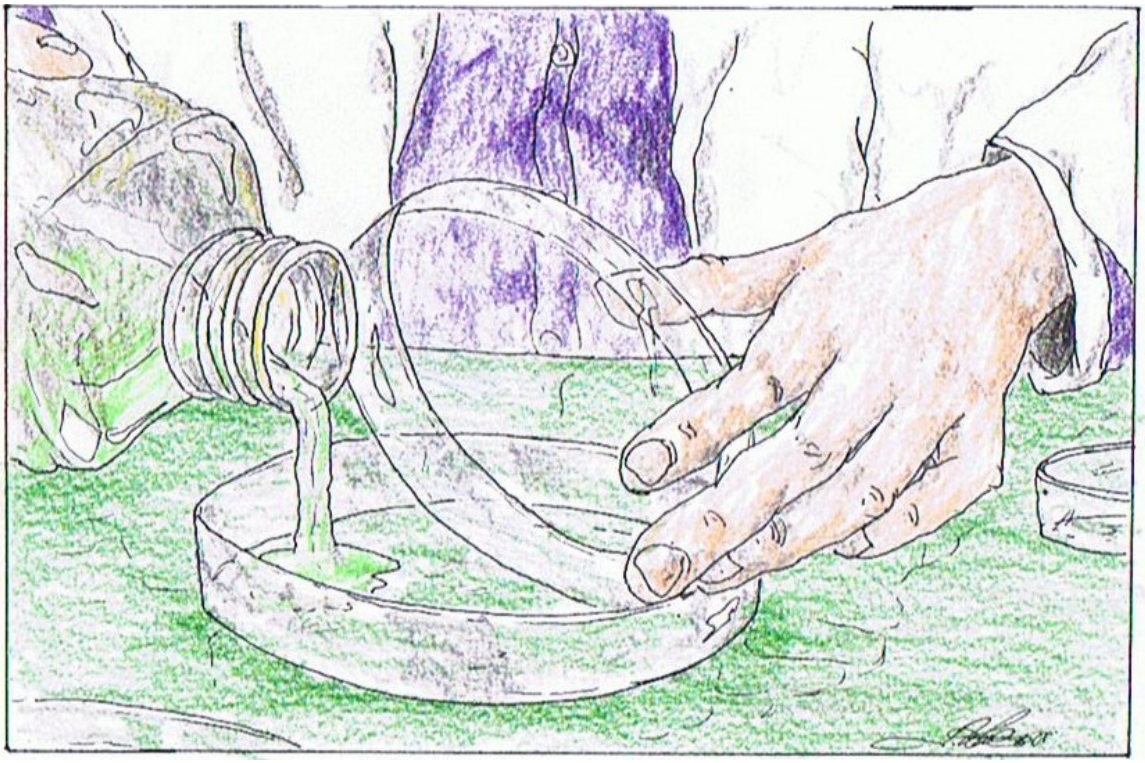
Protozoan Diseases

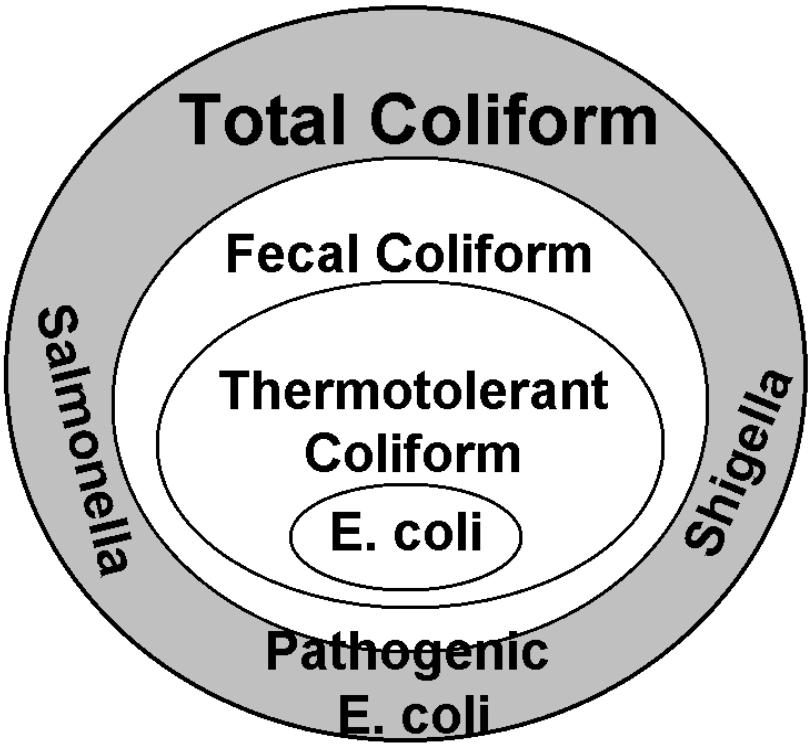
Protozoan pathogens are larger than bacteria and viruses, but still microscopic. They invade and inhabit the gastrointestinal tract. Some parasites enter the environment in a dormant form, with a protective cell wall called a "***cyst***." The cyst can survive in the environment for long periods of time and be extremely resistant to conventional disinfectants such as chlorine. Effective filtration treatment is therefore critical to removing these organisms from water sources.

Giardiasis
Giardiasis is a commonly reported protozoan-caused disease. It has also been referred to as "***backpacker's disease***" and "***beaver fever***" because of the many cases reported among hikers and others who consume untreated surface water. Symptoms include chronic diarrhea, abdominal cramps, bloating, frequent loose and pale greasy stools, fatigue and weight loss. The incubation period is 5-25 days or longer, with an average of 7-10 days. Many infections are asymptomatic (no symptoms). Giardiasis occurs worldwide. Waterborne outbreaks in the United States occur most often in communities receiving their drinking water from streams or rivers without adequate disinfection or a filtration system. The organism, ***Giardia lamblia,*** has been responsible for more community-wide outbreaks of disease in the U.S. than any other pathogen. Drugs are available for treatment but are not 100% effective.

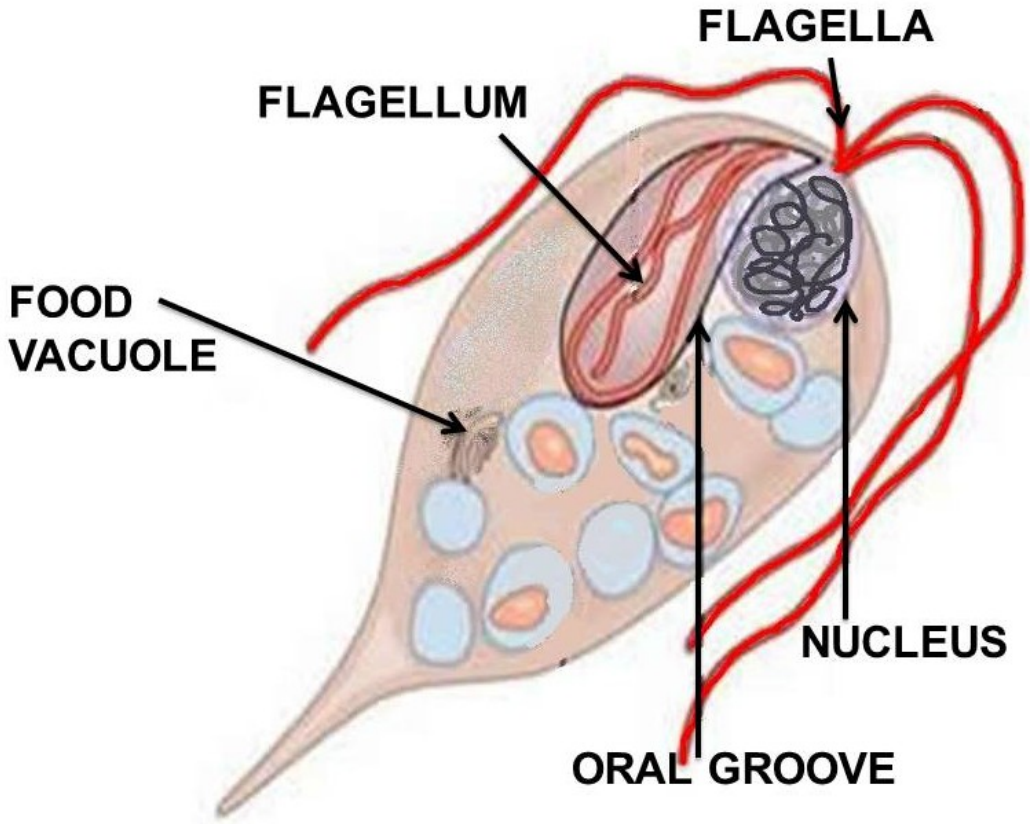
Cryptosporidiosis
Cryptosporidiosis is an example of a protozoan disease that is common worldwide, but was only recently recognized as causing human disease. The major symptom in humans is diarrhea, which may be profuse and watery. The diarrhea is associated with cramping abdominal pain. General malaise, fever, anorexia, nausea, and vomiting occur less often. Symptoms usually come and go, and end in fewer than 30 days in most cases. The incubation period is 1-12 days, with an average of about seven days. ***Cryptosporidium*** organisms have been identified in human fecal specimens from more than 50 countries on six continents. The mode of transmission is fecal-oral, either by person-to-person or animal-to-person. There is no specific treatment for ***Cryptosporidium*** infections.

All of these diseases, with the exception of hepatitis A, have one symptom in common: diarrhea. They also have the same mode of transmission, fecal-oral, whether through person-to-person or animal-to-person contact, and the same routes of transmission, being either foodborne or waterborne. Although most pathogens cause mild, self-limiting disease, on occasion, they can cause serious, even life threatening illness. Particularly vulnerable are persons with weak immune systems such as those with HIV infections or cancer. By understanding the nature of waterborne diseases, the importance of properly constructed, operated and maintained public water systems becomes obvious. While water treatment cannot achieve sterile water (no microorganisms), the goal of treatment must clearly be to produce drinking water that is as pathogen-free as possible at all times. For those who operate water systems with inadequate source protection or treatment facilities, the potential risk of a waterborne disease outbreak is real. For those operating systems that currently provide adequate source protection and treatment, operating and maintaining the system at a high level on a continuing basis is critical to prevent disease.




Total Coliform
Fecal Coliform
Thermotolerant Coliform
E. coli
Salmonella
Shigella
Pathogenic E. coli

Giardia Lamblia



GIARDIA LAMBLIA

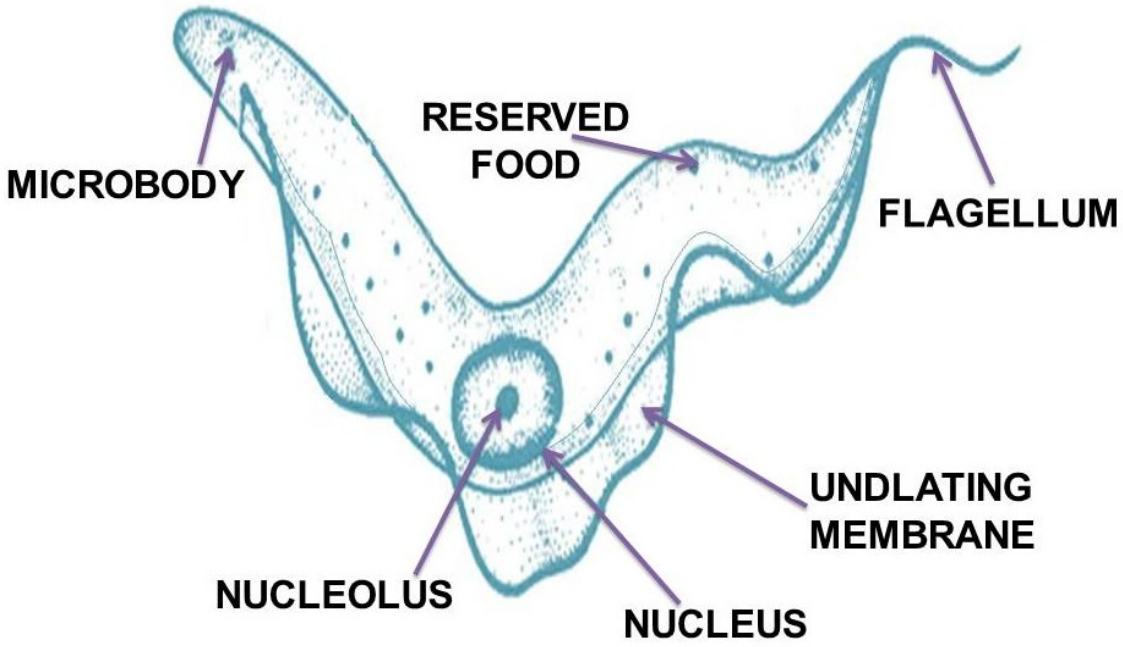
Giardia lamblia (synonymous with Lamblia intestinalis and Giardia duodenalis) is a flagellated protozoan parasite that colonizes and reproduces in the small intestine, causing giardiasis. The giardia parasite attaches to the epithelium by a ventral adhesive disc, and reproduces via binary fission. Giardiasis does not spread via the bloodstream, nor does it spread to other parts of the gastro-intestinal tract, but remains confined to the lumen of the small intestine. Giardia trophozoites absorb their nutrients from the lumen of the small intestine, and are anaerobes.

Giardia infection can occur through ingestion of dormant cysts in contaminated water, or by the fecal-oral route (through poor hygiene practices). The Giardia cyst can survive for weeks to months in cold water and therefore can be present in contaminated wells and water systems, and even clean-looking mountain streams, as well as city reservoirs, as the Giardia cysts are resistant to conventional water treatment methods, such as chlorination and ozonolysis. Zoonotic transmission is also possible, and therefore Giardia infection is a concern for people camping in the wilderness or swimming in contaminated streams or lakes, especially the artificial lakes formed by beaver dams (hence the popular name for giardiasis, "Beaver Fever"). As well as water-borne sources, fecal-oral transmission can also occur, for example in day care centers, where children may have poorer hygiene practices.

Those who work with children are also at risk of being infected, as are family members of infected individuals. Not all Giardia infections are symptomatic, so some people can unknowingly serve as carriers of the parasite.

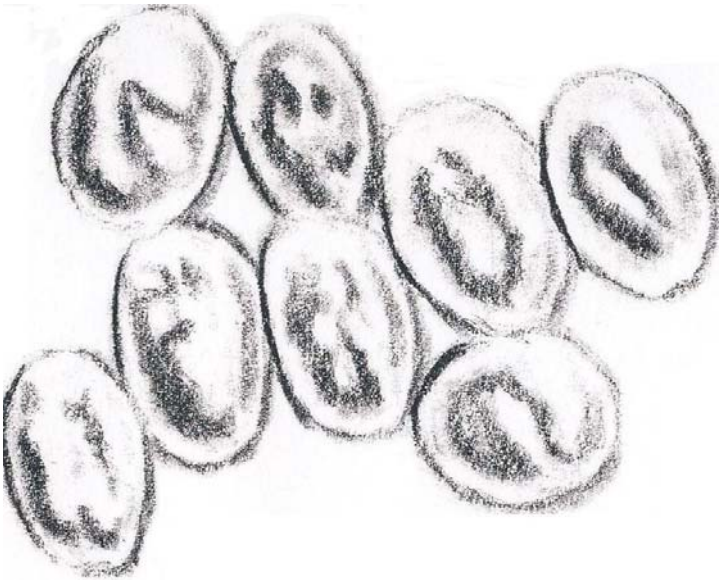
The life cycle begins with a non-infective cyst being excreted with feces of an infected individual. Once out in the environment, the cyst becomes infective. A distinguishing characteristic of the cyst is 4 nuclei and a retracted cytoplasm. Once ingested by a host, the trophozoite emerges to an active state of feeding and motility. After the feeding stage, the trophozoite undergoes asexual replication through longitudinal binary fission. The resulting trophozoites and cysts then pass through the digestive system in the feces. While the trophozoites may be found in the feces, only the cysts are capable of surviving outside of the host.

Distinguishing features of the trophozoites are large karyosomes and lack of peripheral chromatin, giving the two nuclei a halo appearance. Cysts are distinguished by a retracted cytoplasm. This protozoa lacks mitochondria, although the discovery of the presence of mitochodrial remnant organelles in one recent study "indicate that Giardia is not primitively amitochondrial and that it has retained a functional organelle derived from the original mitochondrial endosymbiont"



PROTOZOAN PARASITE

Cryptosporidium

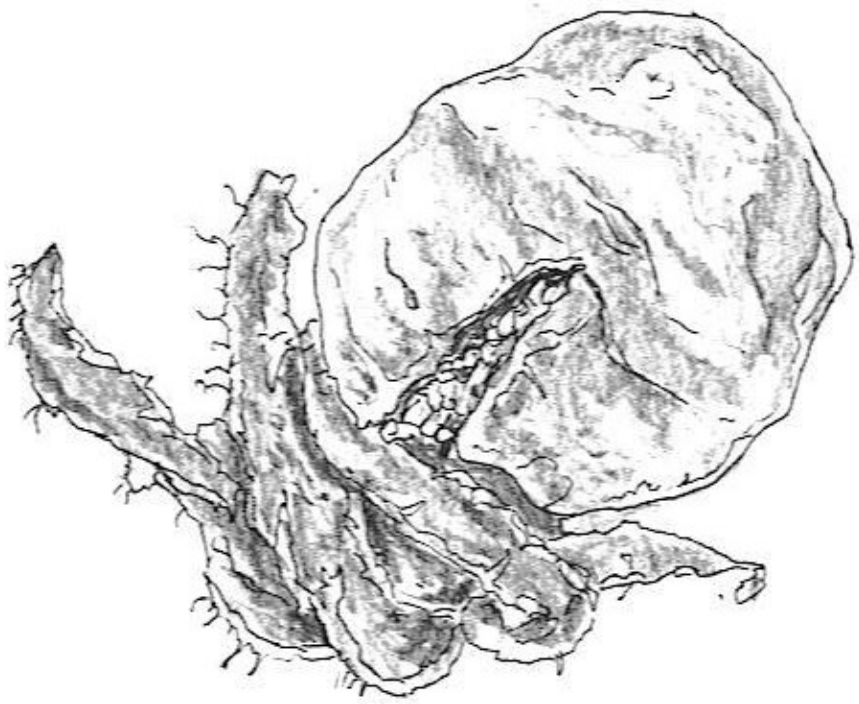


Cryptosporidium is a protozoan pathogen of the Phylum Apicomplexa and causes a diarrheal illness called cryptosporidiosis. Other apicomplexan pathogens include the malaria parasite Plasmodium, and Toxoplasma, the causative agent of toxoplasmosis. Unlike Plasmodium, which transmits via a mosquito vector, Cryptosporidium does not utilize an insect vector and is capable of completing its life cycle within a single host, resulting in cyst stages which are excreted in feces and are capable of transmission to a new host.

A number of species of Cryptosporidium infect mammals. In humans, the main causes of disease are C. parvum and C. hominis (previously C. parvum genotype 1). C. canis, C. felis, C. meleagridis, and C. muris can also cause disease in humans. In recent years, cryptosporidiosis has plagued many commercial Leopard gecko breeders. Several species of the Cryptosporidium family (C. serpentes and others) are involved, and outside of geckos it has been found in monitor lizards, iguanas, tortoises as well as several snake species.

Cryptosporidiosis is typically an acute short-term infection but can become severe and non-resolving in children and immunocompromised individuals. The parasite is transmitted by environmentally hardy cysts (oocysts) that, once ingested, excyst in the small intestine and result in an infection of intestinal epithelial tissue.

The genome of Cryptosporidium parvum was sequenced in 2004 and was found to be unusual amongst Eukaryotes in that the mitochondria seem not to contain DNA. A closely-related species, C. hominis, also has its genome sequence available. CryptoDB.org is a NIH-funded database that provides access to the Cryptosporidium genomics data sets.



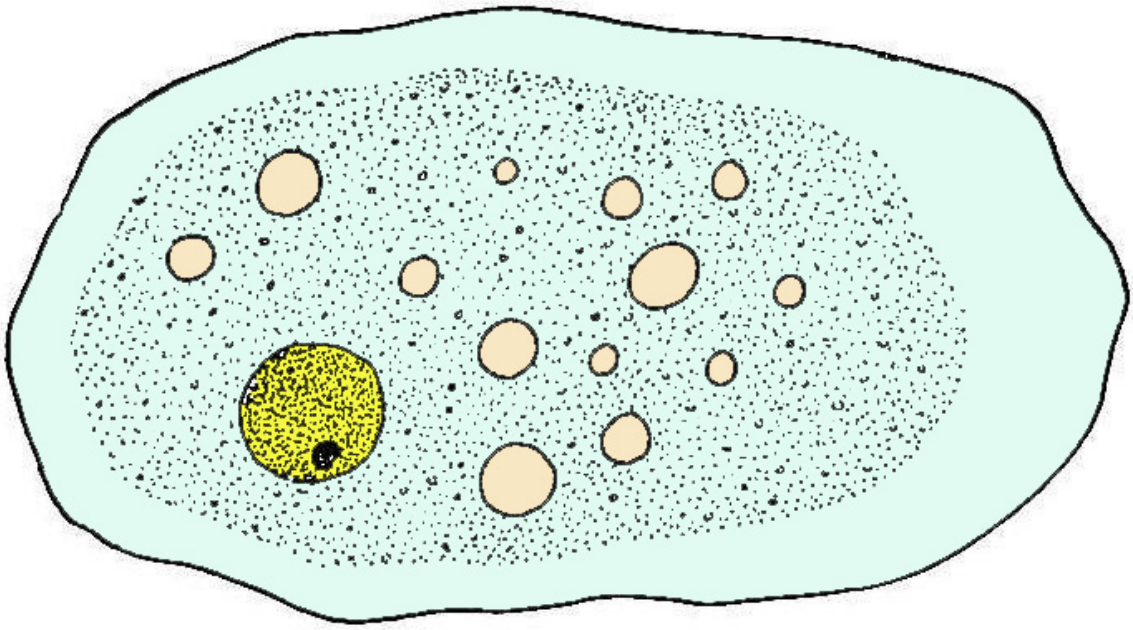
CRYPTO-PARVUM

When *C. parvum* was first identified as a human pathogen, diagnosis was made by a biopsy of intestinal tissue (Keusch, *et al*., 1995). However, this method of testing can give false negatives due the "patchy" nature of the intestinal parasitic infection (Flanigan and Soave, 1993). Staining methods were then developed to detect and identify the oocysts directly from stool samples. The modified acid-fast stain is traditionally used to most reliably and specifically detect the presence of cryptosporidial oocysts.

There have been six major outbreaks of cryptosporidiosis in the United States as a result of contamination of drinking water (Juranek, 1995). One major outbreak in Milwaukee in 1993 affected over 400,000 persons. Outbreaks such as these usually result from drinking water taken from surface water sources such as lakes and rivers (Juranek, 1995). Swimming pools and water park wave pools have also been associated with outbreaks of cryptosporidiosis. Also, untreated groundwater or well water public drinking water supplies can be sources of contamination.

The highly environmentally resistant cyst of *C. parvum* allows the pathogen to survive various drinking water filtrations and chemical treatments such as chlorination. Although municipal drinking water utilities may meet federal standards for safety and quality of drinking water, complete protection from cryptosporidial infection is not guaranteed. In fact, *all* waterborne outbreaks of cryptosporidiosis have occurred in communities where the local utilities met all state and federal drinking water standards (Juranek, 1995).

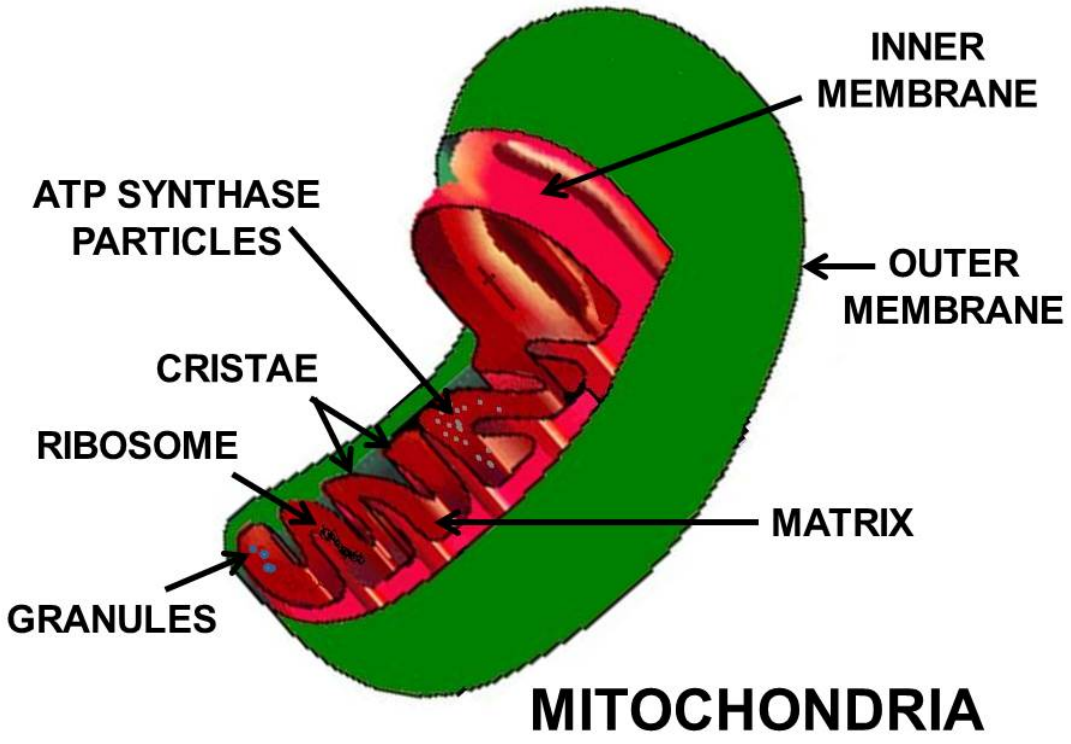
Entamoeba histolytica



Entamoeba histolytica, another water-borne pathogen, can cause diarrhea or a more serious invasive liver abscess. When in contact with human cells, these amoebae are cytotoxic. There is a rapid influx of calcium into the contacted cell, it quickly stops all membrane movement save for some surface blebbing. Internal organization is disrupted, organelles lyse, and the cell dies. The ameba may eat the dead cell or just absorb nutrients released from the cell.

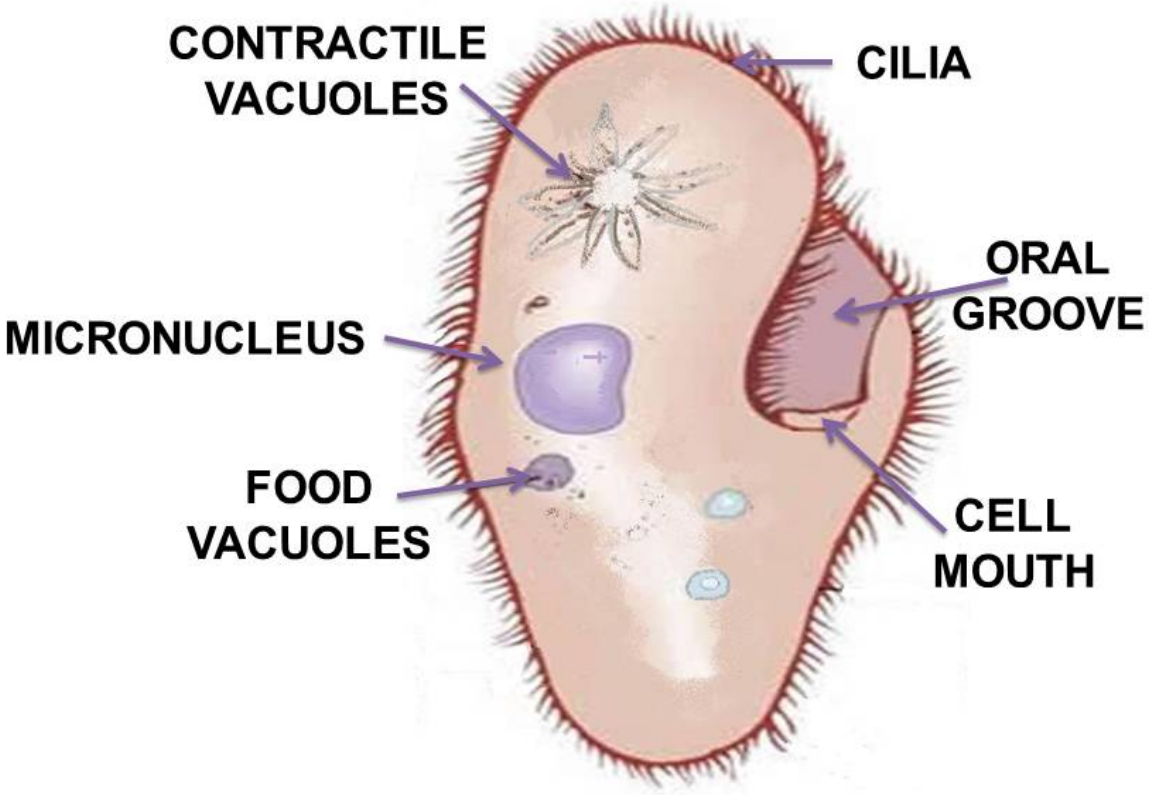
On average, about one in 10 people who are infected with *E. histolytica* becomes sick from the infection. The symptoms often are quite mild and can include loose stools, stomach pain, and stomach cramping. Amebic dysentery is a severe form of amebiasis associated with stomach pain, bloody stools, and fever. Rarely, *E. histolytica* invades the liver and forms an abscess. Even less commonly, it spreads to other parts of the body, such as the lungs or brain.

Scientific classification
Domain: Eukaryota
Phylum: Amoebozoa
Class: Archamoebae
Genus: Entamoeba
Species: E. histolytica



Mitochondria

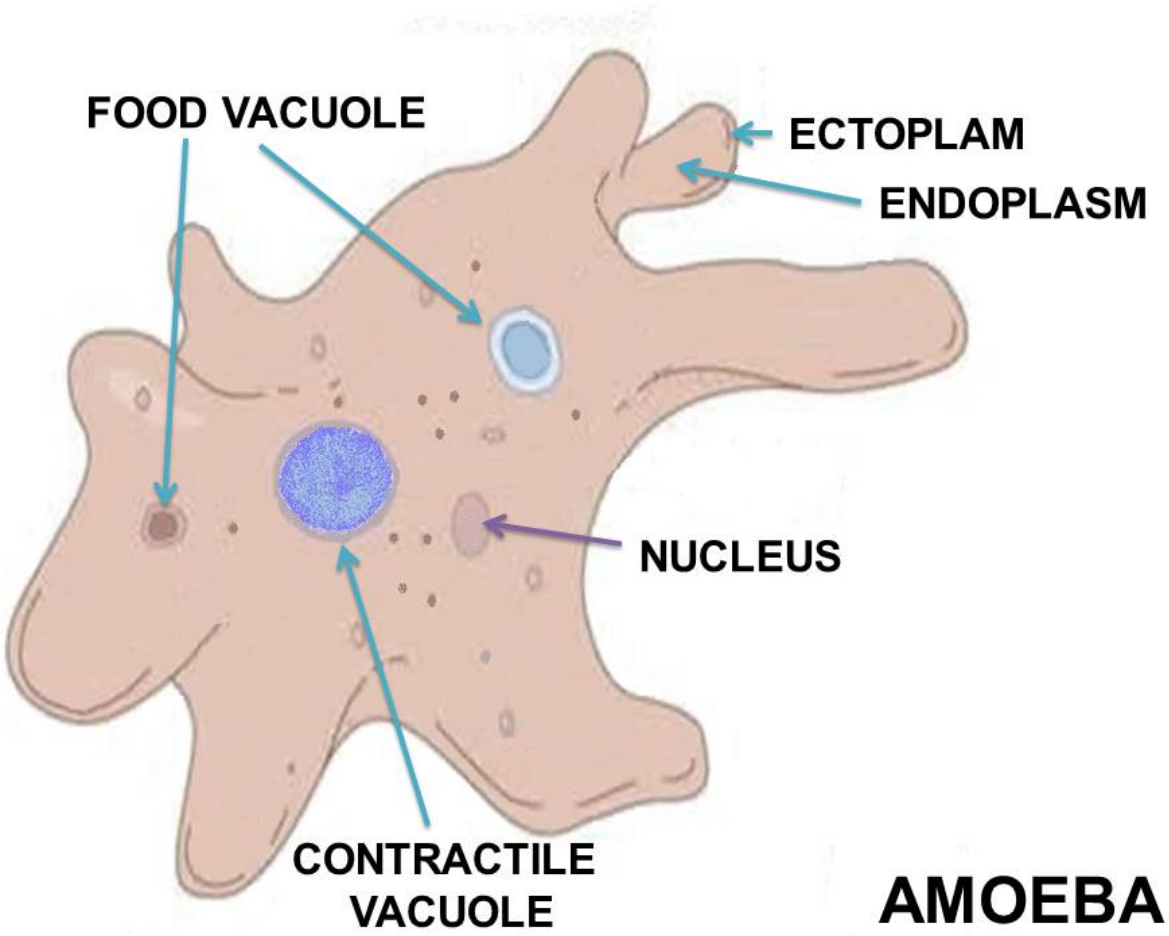
The bacterial cell is surrounded by a lipid membrane, or cell membrane, which encloses the contents of the cell and acts as a barrier to hold nutrients, proteins and other essential components of the cytoplasm within the cell. As they are prokaryotes, bacteria do not tend to have membrane-bound organelles in their cytoplasm and thus contain few large intracellular structures. They consequently lack a nucleus, mitochondria, chloroplasts and the other organelles present in eukaryotic cells, such as the Golgi apparatus and endoplasmic reticulum.



PARAMECIUM

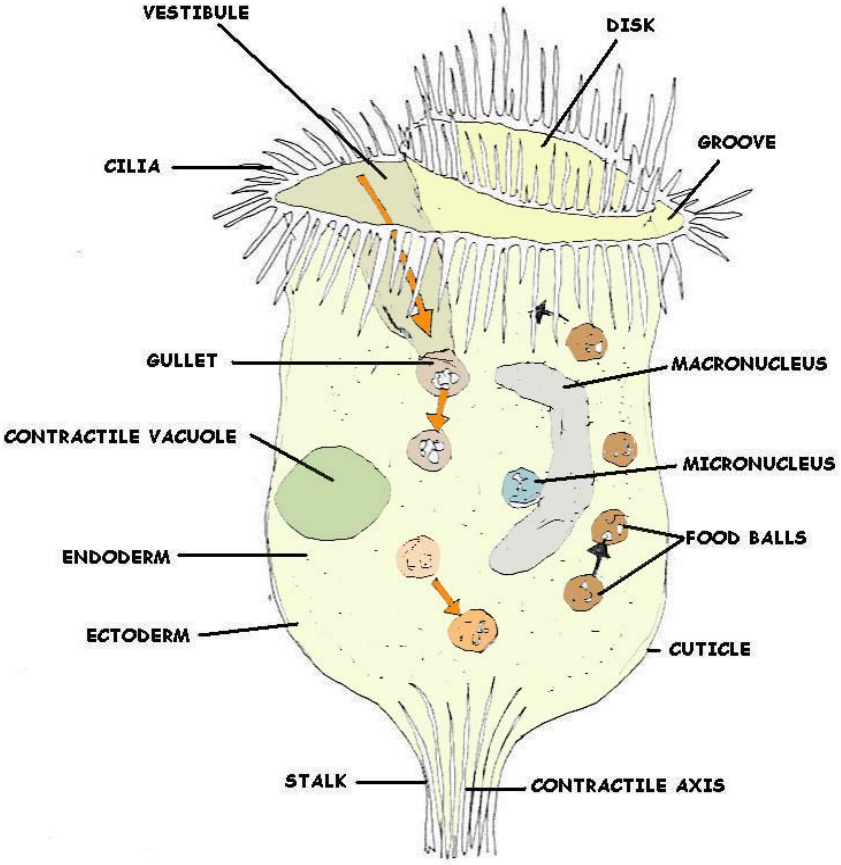
Paramecia

Paramecia are a group of unicellular ciliate protozoa formerly known as slipper animalcules from their slipper shape. They are commonly studied as a representative of the ciliate group. Simple cilia cover the body which allows the cell to move with a synchronous motion (like a caterpilla). There is also a deep oral groove containing inconspicuous compound oral cilia (as found in other peniculids) that is used to draw food inside. They generally feed upon bacteria and other small cells. Osmoregulation is carried out by a pair of contractile vacuoles, which actively expel water absorbed by osmosis from their surroundings. Paramecia are widespread in freshwater environments, and are especially common in scums. Paramecia are attracted by acidic conditions. Certain single-celled eukaryotes, such as Paramecium, are examples for exceptions to the universality of the genetic code (translation systems where a few codons differ from the standard ones).



Amoeba

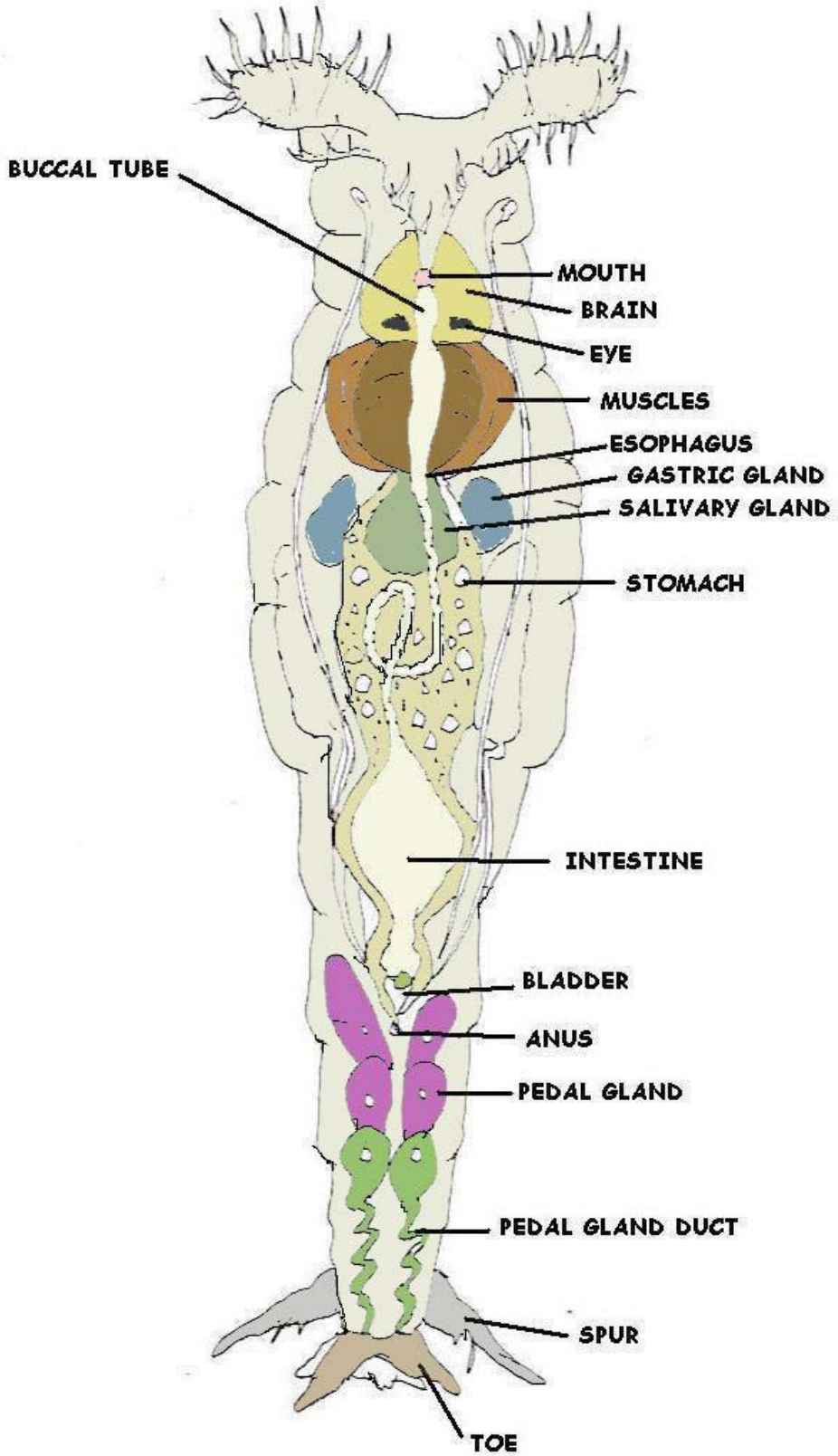
Amoeba (sometimes amœba or ameba, plural amoebae) is a genus of protozoa that moves by means of pseudopods, and is well-known as a representative unicellular organism. The word amoeba or ameba is variously used to refer to it and its close relatives, now grouped as the Amoebozoa, or to all protozoa that move using pseudopods, otherwise termed amoeboids.



Vorticella

Vorticella is a genus of protozoa, with over 100 known species. They are stalked inverted bell-shaped ciliates, placed among the peritrichs. Each cell has a separate stalk anchored onto the substrate, which contains a contracile fibril called a myoneme. When stimulated this shortens, causing the stalk to coil like a spring. Reproduction is by budding, where the cell undergoes longitudinal fission and only one daughter keeps the stalk. Vorticella mainly lives in freshwater ponds and streams - generally anywhere protists are plentiful. Other genera such as Carchesium resemble Vorticella but are branched or colonial.

Domain: Eukaryota
Phylum: Ciliophora
Class: Oligohymenophorea
Subclass: Peritrichia
Order: Sessilida
Family: Vorticellidae
Genus: Vorticella


BUCCAL TUBE
MOUTH
BRAIN
EYE
MUSCLES
ESOPHAGUS
GASTRIC GLAND
SALIVARY GLAND
STOMACH
INTESTINE
BLADDER
ANUS
PEDAL GLAND
PEDAL GLAND DUCT
SPUR
TOE

ROTIFER

Rotifer

The rotifers make up a phylum of microscopic and near-microscopic pseudocoelomate animals. They were first described by John Harris in 1696 (Hudson and Gosse, 1886). Leeuwenhoek is mistakenly given credit for being the first to describe rotifers but Harris had produced sketches in 1703. Most rotifers are around 0.1-0.5 mm long, and are common in freshwater throughout the world with a few saltwater species. Rotifers may be free swimming and truly planktonic, others move by inch worming along the substrate, whilst some are sessile, living inside tubes or gelatinous holdfasts. About 25 species are colonial (e.g. Sinantherina semibullata), either sessile or planktonic.

Rotifers get their name (derived from Greek and meaning "wheel-bearer"; they have also been called wheel animalcules) from the corona, which is composed of several ciliated tufts around the mouth that in motion resemble a wheel. These create a current that sweeps food into the mouth, where it is chewed up by a characteristic pharynx (called the mastax) containing a tiny, calcified, jaw-like structure called the trophi. The cilia also pull the animal, when unattached, through the water. Most free-living forms have pairs of posterior toes to anchor themselves while feeding. Rotifers have bilateral symmetry and a variety of different shapes. There is a well-developed cuticle which may be thick and rigid, giving the animal a box-like shape, or flexible, giving the animal a worm-like shape; such rotifers are respectively called loricate and illoricate.

Like many other microscopic animals, adult rotifers frequently exhibit eutely - they have a fixed number of cells within a species, usually on the order of one thousand. Males in the class Monogononta may be either present or absent depending on the species and environmental conditions. In the absence of males, reproduction is by parthenogenesis and results in clonal offspring that are genetically identical to the parent. Individuals of some species form two distinct types of parthenogenetic eggs; one type develops into a normal parthenogenetic female, while the other occurs in response to a changed environment and develops into a degenerate male that lacks a digestive system, but does have a complete male reproductive system that is used to inseminate females thereby producing fertilized 'resting eggs'. Resting eggs develop into zygotes that are able to survive extreme environmental conditions such as may occur during winter or when the pond dries up. These eggs resume development and produce a new female generation when conditions improve again. The life span of monogonont females varies from a couple of days to about three weeks.

Bdelloid rotifers are unable to produce resting eggs, but many can survive prolonged periods of adverse conditions after desiccation. This facility is termed anhydrobiosis, and organisms with these capabilities are termed anhydrobionts. Under drought conditions, bdelloid rotifers contract into an inert form and lose almost all body water; when rehydrated, however, they resume activity within a few hours. Bdelloids can survive the dry state for prolonged periods, with the longest well-documented dormancy being nine years. While in other anhydrobionts, such as the brine shrimp, this desiccation tolerance is thought to be linked to the production of trehalose, a non-reducing disaccharide (sugar), bdelloids apparently lack the ability to synthesize trehalose. Bdelloid rotifer genomes contain two or more divergent copies of each gene. Four copies of hsp82 are, for example, found. Each is different and found on a different chromosome, excluding the possibility of homozygous sexual reproduction.

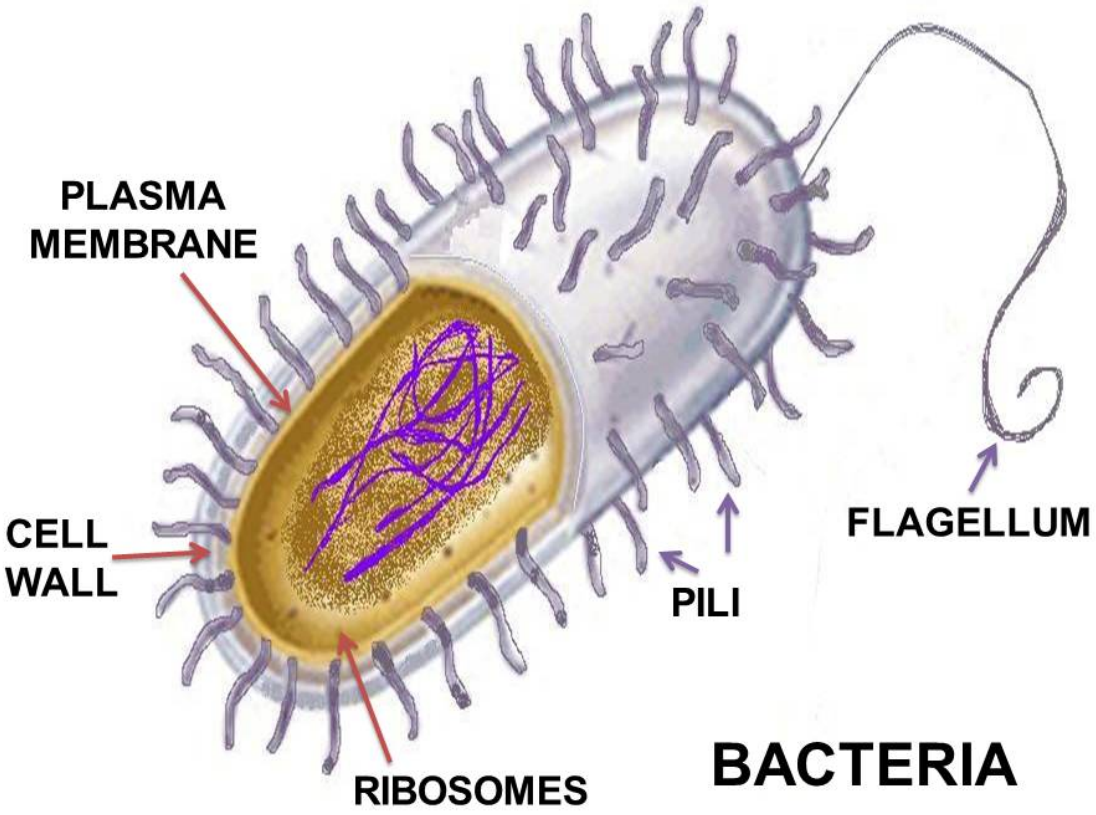
Waterborne Diseases

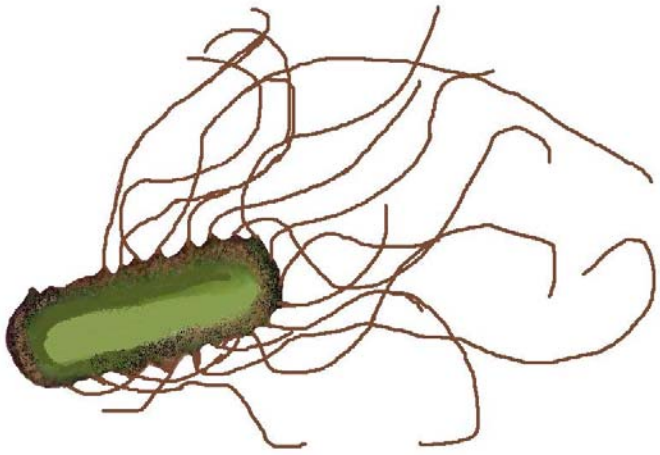
Name	Causative organism	Source of organism	Disease
Viral gastroenteritis	**Rotavirus** (mostly in young children)	Human feces	Diarrhea or vomiting
Norwalk Agent	**Noroviruses** (genus *Norovirus*, family *Caliciviridae*) [*1]	Human feces; also, shellfish; lives in polluted waters	Diarrhea and vomiting
Salmonellosis	***Salmonella*** (bacterium)	Animal or human feces	Diarrhea or vomiting
Gastroenteritis Escherichia *coli*	-- ***E. coli O1* 57:H7** (bacterium): Other *E. coli* organisms:	Human feces	Symptoms vary with type caused
Typhoid	***Salmonella typhi*** (bacterium)	Human feces, urine	Inflamed intestine, enlarged spleen, high temperature-sometimes fatal
Shigellosis	***Shigella*** (bacterium)	Human feces	Diarrhea
Cholera	***Vibrio choleras*** (bacterium)	Human feces; also, shellfish; lives in many coastal waters	Vomiting, severe diarrhea, rapid dehydration, mineral loss-high mortality
Hepatitis A	**Hepatitis A** virus	Human feces; shellfish grown in polluted waters	Yellowed skin, enlarged liver, fever, vomiting, weight loss, abdominal pain-low mortality, lasts up to four months
Amebiasis	***Entamoeba histolytica*** (protozoan)	Human feces	Mild diarrhea, dysentery, extra intestinal infection
Giardiasis	***Giardia lamblia*** (protozoan)	Animal or human feces	Diarrhea, cramps, nausea, and general weakness — lasts one week to months
Cryptosporidiosis	***Cryptosporidium parvum***	Animal or human feces	Diarrhea, stomach pain — lasts (protozoan) days to weeks

Notes:

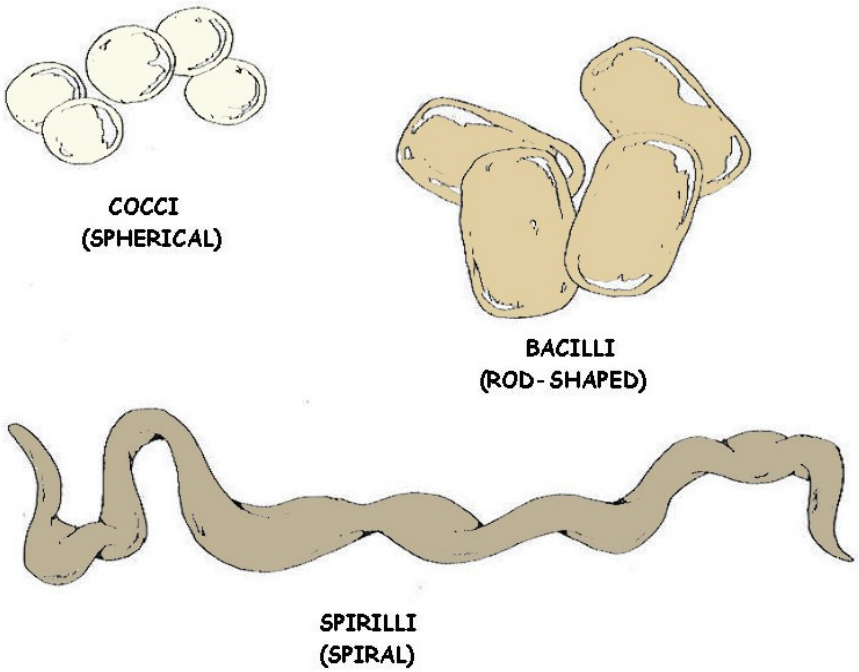
*1 http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus.htm
http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5009a1.htm

Bacteria Section





Peritrichous Bacteria



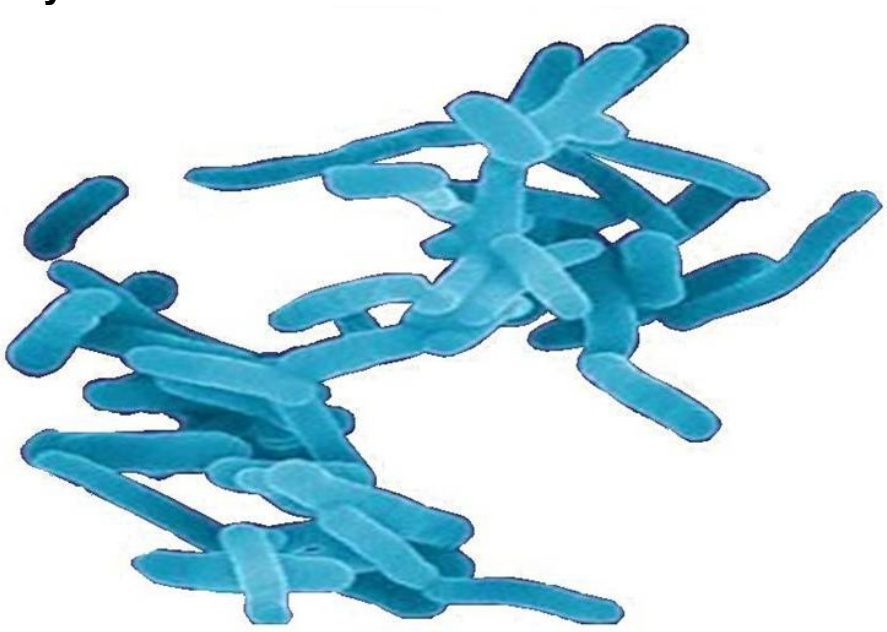
BACTERIA TYPES

Microbiologists broadly classify bacteria according to their shape: spherical, rod-shaped, and spiral-shaped. Pleomorphic bacteria can assume a variety of shapes. Bacteria may be further classified according to whether they require oxygen (aerobic or anaerobic) and how they react to a test with Gram's stain. Bacteria in which alcohol washes away Gram's stain are called gram-negative, while bacteria in which alcohol causes the bacteria's walls to absorb the stain are called gram-positive.



COLORLESS FILAMENTOUS
SULFUR BACTERIA

Shigella dysenteriae



SHIGELLA DYSENTERIAE

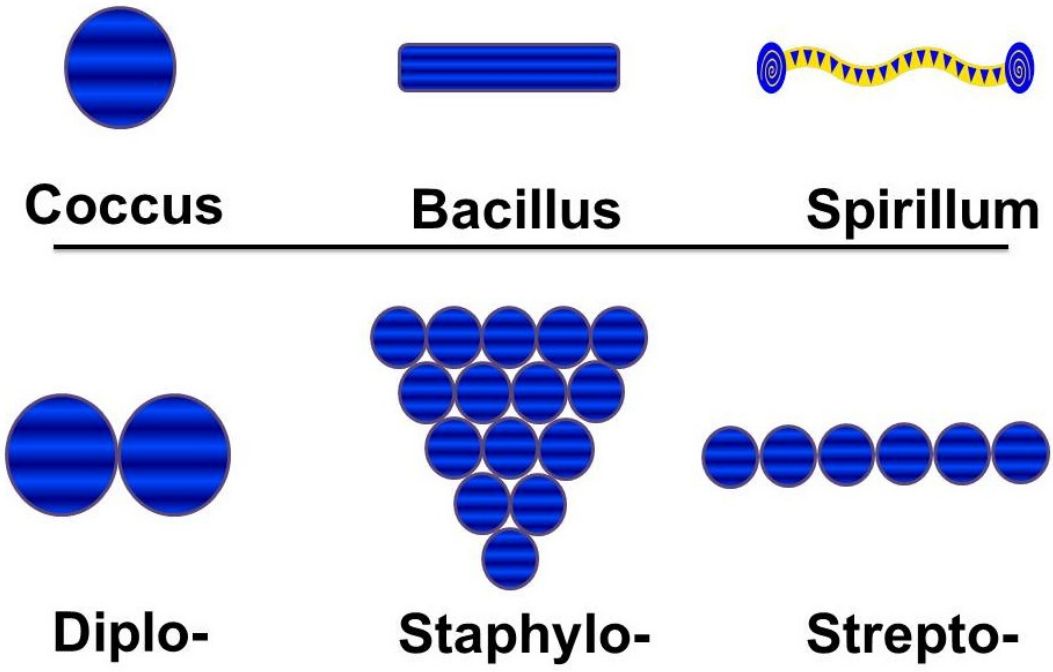
Shigella dysenteriae is a species of the rod-shaped bacterial genus Shigella. Shigella can cause shigellosis (bacillary dysentery). Shigellae are Gram-negative, non-spore-forming, facultatively anaerobic, non-motile bacteria.

S. dysenteriae, spread by contaminated water and food, causes the most severe dysentery because of its potent and deadly Shiga toxin, but other species may also be dysentery agents. Shigella infection is typically via ingestion (fecal–oral contamination); depending on age and condition of the host as few as ten bacterial cells can be enough to cause an infection. Shigella causes dysentery that result in the destruction of the epithelial cells of the intestinal mucosa in the cecum and rectum. Some strains produce enterotoxin and Shiga toxin, similar to the verotoxin of E. coli O157:H7. Both Shiga toxin and verotoxin are associated with causing hemolytic uremic syndrome.

Shigella invades the host through epithelial cells of the large intestine. Using a Type III secretion system acting as a biological syringe, the bacterium injects IpaD protein into cell, triggering bacterial invasion and the subsequent lysis of vacuolar membranes using IpaB and IpaC proteins. It utilizes a mechanism for its motility by which its IcsA protein triggers actin polymerization in the host cell (via N-WASP recruitment of Arp2/3 complexes) in a "rocket" propulsion fashion for cell-to-cell spread.

The most common symptoms are diarrhea, fever, nausea, vomiting, stomach cramps, and straining to have a bowel movement. The stool may contain blood, mucus, or pus (e.g. dysentery). In rare cases, young children may have seizures. Symptoms can take as long as a week to show up, but most often begin two to four days after ingestion. Symptoms usually last for several days, but can last for weeks. Shigella is implicated as one of the pathogenic causes of reactive arthritis worldwide.

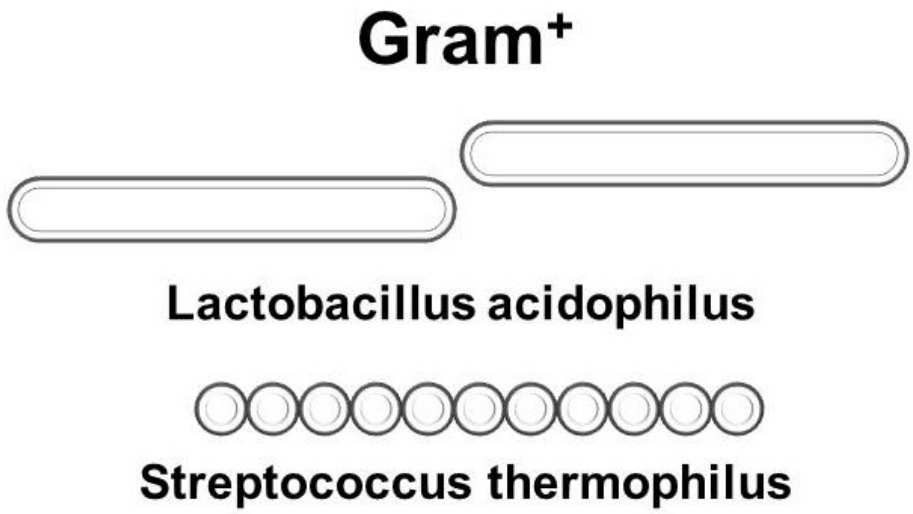


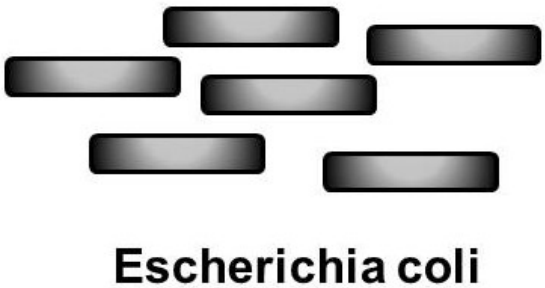


Bacteria Types

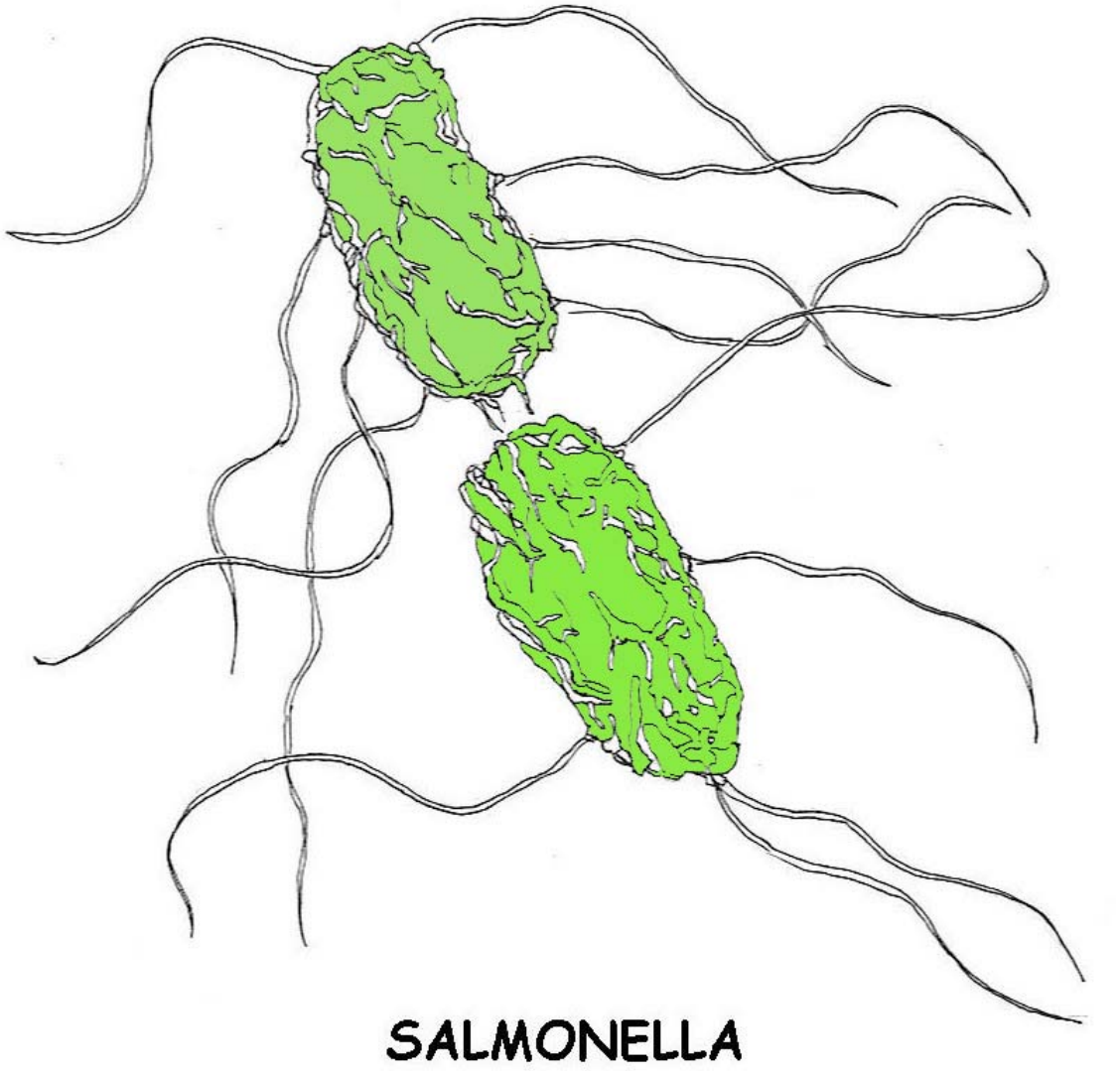
Type	Characteristics
Acetic acid	Rod-shaped, gram-negative, aerobic; highly tolerant of acidic conditions; generate organic acids
Actinomycete	Rod-shaped or filamentous, gram-positive, aerobic; common in soils; essential to growth of many plants; source of much of original antibiotic production in pharmaceutical industry
Coccoid	Spherical, sometimes in clusters or strings, gram-positive, aerobic and anaerobic; resistant to drying and high-salt conditions; *Staphylococcus* species common on human skin, certain strains associated with toxic shock syndrome
Coryneform	Rod-shaped, form club or V shapes, gram-positive, aerobic; found in wide variety of habitats, particularly soils; highly resistant to drying; include *Arthrobacter,* among most common forms of life on earth
Endospore-forming	Usually rod-shaped, can be gram-positive or gram-negative; have highly adaptable, heat-resistant spores that can go dormant for long periods, possibly thousands of years; include *Clostridium* (anaerobic) and *Bacillus* (aerobic)
Enteric	Rod-shaped, gram-negative, aerobic but can live in certain anaerobic conditions; produce nitrite from nitrate, acids from glucose; include *Escherichia coli, Salmonella* (over 1000 types), and *Shigella*
Gliding	Rod-shaped, gram-negative, mostly aerobic; glide on secreted slimy substances; form colonies, frequently with complex fruiting structures
Lactic acid	Gram-positive, anaerobic; produce lactic acid through fermentation; include *Lactobacillus*, essential in dairy product formation, and *Streptococcus*, common in humans
Mycobacterium	Pleomorphic, spherical or rod-shaped, frequently branching, no gram stain, aerobic; commonly form yellow pigments; include *Mycobacterium tuberculosis,* cause of tuberculosis
Mycoplasma	Spherical, commonly forming branching chains, no gram stain, aerobic but can live in certain anaerobic conditions; without cell walls yet structurally resistant to lysis; among smallest of bacteria; named for superficial resemblance to fungal hyphae (*myco-* means 'fungus')
Nitrogen-fixing	Rod-shaped, gram-negative, aerobic; convert atmospheric nitrogen gas to ammonium in soil; include *Azotobacter,* a common genus
Propionic acid	Rod-shaped, pleomorphic, gram-positive, anaerobic; ferment lactic acid; fermentation produces holes in Swiss cheese from the production of carbon dioxide
Pseudomonad	Rod-shaped (straight or curved) with polar flagella, gram-negative, aerobic; can use up to 100 different compounds for carbon and energy
Rickettsia	Spherical or rod-shaped, gram-negative, aerobic; cause Rocky Mountain spotted fever and typhus; closely related to *Agrobacterium,* a common gall-causing plant bacterium
Sheathed	Filamentous, gram-negative, aerobic; 'swarmer' (colonizing) cells form and break out of a sheath; sometimes coated with metals from environment

Spirillum	Spiral-shaped, gram-negative, aerobic; include *Bdellovibrio,* predatory on other bacteria
Spirochete	Spiral-shaped, gram-negative, mostly anaerobic; common in moist environments, from mammalian gums to coastal mudflats; complex internal structures convey rapid movement; include *Treponemapallidum,* cause of syphilis
Sulfate- and Sulfur-reducing	Commonly rod-shaped, mostly gram-negative, anaerobic; include *Desulfovibrio,* ecologically important in marshes
Sulfur- and iron-oxidizing	Commonly rod-shaped, frequently with polar flagella, gram-negative, mostly anaerobic; most live in neutral (nonacidic) environment
Vibrio	Rod- or comma-shaped, gram-negative, aerobic; commonly with a single flagellum; include *Vibrio cholerae,* cause of cholera, and luminescent forms symbiotic with deep-water fishes and squids





Salmonella



Salmonella is a Gram-negative bacterium. It is found in many turtles and other reptiles. In clinical laboratories, it is usually isolated on MacConkey agar, XLD agar, XLT agar, DCA agar, or Önöz agar. Because they cause intestinal infections and are greatly outnumbered by the bacteria normally found in the healthy bowel, primary isolation requires the use of a selective medium, so use of a relatively non-selective medium such as CLED agar is not often practiced. Numbers of salmonella may be so low in clinical samples that stools are routinely also subjected to "enrichment culture", where a small volume of stool is incubated in a selective broth medium, such as selenite broth or Rappaport Vassiliadis soya peptone broth, overnight. These media are inhibitory to the growth of the microbes normally found in the healthy human bowel, while allowing salmonellae to become enriched in numbers. Salmonellae may then be recovered by inoculating the enrichment broth on one or more of the primary selective media. On blood agar, they form moist colonies about 2 to 3 mm in diameter.

When the cells are grown for a prolonged time at a range of 25—28°C, some strains produce a biofilm, which is a matrix of complex carbohydrates, cellulose and proteins. The ability to produce biofilm (a.k.a. "rugose", "lacy", or "wrinkled") can be an indicator of dimorphism, which is the ability of a single genome to produce multiple phenotypes in response to environmental conditions. Salmonellae usually do not ferment lactose; most of them produce hydrogen sulfide which, in media containing ferric ammonium citrate, reacts to form a black spot in the centre of the creamy colonies.

Classification

Salmonella taxonomy is complicated. As of December 7, 2005, there are two species within the genus: S. bongori (previously subspecies V) and S. enterica (formerly called S. choleraesuis), which is divided into six subspecies:

* I—enterica
* II—salamae
* IIIa—arizonae
* IIIb—diarizonae
* IV—houtenae
* V—obsolete (now designated S. bongori)
* VI—indica



There are also numerous (over 2500) serovars within both species, which are found in a disparate variety of environments and which are associated with many different diseases. The vast majority of human isolates (>99.5%) are subspecies S. enterica. For the sake of simplicity, the CDC recommends that Salmonella species be referred to only by their genus and serovar, e.g.

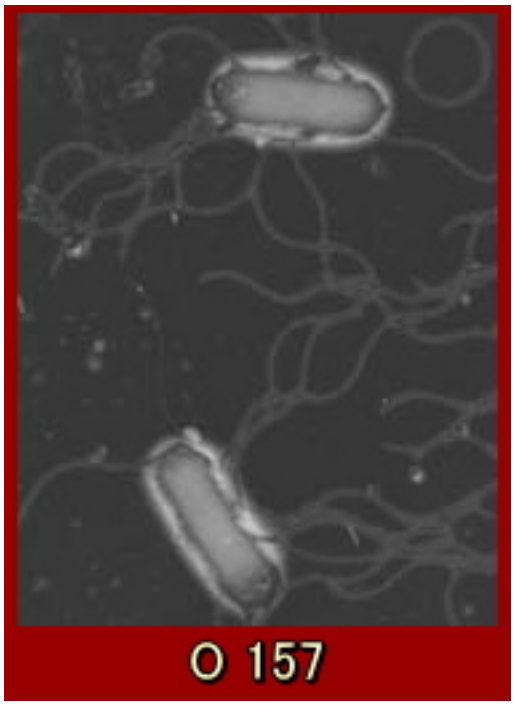
Salmonella Typhi instead of the more technically correct designation, Salmonella enterica subspecies enterica serovar Typhi.

Escherichia Coli Section

Fecal Coliform Bacteria
Fecal coliform bacteria are microscopic organisms that live in the intestines of warm-blooded animals. They also live in the waste material, or feces, excreted from the intestinal tract. When fecal coliform bacteria are present in high numbers in a water sample, it means that the water has received fecal matter from one source or another. Although not necessarily agents of disease, fecal coliform bacteria may indicate the presence of disease-carrying organisms, which live in the same environment as the fecal coliform bacteria.

Reasons for Natural Variation
Unlike the other conventional water quality parameters, fecal coliform bacteria are living organisms. They do not simply mix with the water and float straight downstream. Instead they multiply quickly when conditions are favorable for growth, or die in large numbers when conditions are not. Because bacterial concentrations are dependent on specific conditions for growth, and these conditions change quickly, fecal coliform bacteria counts are not easy to predict. For example, although winter rains may wash more fecal matter from urban areas into a stream, cool water temperatures may cause a major die-off. Exposure to sunlight (with its ultraviolet disinfection properties) may have the same effect, even in the warmer water of summertime.

Expected Impact of Pollution
The primary sources of fecal coliform bacteria to fresh water are wastewater treatment plant discharges, failing septic systems, and animal waste. Bacteria levels do not necessarily decrease as a watershed develops from rural to urban. Instead, urbanization usually generates new sources of bacteria. Farm animal manure and septic systems are replaced by domestic pets and leaking sanitary sewers. In fact, stormwater runoff in urbanized areas has been found to be surprisingly high in fecal coliform bacteria concentrations.



The presence of old, disintegrating storm and sanitary sewers, misplaced sewer pipes, and good breeding conditions are common explanations for the high levels measured.

Coliform Standards (in colonies/100ml)
Drinking water.....1FC
Total body contact (swimming).....200FC
Partial body contact (boating).....1000FC
Threatened sewage effluent .....not to exceed 200 FC

*Total coliform (TC) includes bacteria from cold-blooded animals and various soil organisms. According to recent literature, total coliform counts are normally about 10 times higher than fecal coliform (FC) counts.

Indicator Connection Varies
General coliforms, E. Coli, and Enterococcus bacteria are the "indicator" organisms generally measured to assess microbiological quality of water. However, these aren't generally what get people sick. Other bacteria, viruses, and parasites are what we are actually worried about.

Because it is so much more expensive and tedious to do so, actual pathogens are virtually never tested for. Over the course of a professional lifetime pouring over indicator tests, in a context where all standards are based on indicators, water workers tend to forget that the indicators are not the things we actually care about.

What are these indicators? More information in the Laboratory section.

- **General coliforms** indicate that the water has come in contact with plant or animal life. General coliforms are universally present, including in pristine spring water. They are of little concern at low levels, except to indicate the effectiveness of disinfection. Chlorinated water and water from perfectly sealed tube wells is the only water I've tested which had zero general coliforms. At very high levels they indicate there is what amounts to a lot of compost in the water, which could easily include pathogens (Ten thousand general coliform bacteria will get you a beach closure, compared to two or four hundred fecal coliforms, or fifty enterococcus).
- **Fecal coliforms**, particularly E. coli, indicate that there are mammal or bird feces in the water.
- **Enterococcus bacteria** also indicate that there are feces from warm blooded animals in the water. Enterococcus are a type of fecal streptococci. They are another valuable indicator for determining the amount of fecal contamination of water.
  According to studies conducted by the EPA, enterococci have a greater correlation with swimming-associated gastrointestinal illness in both marine and fresh waters than other bacterial indicator organisms, and are less likely to "die off" in saltwater.

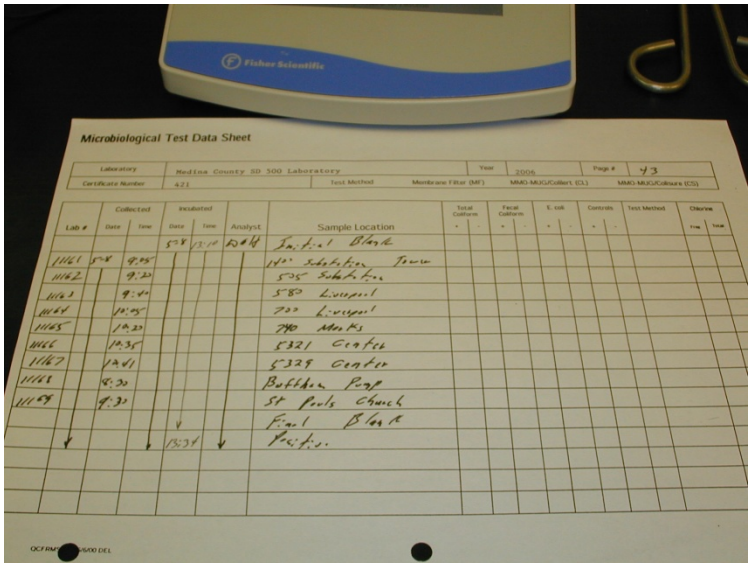
The more closely related the animal, the more likely pathogens excreted with their feces can infect us. Human feces are the biggest concern, because anything which infects one human could infect another. There isn't currently a quantitative method for measuring specifically human fecal bacteria (expensive genetic studies can give a presence/absence result). Ingesting a human stranger's feces via contaminated water supply is a classic means for infections to spread rapidly. The more pathogens an individual carries, the more hazardous their feces. Ingesting feces from someone who is not carrying any pathogens may gross you out, but it can't infect you. Infection rates are around 5% in the US, and approach 100% in areas with poor hygiene and contaminated water supplies. Keep in the back of your mind that **the ratio of indicators to actual pathogens is not fixed**. It will always be different, sometimes very different. Whenever you are trying to form a mental map of reality based on water tests, you should include in the application of your water intuition an adjustment factor for your best guess of the ratio between indicators and actual pathogens.

Membrane Filter Total Coliform Technique

The membrane filter total Coliform technique is used at Medina County for drinking water quality testing. The following is a summary of this test. A sampling procedure sheet is given to all sample takers by Medina County.

The samples are taken in sterile 100 mL containers. These containers, when used for chlorinated water samples, have a sodium thiosulfate pill or solution to dechlorinate the sample.

The sample is placed in cold storage after proper sample taking procedures are followed. (See sample procedures below)



The samples are taken to the laboratory with a chain of custody to assure no tampering of samples can occur.

These samples are logged in at the laboratory.

No longer than 30 hours can lapse between the time of sampling and time of test incubation. (8 hours for heterotrophic, nonpotable 6 hours, others not longer than 24 hours)

All equipment is sterilized by oven and autoclave.
Glassware in oven at 170°C ± 10°C with foil (or other suitable wrap) loosely fitting and secured immediately after sterilization.

Filtration units in autoclave at 121°C for 30 minutes.



Use sterile petri dishes, grid, and pads bought from a reliable company – certified, quality assured - test for satisfactory known positive amounts.

Incubators – 35°C ± .5°C (60% relative humidity)
M-endo medium is prepared and heated to near boiling removed from heat cooled to 45°C pH adjusted to 7.2 ± .2 and immediately dispensed 8ml to plates. Keep refrigerated and discard after 2 weeks.

Plates can be stored in a dated box with expiration date and discarded if not used. No denatured alcohol should be used. Everclear or 95% proof alcohol or absolute methyl may be used for sterilizing forceps by flame.

Procedure:
Counters are alcohol wiped.
Bench sheets are filled out.
Samples are removed from refrigeration.
Sterile wrapped utensils are placed on counters.
Filtration units are placed onto sterile membrane filters by aseptic technique using sterile forceps.
Sterile petri dishes are labeled.
The samples closures are clipped.
The sample is shaken 25 times 1 foot in length within 7 seconds.
100 mL is filtered and rinsed with sterile distilled water 3 times.
The membrane filter is aseptically removed from filter holder.
A sterile padded petri dish is used and the membrane filter is rolled onto the pad making sure no air bubbles form.
The sterile labeled lid is placed on the petri dish.
2 blanks and a known is run with each series of samples.
The samples are placed in the 35^{o}C $\pm$ .5^{o}C incubator stacked no higher than 3 for 22 – 24 hours (Humidity can be maintained by saturated paper towels placed under containers holding petri dishes.)
After 22- 24 hours view the petri dishes under a 10 –15 power magnification with cool white fluorescent light.
Count all colonies that appear pink to dark red with a metallic surface sheen – the sheen may vary in size from a pin head to complete coverage.
Report as Total Coliform per 100 mL.
If no colonies are present report as <1 coliform/100mL.

Anything greater than 1 is over the limit for drinking water for 2 samples taken 24 hours apart. Further investigation may be necessary – follow Standard Methods accordingly.



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Aran™ Aqua Analytical Laboratory Director.

Escherichia coli EPEC

Two types of pathogenic Escherichia coli, enteropathogenic E. coli (EPEC) and enterohemorrhagic E. coli (EHEC), cause diarrheal disease by disrupting the intestinal environment through the intimate attachment of the bacteria to the intestinal epithelium.

E. coli O157:H7
E. coli O157:H7 (bacterium) found in human feces. Symptoms vary with type caused gastroenteritis.

Escherichia coli O157:H7 is an emerging cause of foodborne illness. An estimated 73,000 cases of infection and 61 deaths occur in the United States each year. Infection often leads to bloody diarrhea, and occasionally to kidney failure. Most illnesses have been associated with eating undercooked, contaminated ground beef. Person-to-person contact in families and child care centers is also an important mode of transmission. Infection can also occur after drinking raw milk and after swimming in or drinking sewage-contaminated water.

Consumers can prevent *E. coli* O157:H7 infection by thoroughly cooking ground beef, avoiding unpasteurized milk, and washing hands carefully. Because the organism lives in the intestines of healthy cattle, preventive measures on cattle farms and during meat processing are being investigated.

What is *Escherichia coli* O157:H7?
E. coli O157:H7 is one of hundreds of strains of the bacterium Escherichia coli. Although most strains are harmless and live in the intestines of healthy humans and animals, this strain produces a powerful toxin and can cause severe illness.

E. coli O157:H7 was first recognized as a cause of illness in 1982 during an outbreak of severe bloody diarrhea; the outbreak was traced to contaminated hamburgers. Since then, most infections have come from eating undercooked ground beef.

The combination of letters and numbers in the name of the bacterium refers to the specific markers found on its surface and distinguishes it from other types of *E. coli.*

Currently, there are four recognized classes of enterovirulent *E. coli* (collectively referred to as the EEC group) that cause gastroenteritis in humans. Among these is the enterohemorrhagic (EHEC) strain designated *E. coli* O157:H7. *E. coli* is a normal inhabitant of the intestines of all animals, including humans. When aerobic culture methods are used, *E. coli* is the dominant species found in feces.

Normally *E. coli* serves a useful function in the body by suppressing the growth of harmful bacterial species and by synthesizing appreciable amounts of vitamins. A minority of *E. coli* strains are capable of causing human illness by several different mechanisms. *E. coli* serotype O157:H7 is a rare variety of *E. coli* that produces large quantities of one or more related, potent toxins that cause severe damage to the lining of the intestine. These toxins [verotoxin (VT), shiga-like toxin] are closely related or identical to the toxin produced by *Shigella dysenteriae*.

How does *E. coli* or other fecal coliforms get in the water?
E. coli comes from human and animal wastes. During rainfalls, snow melts, or other types of precipitation, *E. coli* may be washed into creeks, rivers, streams, lakes, or groundwater. When these waters are used as sources of drinking water and the water is not treated or inadequately treated, *E. coli* may end up in drinking water.

How is water treated to protect me from *E. coli*?
The water can be treated using chlorine, ultra-violet light, or ozone, all of which act to kill or inactivate *E. coli.* Systems using surface water sources are required to disinfect to ensure that all bacterial contamination such as *E. coli*. is inactivated. Systems using ground water sources are not required to disinfect, although many of them do.

How does the U.S. Environmental Protection Agency regulate *E. coli*?
According to EPA regulations, a system that operates at least 60 days per year, and serves 25 people or more or has 15 or more service connections, is regulated as a public water system under the Safe Drinking Water Act. If a system is not a public water system as defined by EPA regulations, it is not regulated under the Safe Drinking Water Act, although it may be regulated by state or local authorities.

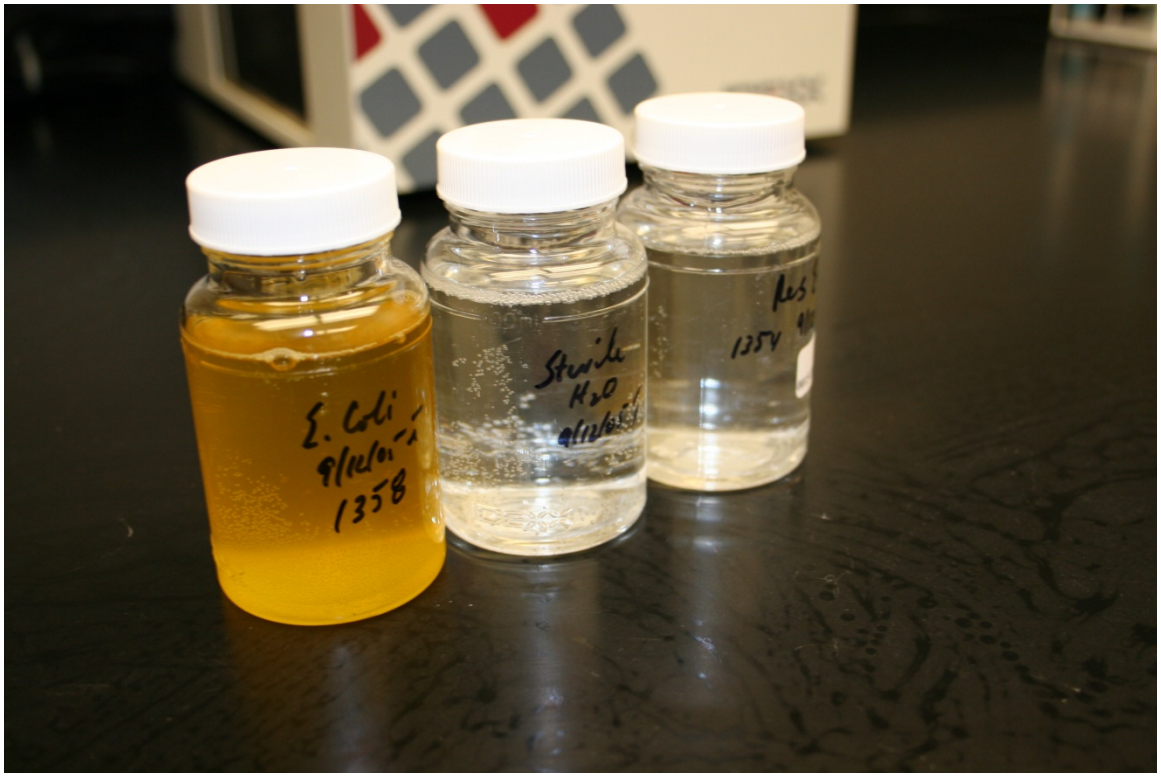
Under the Safe Drinking Water Act, the EPA requires public water systems to monitor for coliform bacteria. Systems analyze first for total coliform, because this test is faster to produce results. Any time that a sample is positive for total coliform, the same sample must be analyzed for either fecal coliform or *E. coli*. Both are indicators of contamination with animal waste or human sewage.

The largest public water systems (serving millions of people) must take at least 480 samples per month. Smaller systems must take at least five samples a month unless the state has conducted a sanitary survey – a survey in which a state inspector examines system components and ensures they will protect public health – at the system within the last five years.

Systems serving 25 to 1,000 people typically take one sample per month. Some states reduce this frequency to quarterly for ground water systems if a recent sanitary survey shows that the system is free of sanitary defects. Some types of systems can qualify for annual monitoring. Systems using surface water, rather than ground water, are required to take extra steps to protect against bacterial contamination because surface water sources are more vulnerable to such contamination. At a minimum, all systems using surface waters must disinfect. Disinfection will kill *E. coli* O157:H7.

What can I do to protect myself from *E. coli* O157:H7 in drinking water?
Approximately 89 percent of Americans are receiving water from community water systems that meet all health-based standards. Your public water system is required to notify you if, for any reason, your drinking water is not safe. If you wish to take extra precautions, you can boil your water for one minute at a rolling boil, longer at higher altitudes. To find out more information about your water, see the Consumer Confidence Report from your local water supplier or contact your local water supplier directly. You can also obtain information about your local water system on the EPA's website at www.epa.gov/safewater/dwinfo.htm.

Positive Tests
If you draw water from a private well, you can contact your state health department to obtain information on how to have your well tested for total coliforms, and *E. coli* contamination. If your well tests positive for *E. coli*, there are several steps that you should take: (1) begin boiling all water intended for consumption, (2) disinfect the well according to procedures recommended by your local health department, and (3) monitor your water quality to make certain that the problem does not recur. If the contamination is a recurring problem, you should investigate the feasibility of drilling a new well or install a point-of-entry disinfection unit, which can use chlorine, ultraviolet light, or ozone.

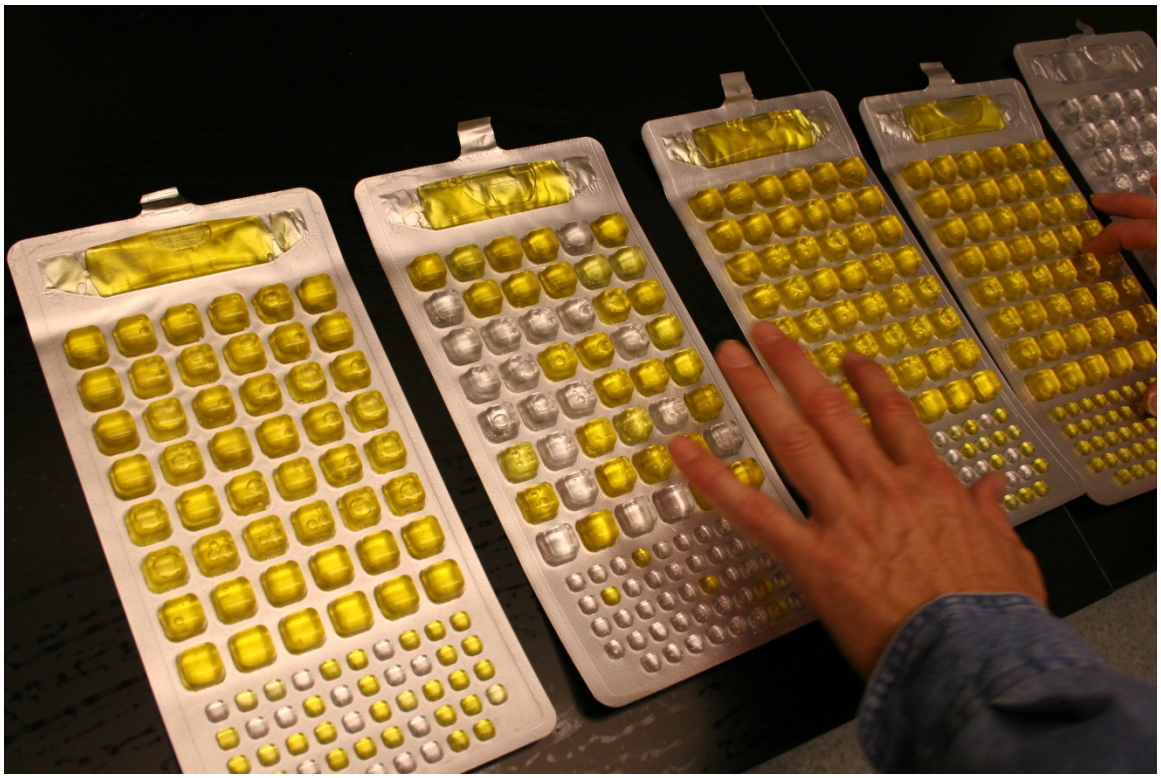


How is *E. coli* O157:H7 spread?
The organism can be found on a small number of cattle farms and can live in the intestines of healthy cattle. Meat can become contaminated during slaughter, and organisms can be thoroughly mixed into beef when it is ground. Bacteria present on a cow's udders or on equipment may get into raw milk. Eating meat, especially ground beef that has not been cooked sufficiently to kill *E. coli* O157:H7 can cause infection. Contaminated meat looks and smells normal. Although the number of organisms required to cause disease is not known, it is suspected to be very small.

Among other known sources of infection are consumption of sprouts, lettuce, salami, unpasteurized milk and juice, and swimming in or drinking sewage-contaminated water. Bacteria in diarrheal stools of infected persons can be passed from one person to another if hygiene or hand washing habits are inadequate. This is particularly likely among toddlers who are not toilet trained. Family members and playmates of these children are at high risk of becoming infected. Young children typically shed the organism in their feces for a week or two after their illness resolves. Older children rarely carry the organism without symptoms.

What illness does *E. coli* O157:H7 cause?
E. coli O157:H7 infection often causes severe bloody diarrhea and abdominal cramps; sometimes the infection causes non-bloody diarrhea or no symptoms. Usually little or no fever is present, and the illness resolves in 5 to 10 days. Hemorrhagic colitis is the name of the acute disease caused by *E. coli* O157:H7.

In some persons, particularly children under 5 years of age and the elderly, the infection can also cause a complication called hemolytic uremic syndrome, in which the red blood cells are destroyed and the kidneys fail. About 2%-7% of infections lead to this complication. In the United States, hemolytic uremic syndrome is the principal cause of acute kidney failure in children, and most cases of hemolytic uremic syndrome are caused by *E. coli* O157:H7.



How is *E. coli* O157:H7 infection diagnosed?
Infection with *E. coli* O157:H7 is diagnosed by detecting the bacterium in the stool. Most laboratories that culture stool do not test for *E. coli* O157:H7, so it is important to request that the stool specimen be tested on sorbitol-MacConkey (SMAC) agar for this organism. All persons who suddenly have diarrhea with blood should get their stool tested for *E. coli* O157:H7.

How is the illness treated?
Most persons recover without antibiotics or other specific treatment in 5-10 days. There is no evidence that antibiotics improve the course of disease, and it is thought that treatment with some antibiotics may precipitate kidney complications. Antidiarrheal agents, such as loperamide (Imodium), should also be avoided. Hemolytic uremic syndrome is a life-threatening condition usually treated in an intensive care unit. Blood transfusions and kidney dialysis are often required. With intensive care, the death rate for hemolytic uremic syndrome is 3%-5%.

Legionnaires' Disease Legionella Section

Introduction **Genus: *Legionella* Species: *pneumophila***

The first discovery of bacteria from genus Legionella came in 1976 when an outbreak of pneumonia at an American Legion convention led to 29 deaths. The causative agent, what would come to be known as Legionella pneumophila, was isolated and given its own genus. The organisms classified in this genus are Gram-negative bacteria that are considered intracellular parasites. The disease has two distinct forms:



- Legionnaires' disease, the more severe form of infection which includes pneumonia, and
- Pontiac fever, a milder illness.

What have been the water sources for Legionnaires' disease?
The major source is water distribution systems of large buildings, including hotels and hospitals. Cooling towers have long been thought to be a major source for *Legionella*, but new data suggest that this is an overemphasized mode of transmission. Other sources include mist machines, humidifiers, whirlpool spas, and hot springs. Air conditioners are not a source for Legionnaires' disease. They were suspected to be the source in the original American Legion outbreak in a Philadelphia hotel, but new data now suggests that the water in the hotel was the actual culprit.



Legionnaire's disease is caused most commonly by the inhalation of small droplets of water or fine aerosol containing Legionella bacteria. Legionella bacteria are naturally found in environmental water sources such as rivers, lakes and ponds and may colonize man-made water systems that include air conditioning systems, humidifiers, cooling tower waters, hot water systems, spas and pools.

How do people contract Legionella?
The most popular theory is that the organism is aerosolized in water and people inhale the droplets containing *Legionella*. However, new evidence suggests that another way of contracting *Legionella* is more common. "Aspiration" is the most common way that bacteria enter into the lungs to cause pneumonia. Aspiration means choking such that secretions in the mouth get past the choking reflexes and instead of going into the esophagus and stomach, mistakenly, enter the lung. The protective mechanisms to prevent aspiration is defective in patients who smoke or have lung disease. Aspiration now appears to be the most common mode of transmission.

Legionella may multiply to high numbers in cooling towers, evaporative condensers, air washers, humidifiers, hot water heaters, spas, fountains, and plumbing fixtures. Within one month, Legionella can multiply, in warm water-containing systems, from less than 10 per milliliter to over 1,000 per milliliter of water. Once high numbers of Legionella have been found, a relatively simple procedure for disinfecting water systems with chlorine and detergent is available. This procedure is not part of a routine maintenance program because equipment may become corroded.

Property owners have been sued for the spread of Legionella, resulting in expensive settlements. Regular monitoring with a battery of DFA monoclonal antibodies for several serogroups and species of Legionella morphologically intact bacteria provides a means for exercising 'reasonable care' to deter potential litigation.

Currently, there are no United States government regulations concerning permissible numbers of legionella in water systems and there are no federal or state certification programs for laboratories that perform legionella testing of environmental samples.

Epifluorescence Microscopy DFA Method
The epifluorescence microscopy DFA method that most labs use was published in the British Journal, Water Research 19:839-848, 1985 "Disinfection of circulating water systems by ultraviolet light and halogenation", R. Gilpin, et al. so we can count viable-but-nonculturable (VBNC) legionella.

Most labs will provide a quantitative epifluorescence microscopic analysis of your cooling tower and potable water samples for 14 serogroups of Legionella pneumophila and 15 other Legionella species (listed below).

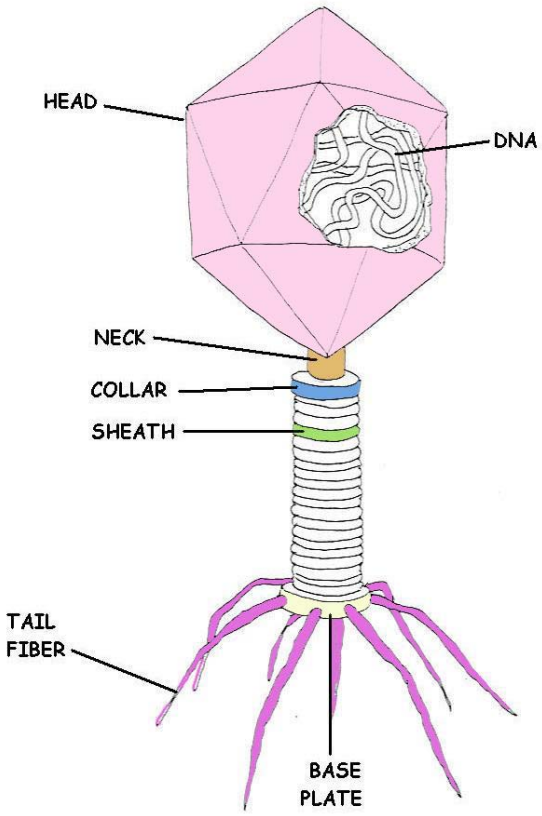
Legionella anisa	*Legionella bozemanii* sg 1 & 2
Legionella dumoffi	*Legionella feeleii* sg 1 & 2
Legionella gormanii	*Legionella hackeliae* sg 1 & 2
Legionella jordanis	*Legionella longbeachae* sg 1& 2
Legionella maceachernii	*Legionella micdadei*
Legionella oakridgensis	*Legionella parisiensis*
Legionella pneumophila sg 1-14	*Legionella sainthelensi*
Legionella santicrucis	*Legionella wadsworthii*

Heterotrophic bacterial CFU are often inversely proportional to numbers of Legionella in cooling tower samples, in our experience. Routine biocide treatments will not eradicate Legionella bacteria in the environment, only in laboratory studies.

Culture methods are good during outbreaks for bio-typing; but culture methods lack sensitivity for routine, quantitative monitoring. Many factors will inhibit growth or identification of legionella on BCYE with or without antimicrobial agents, heat or acid treatment.

Culture methods will not identify non-culturable legionella that can still cause outbreaks (non-culturable, viable legionella have been reported in several peer-reviewed journals). Only DFA tests performed by trained laboratory personnel can identify these legionella. Direct fluorescent antibody (DFA) tests using a battery of monoclonal antibodies provide more useful routine monitoring information than culture methods. Legionella species of bacteria cause Legionnaire's disease. They are gram negative (but stain poorly), strictly aerobic rods.

The U.S. Environmental Protection Agency and the U.S. Occupational Safety and Health Administration recommend routine maintenance of water-containing equipment. Most State health departments recommend monthly testing for Legionella as part of a routine maintenance program.



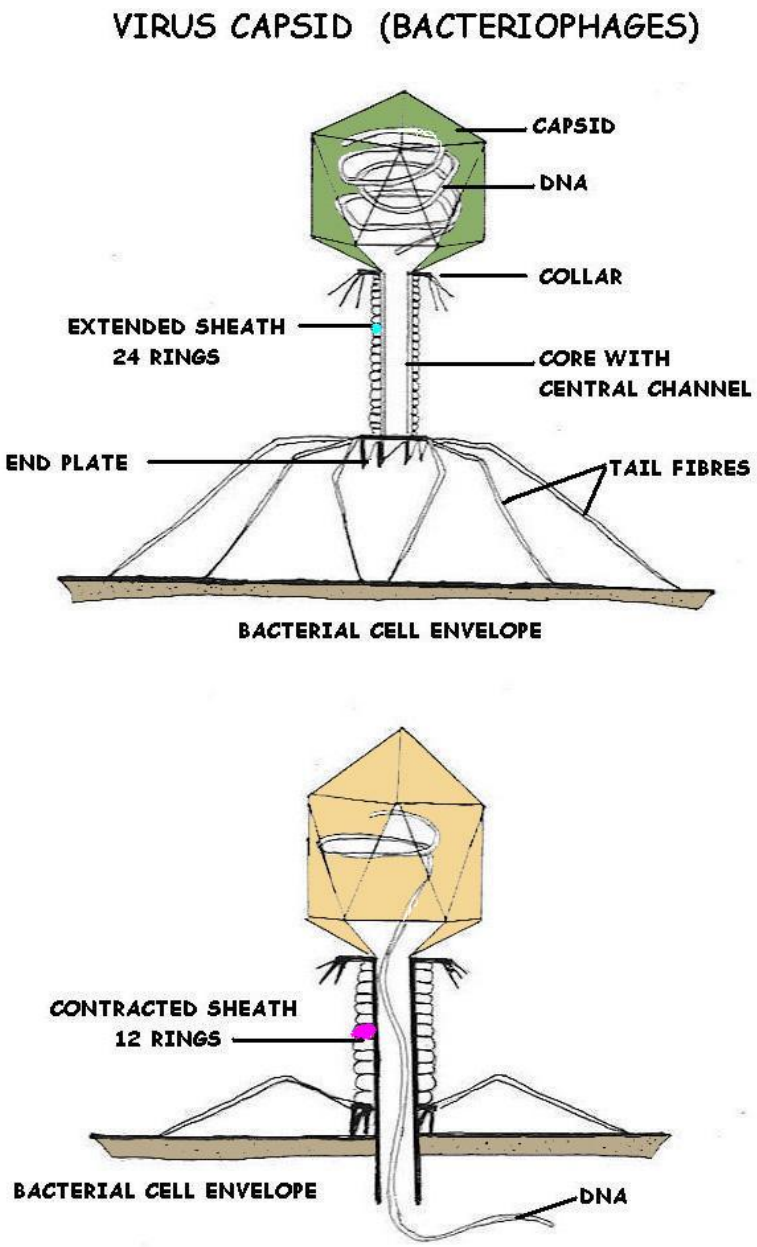
BACTERIOPHAGE

Bacteriophage

A bacteriophage (from 'bacteria' and Greek phagein, 'to eat') is any one of a number of viruses that infect bacteria. The term is commonly used in its shortened form, phage.

Typically, bacteriophages consist of an outer protein hull enclosing genetic material. The genetic material can be ssRNA (single stranded RNA), dsRNA, ssDNA, or dsDNA between 5 and 500 kilo base pairs long with either circular or linear arrangement. Bacteriophages are much smaller than the bacteria they destroy - usually between 20 and 200 nm in size.

Phages are estimated to be the most widely distributed and diverse entities in the biosphere. Phages are ubiquitous and can be found in all reservoirs populated by bacterial hosts, such as soil or the intestine of animals. One of the densest natural sources for phages and other viruses is sea water, where up to 9×108 virions per milliliter have been found in microbial mats at the surface, and up to 70% of marine bacteria may be infected by phages.

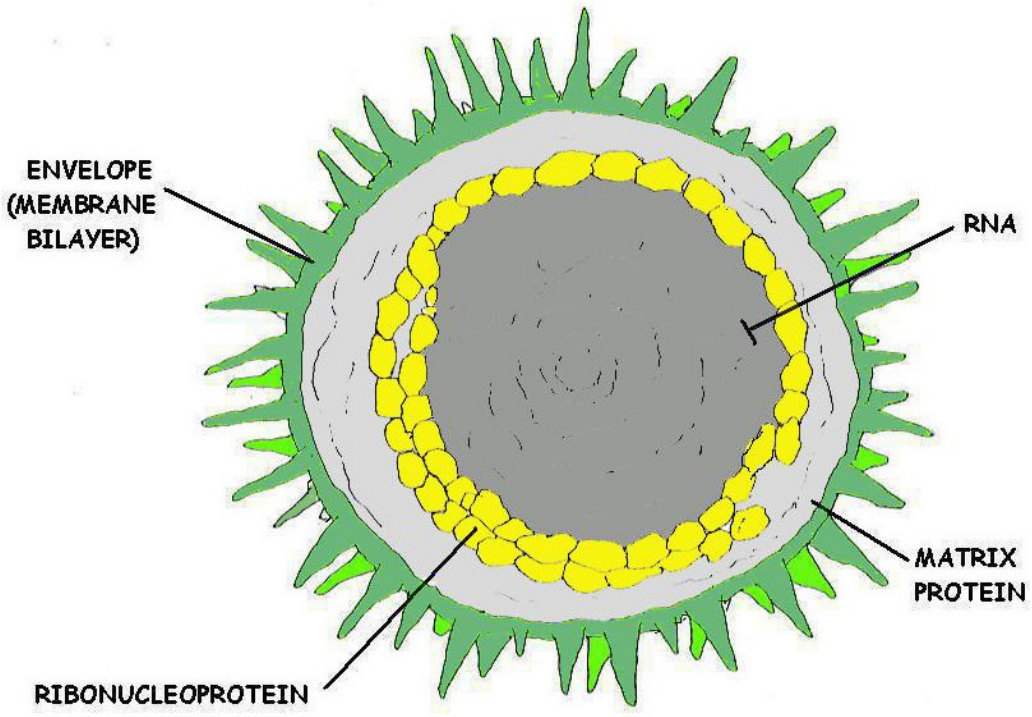


Release of Virions

Phages may be released via cell lysis or by host cell secretion. In the case of the T4 phage, in just over twenty minutes after injection upwards of three hundred phages will be released via lysis within a certain timescale. This is achieved by an enzyme called endolysin which attacks and breaks down the peptidoglycan. In contrast, "lysogenic" phages do not kill the host but rather become long-term parasites and make the host cell continually secrete more new virus particles. The new virions bud off the plasma membrane, taking a portion of it with them to become enveloped viruses possessing a viral envelope. All released virions are capable of infecting a new bacterium.

Viruses

Viruses are acellular microorganisms. They are made up of only genetic material and a protein coat. Viruses depend on the energy and metabolic machinery of the host cell to reproduce. A virus is an infectious agent found in virtually all life forms, including humans, animals, plants, fungi, and bacteria. Viruses consist of genetic material—either deoxyribonucleic acid (DNA) or ribonucleic acid (RNA)—surrounded by a protective coating of protein, called a capsid, with or without an outer lipid envelope. Viruses are between 20 and 100 times smaller than bacteria and hence are too small to be seen by light microscopy.



CROSS SECTIONAL VIEW

Viruses vary in size from the largest poxviruses of about 450 nanometers (about 0.000014 in) in length to the smallest polioviruses of about 30 nanometers (about 0.000001 in). Viruses are not considered free-living, since they cannot reproduce outside of a living cell; they have evolved to transmit their genetic information from one cell to another for the purpose of replication. Viruses often damage or kill the cells that they infect, causing disease in infected organisms. A few viruses stimulate cells to grow uncontrollably and produce cancers. Although many infectious diseases, such as the common cold, are caused by viruses, there are no cures for these illnesses. The difficulty in developing antiviral therapies stems from the large number of variant viruses that can cause the same disease, as well as the inability of drugs to disable a virus without disabling healthy cells. However, the development of antiviral agents is a major focus of current research, and the study of viruses has led to many discoveries important to human health.

Virions
Individual viruses, or virus particles, also called virions, contain genetic material, or genomes, in one of several forms. Unlike cellular organisms, in which the genes always are made up of DNA, viral genes may consist of either DNA or RNA. Like cell DNA, almost all viral DNA is double-stranded, and it can have either a circular or a linear arrangement. Almost all viral RNA is single-stranded; it is usually linear, and it may be either segmented (with different genes on different RNA molecules) or non-segmented (with all genes on a single piece of RNA).

Capsids
The viral protective shell, or capsid, can be either helical (spiral-shaped) or icosahedral (having 20 triangular sides). Capsids are composed of repeating units of one or a few different proteins. These units are called protomers or capsomers. The proteins that make up the virus particle are called structural proteins. Viruses also carry genes for making proteins that are never incorporated into the virus particle and are found only in infected cells. These viral proteins are called nonstructural proteins; they include factors required for the replication of the viral genome and the production of the virus particle.

Capsids and the genetic material (DNA or RNA) they contain are together referred to as nucleocapsids. Some virus particles consist only of nucleocapsids, while others contain additional structures.

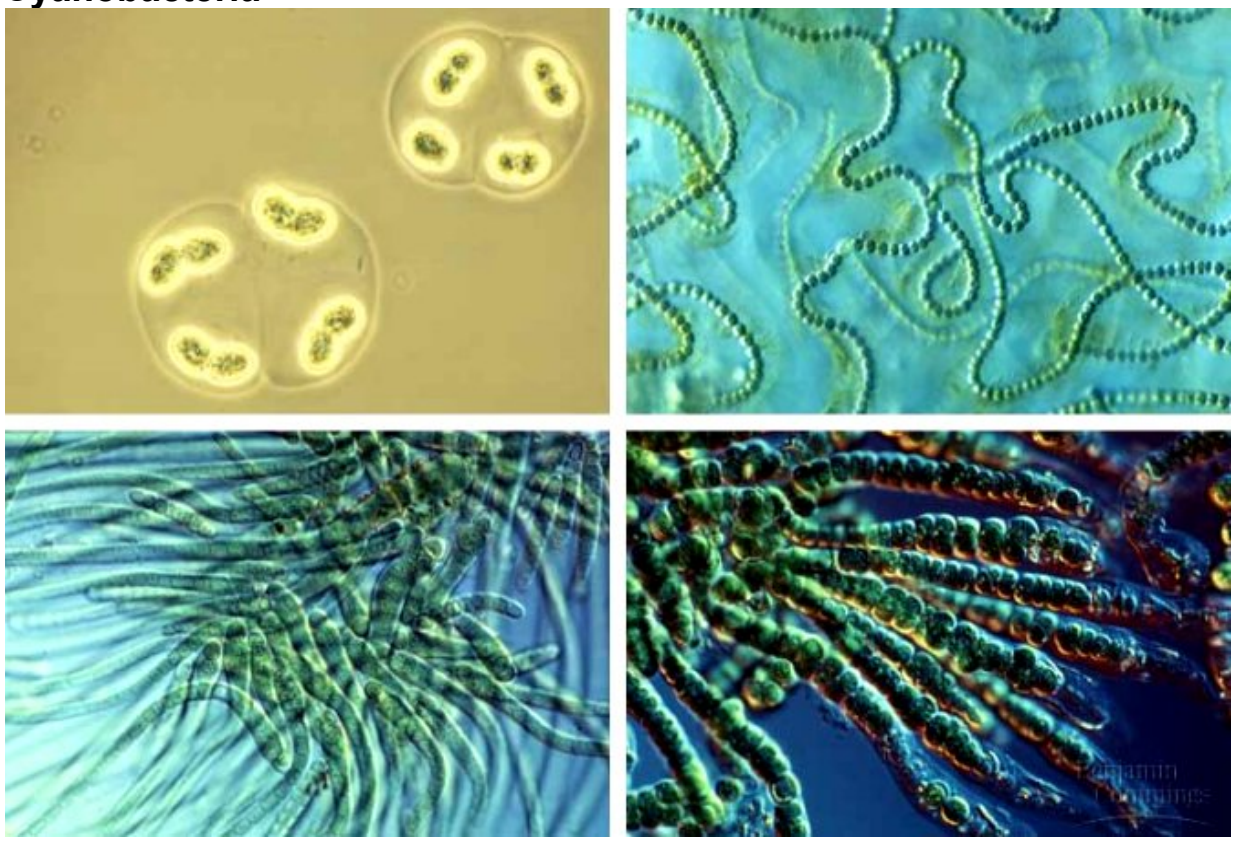
Some icosahedral and helical animal viruses are enclosed in a lipid envelope acquired when the virus buds through host-cell membranes. Inserted into this envelope are glycoproteins that the viral genome directs the cell to make; these molecules bind virus particles to susceptible host cells.

Bacteriophages
The most elaborate viruses are the bacteriophages, which use bacteria as their hosts. Some bacteriophages resemble an insect with an icosahedral head attached to a tubular sheath. From the base of the sheath extend several long tail fibers that help the virus attach to the bacterium and inject its DNA to be replicated, direct capsid production, and virus particle assembly inside the cell.

Viroids and Prions
Viroids and prions are smaller than viruses, but they are similarly associated with disease. Viroids are plant pathogens that consist only of a circular, independently replicating RNA molecule. The single-stranded RNA circle collapses on itself to form a rod-like structure. The only known mammalian pathogen that resembles plant viroids is the deltavirus (hepatitis D), which requires hepatitis B virus proteins to package its RNA into virus particles. Co-infection with hepatitis B and D can produce more severe disease than can infection with hepatitis B alone. Prions are mutated forms of a normal protein found on the surface of certain animal cells.

Virus Classification
Viruses are classified according to their type of genetic material, their strategy of replication, and their structure. The International Committee on Nomenclature of Viruses (ICNV), established in 1966, devised a scheme to group viruses into families, subfamilies, genera, and species. The ICNV report published in 1995 assigned more than 4000 viruses into 71 virus families. Hundreds of other viruses remain unclassified because of the lack of sufficient information.

Cyanobacteria



Cyanobacteria

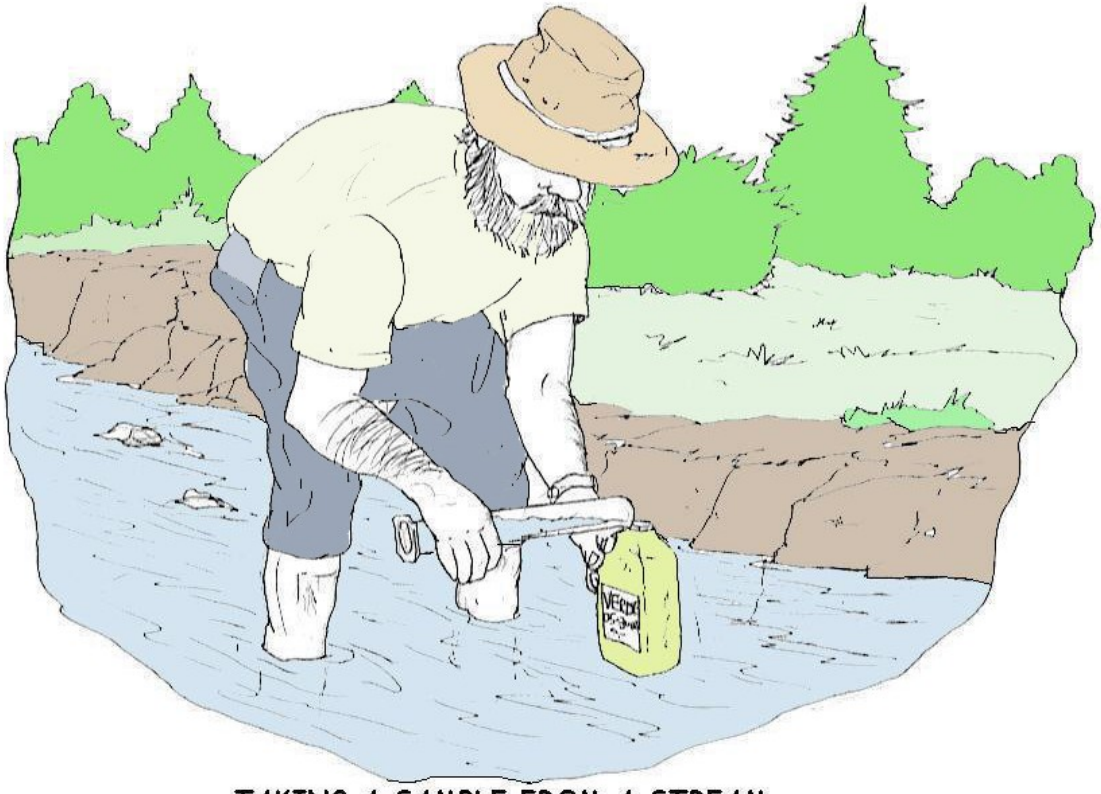
Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta, is a phylum of bacteria that obtain their energy through photosynthesis. The name "cyanobacteria" comes from the color of the bacteria (Greek: kyanós = blue). They are a significant component of the marine nitrogen cycle and an important primary producer in many areas of the ocean, but are also found on land.

Cyanobacteria include unicellular and colonial species. Colonies may form filaments, sheets or even hollow balls. Some filamentous colonies show the ability to differentiate into several different cell types: vegetative cells, the normal, photosynthetic cells that are formed under favorable growing conditions; akinetes, the climate-resistant spores that may form when environmental conditions become harsh; and thick-walled heterocysts, which contain the enzyme nitrogenase, vital for nitrogen fixation. Heterocysts may also form under the appropriate environmental conditions (anoxic) wherever nitrogen is necessary. Heterocyst-forming species are specialized for nitrogen fixation and are able to fix nitrogen gas, which cannot be used by plants, into ammonia (NH_3), nitrites (NO_2) or nitrates (NO_3), which can be absorbed by plants and converted to protein and nucleic acids.

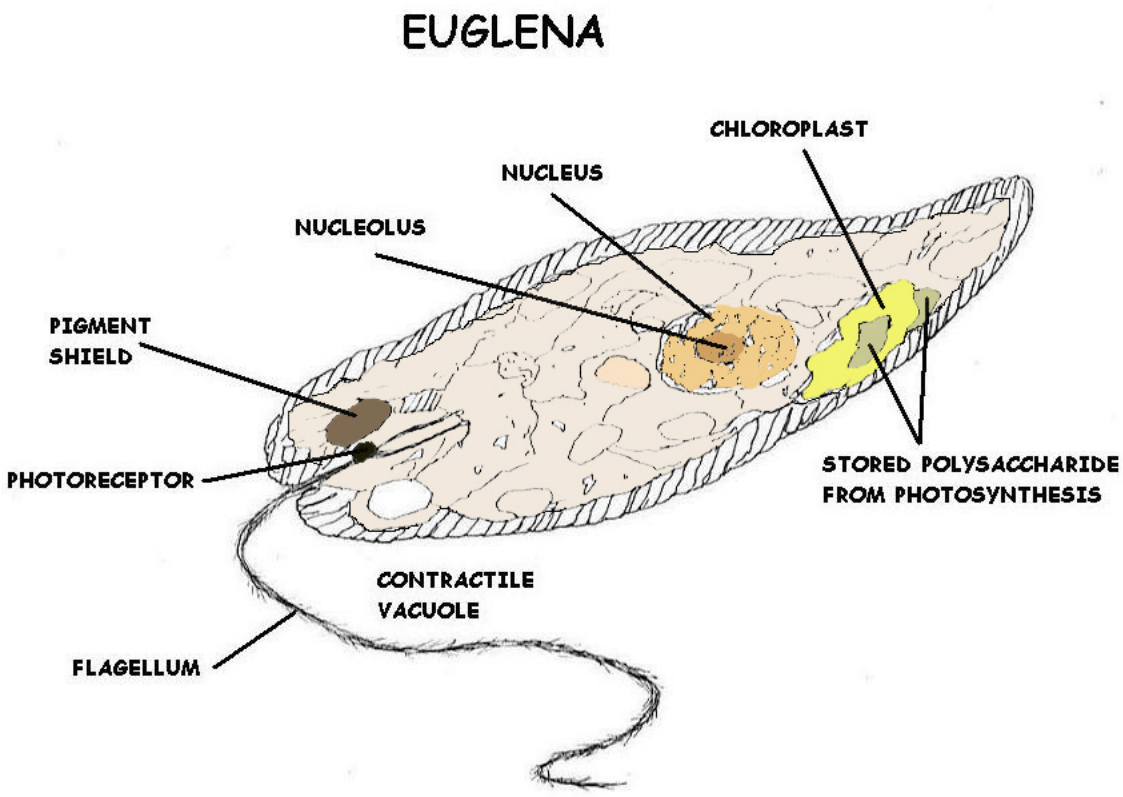
The rice paddies of Asia, which produce about 75% of the world's rice, could not do so were it not for healthy populations of nitrogen-fixing cyanobacteria in the rice paddy fertilizer too.

Many cyanobacteria also form motile filaments, called hormogonia, that travel away from the main biomass to bud and form new colonies elsewhere. The cells in a hormogonium are often thinner than in the vegetative state, and the cells on either end of the motile chain may be tapered. In order to break away from the parent colony, a hormogonium often must tear apart a weaker cell in a filament, called a necridium.

Each individual cell of a cyanobacterium typically has a thick, gelatinous cell wall. They differ from other gram-negative bacteria in that the quorum sensing molecules autoinducer-2[4] and acyl-homoserine lactones are absent. They lack flagella, but hormogonia and some unicellular species may move about by gliding along surfaces. In water columns some cyanobacteria float by forming gas vesicles, like in archaea.



TAKING A SAMPLE FROM A STREAM



Euglena

Euglenas are common protists, of the class Euglenoidea of the phylum Euglenophyta. Currently, over 1000 species of Euglena have been described. Marin et al. (2003) revised the genus so, and including several species without chloroplasts, formerly classified as Astasia and Khawkinea. Euglena sometimes can be considered to have both plant and animal features.

Euglena gracilis has a long hair-like thing that stretches from its body. You need a very powerful microscope to see it. This is called a flagellum, and the euglena uses it to swim. It also has a red eyespot. Euglena gracilis uses its eyespot to locate light. Without light, it cannot use its chloroplasts to make itself food. In order for Euglena gracilis to make more Euglena gracilis it will complete a process called mitosis. That means it can split itself in half and become two Euglena gracilis. It can only do this if it is well-fed and if the temperature is right. Euglena gracilis can reproduce better in warm temperatures.

Euglena gracilis, and other euglena, are harmless to people, but they are often signs that water is polluted, since they do well where there is a lot of green algae to eat. Green algae does well where there is a lot of nitrogen (comes from waste) in the water. If you don't clean your swimming pool, leaves and twigs get in the water and turn into waste. Then algae and euglena show up.

KINGDOM: Protist, PHYLUM: Euglenophyta, CLASS: Euglenophyceae, ORDER: Euglenales, FAMILY: Euglenidae, GENUS: Euglena, SPECIES: Euglena gracilis

Peptidoglycan

Peptidoglycan, also known as murein, is a polymer consisting of sugars and amino acids that forms a mesh-like layer outside the plasma membrane of eubacteria. The sugar component consists of alternating residues of β-(1,4) linked N-acetylglucosamine and N-acetylmuramic acid residues. Attached to the N-acetylmuramic acid is a peptide chain of three to five amino acids. The peptide chain can be cross-linked to the peptide chain of another strand forming the 3D mesh-like layer.



Hepatitis



There are five types of hepatitis -- A through E -- all of which cause inflammation of the liver. Type D affects only those who also have hepatitis B, and hepatitis E is extremely rare in the United States.

- Type A hepatitis is contracted through anal-oral contact, by coming in contact with the feces of someone with hepatitis A, or by eating or drinking hepatitis A contaminated food or water.
- Type B hepatitis can be contracted from infected blood, seminal fluid, vaginal secretions, or contaminated drug needles, including tattoo or body-piercing equipment. It can also be spread from a mother to her newborn.
- Type C hepatitis is not easily spread through sex. You're more likely to get it through contact with infected blood, contaminated razors, needles, tattoo and body-piercing equipment, or manicure or pedicure tools that haven't been properly sanitized, and a mother can pass it to her baby during delivery.
- Type D hepatitis can be passed through contact with infected blood, contaminated needles, or by sexual contact with an HIV-infected person.
- Type E hepatitis is most likely to be transmitted in feces, through oral contact, or in water that's been contaminated.


MIKE ROBES' ICE CREAM
BOMBS

Math Conversion Factors and Practical Exercise

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
2.54 CM =Inch
1 Gallon of Water = 8.34 Pounds
1 mg/L = 1 PPM
17.1 mg/L = 1 Grain/Gallon
1% = 10,000 mg/L
694 Gallons per Minute = MGD
1.55 Cubic Feet per Second = 1 MGD
60 Seconds = 1 Minute
1440 Minutes = 1 Day
.746 kW = 1 Horsepower

LENGTH
12 Inches = 1 Foot
3 Feet = 1 Yard
5280 Feet = 1 Mile

AREA
144 Square Inches = 1 Square Foot
43,560 Square Feet =1 Acre

VOLUME
1000 Milliliters = 1 Liter
3.785 Liters = 1 Gallon
231 Cubic Inches = 1 Gallon
7.48 Gallons = 1 Cubic Foot of water
62.38 Pounds = 1 Cubic Foot of water

Dimensions

SQUARE: Area (sq.ft.) = Length X Width
Volume (cu.ft.) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq.ft.) = 3.14 X Radius (ft) X Radius (ft)

CYLINDER: Volume (Cu. ft) = 3.14 X Radius (ft) X Radius (ft) X Depth (ft)

PIPE VOLUME: .785 X Diameter ^{2} X Length = ? To obtain gallons multiply by 7.48

SPHERE: $\frac{(3.14)\ (\text{Diameter})^3}{(6)}$ Circumference = 3.14 X Diameter

General Conversions

Flowrate

Multiply	—>	to get
to get	<—	Divide
cc/min	1	mL/min
cfm (ft^3/min)	28.31	L/min
cfm (ft^3/min)	1.699	m^3/hr
cfh (ft^3/hr)	472	mL/min
cfh (ft^3/hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m^3/hr
GPM	3.785	L/min
oz/min	29.57	mL/min



POUNDS PER DAY= Concentration (mg/L) X Flow (MG) X 8.34
A.K.A. **Solids Applied Formula** = Flow X Dose X 8.34 ***Professor Rusty's Favorite Math Formula***

PERCENT EFFICIENCY = $\frac{\text{In} - \text{Out}}{\text{In}} \times 100$

TEMPERATURE: $^0F = (^0C \times 9/5) + 32$ 9/5 =1.8
$^0C = (^0F - 32) \times 5/9$ 5/9 = .555

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): Q = A X V (**Q**uantity = **A**rea X **V**elocity)

FLOW RATE (gpm): Flow Rate (gpm) = $\frac{2.83 (\text{Diameter, in})^2 (\text{Distance, in})}{\text{Height, in}}$

% SLOPE = $\frac{\text{Rise (feet)}}{\text{Run (feet)}} \times 100$

ACTUAL LEAKAGE = $\frac{\text{Leak Rate (GPD)}}{\text{Length (mi.) X Diameter (in)}}$

VELOCITY = $\frac{\text{Distance (ft)}}{\text{Time (Sec)}}$

N = Manning's Coefficient of Roughness
R = Hydraulic Radius (ft.)
S = Slope of Sewer (ft/ft.)

HYDRAULIC RADIUS (ft) = $\frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$

WATER HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960}$

BRAKE HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960 \text{ X Pump Efficiency}}$

MOTOR HORSEPOWER = $\frac{\text{Flow (gpm) X Head (ft)}}{3960 \text{ X Pump Eff. X Motor Eff.}}$

MEAN OR AVERAGE = $\frac{\text{Sum of the Values}}{\text{Number of Values}}$

TOTAL HEAD (ft) = Suction Lift (ft) X Discharge Head (ft)

SURFACE LOADING RATE = $\frac{\text{Flow Rate (gpm)}}{\text{Surface Area (sq. ft)}}$ (gal/min/sq.ft)

MIXTURE STRENGTH (%) = $\frac{\text{(Volume 1, gal) (Strength 1, \%) + (Volume 2, gal) (Strength 2,\%)}}{\text{(Volume 1, gal) + (Volume 2, gal)}}$

INJURY FREQUENCY RATE = $\frac{\text{(Number of Injuries) 1,000,000}}{\text{Number of hours worked per year}}$

DETENTION TIME (hrs) = $\frac{\text{Volume of Basin (gals) X 24 hrs}}{\text{Flow (GPD)}}$

SLOPE = Rise (ft) / Run (ft)

SLOPE (%) = Rise (ft) X 100 / Run (ft)

POPULATION EQUIVALENT (PE):

1 PE = .17 Pounds of BOD per Day
1 PE = .20 Pounds of Solids per Day
1 PE = 100 Gallons per Day

LEAKAGE (GPD/inch) = Leakage of Water per Day (GPD) / Sewer Diameter (inch)

CHLORINE DEMAND (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

τQ = Allowable time for decrease in pressure from 3.5 PSU to 2.5 PSI
τq = As below

$\tau Q = (0.022)\ (d_1^2 L_1)/Q$ $\quad \tau q = [\ 0.085]\ [(d_1^2 L1)/(d_1 L_1)]$ / q

Q = 2.0 cfm air loss
θ = .0030 cfm air loss per square foot of internal pipe surface
δ = Pipe diameter (inches)
L = Pipe Length (feet)

$V = \frac{1.486}{\nu} R^{2/3} S^{1/2}$

V = Velocity (ft./sec.)
ν = Pipe Roughness
R = Hydraulic Radius (ft)
S= Slope (ft/ft)

HYDRAULIC RADIUS (ft) = Flow Area (ft. 2) / Wetted Perimeter (ft.)

WIDTH OF TRENCH (ft) = Base (ft) + (2 Sides) X Depth (ft 2) / Slope



Professor Melissa explaining math formulas.

Scratch Paper

Volume in Cubic Feet

Cube Formula
V= (L) (W) (D)
Volume= Length X Width X Depth

Cylinder Formula
V= (.785) (D^2) (d)

Build it, Fill it and Dose it.

1. Convert 10 cubic feet to gallons of water?

There is 7.48 gallons in one cubic foot.

2. A tank weighs 800 pounds, how many gallons are in the tank?

3. Convert a flow rate of 953 gallons per minute to million gallons per day.
There is 1440 minutes in a day.

4. Convert a flow rate of 610 gallons per minute to millions of gallons per day.

5. Convert a flow of 550 gallons per minute to gallons per second.

6. Now, convert this number to liters per second.

7. A tank is 6' X 15' x 7' and can hold a maximum of _____ gallons of water.
V= (L) (W) (D) X 7.48 =

8. A tank is 25' X 75' X 10', what is the volume of water in gallons?
V= (L) (W) (D) X 7.48 =

9. In Liters?
V= (L) (W) (D) X 7.48 =_____ X 3.785

10. A tank holds 67,320 gallons of water. The length is 60' and the width is 15'. How deep is the tank?

Gallons_____ ÷ 7.48 = _____ 60 X 15 =

11. The diameter of a tank is 60' and the depth is 25'. How many gallons does it hold?

Cylinder Formula
$V= (.785) (D^2) (d)$

.785 X 60' X 60' X 25' X 7.48 =

Cubic Feet Information
There is no universally agreed symbol but the following are used:
cubic feet, cubic foot, cubic ft
cu ft, cu feet, cu foot
ft^3, $feet^3$, $foot^3$
$feet^3$, $foot^3$, ft^3
feet/-3, foot/-3, ft/-3

Water Treatment Production Math Numbering System
In water treatment, we express our production numbers in Million Gallon numbers. Example 2,000,000 or 2 million gallons would be expressed as 2 MG or 2 MGD.
Hints. A million has six zeros; you can always divide your final number by 1,000,000 or move the decimal point to the left six places. Example 528,462 would be expressed .56 MGD.

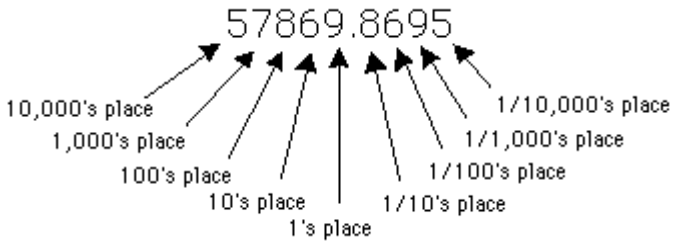
12. The diameter of a tank is 15 Centimeters or cm and the depth is 25 cm, what is the volume in liters?

2.54cm = 1 inch, 12 inches = 1 foot
15 cm ÷ 2.54 cm ÷ 12 inches = .492 feet

.785 X .492' X .492' X _____' =_____ X 7.48 = _____ X 3.785 L =

Percentage and Fractions
Let's look again at the sequence of numbers 1000, 100, 10, 1, and continue the pattern to get new terms by dividing previous terms by 10:

.1 = 1/10
.01 = 1/100
.001 = 1/1000



So just as the digits to the left of the decimal represent 1's, 10's, 100's, and so forth, digits to the right of the decimal point represent 1/10's, 1/100's, 1/1000's, and so forth.

Let's express 5% as a decimal. 5 ÷ 100 = 0.05 or you can move the decimal point to the left two places.

Changing a fraction to a decimal:
Divide the numerator by the denominator

A. 5/10 (five tenths) = five divided by ten:

```
   .5
  ---
10 ) 5.0
   5 0
  ---
```

So 5/10 (five tenths) = .5 (five tenths).

B. How about 1/2 (one half) or 1 divided by 2 ?

```
   .5
  ---
2 ) 1.0
   1 0
  ---
```

So 1/2 (one half) = .5 (five tenths)
Notice that equivalent fractions convert to the same decimal representation.

8/12 is a good example. 8 ÷ 12 =.66666666 or rounded off to .667

How about 6/12 or 6 inches? .5 or half a foot

Flow and Velocity
This depends on measuring the average velocity of flow and the cross-sectional area of the channel and calculating the flow from:
$Q(m^3/s) = A(m^2) \times V(m/s)$

Or

Q = A X V

Q CFM = Cubic Ft, Inches, Yards of time, Sec, Min, Hrs, Days
A = Area, squared Length X Width
V f/m = Inch, Ft, Yards, Per Time, Sec, Min, Ft or Speed
13. A channel is 3 feet wide and has water flowing to a depth of 2.5 feet. If the velocity through the channel is 2 fps or feet per second, what is the cfs flow rate through the channel?
Q = A X V

Q = 7.5 sq. ft. X 2 fps What is Q?
A= 3' X 2.5' = 7.5
V= 2 fps

14. A channel is 40 inches wide and has water flowing to a depth of 1.5 ft. If the velocity of the water is 2.3 fps, what is the cfs flow in the channel? **Q = A X V**
First we must convert 40 inches to feet.
40 ÷ 12" = 3.333 feet

A = 3.333' X 1.5' = 4.999 or round up to 5
V = 2.3 fps
We can round this answer up.

15. A channel is 3 feet wide and has a water flow at a velocity of 1.5 fps. If the flow through the channel is 8.1 cfs, what is the depth of the water?

Q = 8.1 cfs
V = 1.5 fps
A = ?

8.1 ÷1.5 = _____ Total Area

16. The flow through a 6 inch diameter pipe is moving at a velocity of 3 ft/sec. What is the cfs flow rate through the pipeline?

Q =
A = .785 X .5' X .5' =
V = 3 fps

17. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the gpm flow rate through the pipe?

Q = _____ cfs X 60 sec/min X 7.48 = _____ gpm
A = .785 X .667' X .667'
V = 3.4 fps

18. A 6 inch diameter pipe delivers 280 gpm. What is the velocity of flow in the pipe in ft/sec?

Take the water out of the pipe. 280 gpm ÷ 7.48 ÷ 60 sec/min = _____ cfs
Q =
A = .785 X .5' X .5' =
V =

19. A new section of 12 inch diameter pipe is to be disinfected before it is placed in service. If the length is 2000 feet, how many gallons of 5% NaOCl will be need for a dosage of 200 mg/L?

Cylinder Formula
$V= (.785) (D^2) (d)$

.785 X 1' X 1' X 2000' = _____ cu.ft. X 7.48 = _____ ÷ 1,000,000 = _____MG

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal if 100% concentrate. If not, divide the lbs/day by the given %

0.0117436 MG X 200 mg/L X 8.34 =_____ lbs/day ÷ .05 =

20. A section of 6 inch diameter pipe is to be filled with water. The length of the pipe is 1320 feet long. How many kilograms of chlorine will be needed for a chlorine dose of 3 mg/L?

.785 X .5' X .5' X 1320' X 7.48 =_____ Make it MGD

Pounds per day formula = Flow X Dose X 8.34 X 45.4 Grams per pound

21. Determine the chlorinator setting in pounds per 24 hour period to treat a flow of 3.4 MGD with a chlorine dose of 3.35 mg/L?

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal

22. To correct an odor problem, you use chlorine continuously at a dosage of 15 mg/L and a flow rate of 85 GPM. Approximately how much will odor control cost annually if chlorine is $0.17 per pound?

85 gpm X 1440 min/day = _____ gpd ÷ 1,000,000 = _____ MGD

_____ MGD X 15 mg/L X 8.34 lbs/gal X $0.17 per pound X 365 days/year =

23. A wet well measures 8 feet by 10 feet and 3 feet in depth between the high and low levels. A pump empties the wet well between the high and low levels 9 times per hour, 24 hours a day. Neglecting inflow during the pumping cycle, calculate the flow into the pump station in millions of gallons per day (MGD).

Build it, fill it and do what it says, hint: X 9 X 24

24. A sewage treatment plant has a flow of 0.7 MGD and a BOD of 225 mg/L. On the basis of a national average of 0.2 lbs BOD per capita per day, what is the approximate population equivalent of the plant?

25. What is the detention time of a clarifier with a 250,000 gallon capacity if it receives a flow of 3.0 MGD?

DT= Volume in Gallons X 24 Divided by MGD

.25 MG X 24 hrs. ÷ 3.0 MGD =_____ Hours of DT

Always convert gallons to MG

Crazy Math Section

The metric system is known for its simplicity. All units of measurement in the metric system are based on decimals—that is, units that increase or decrease by multiples of ten. A series of Greek decimal prefixes is used to express units of ten or greater; a similar series of Latin decimal prefixes is used to express fractions. For example, *deca* equals ten, *hecto* equals one hundred, *kilo* equals one thousand, *mega* equals one million, *giga* equals one billion, and *tera* equals one trillion. For units below one, *deci* equals one-tenth, *centi* equals one-hundredth, *milli* equals one-thousandth, *micro* equals one-millionth, *nano* equals one-billionth, and *pico* equals one-trillionth.

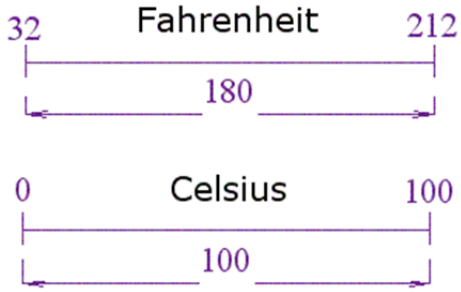
26. How many grams equal 4,500 mg?

Just simply divide by 1,000.

Temperature

There are two main temperature scales. The **Fahrenheit Scale** (used in the US), and the **Celsius Scale** (part of the Metric System, used in most other Countries)
They both measure the same thing (temperature!), just using different numbers.

- If you freeze water, it measures 0° in Celsius, but 32° in Fahrenheit
- If you boil water, it measures 100° in Celsius, but 212° in Fahrenheit
- The difference between freezing and boiling is 100° in Celsius, but 180° in Fahrenheit.



Conversion Method
Looking at the diagram, notice:

- The scales start at a different number (32 vs. 0), so we will need to add or subtract 32
- The scales rise at a different rate (180 vs. 100), so we will also need to multiply

And this is how it works out:

To convert from Celsius to Fahrenheit, first multiply by 180/100, then add 32

To convert from Fahrenheit to Celsius, first subtract 32, then multiply by 100/180

Note: 180/100 can be simplified to **9/5**, and likewise 100/180=**5/9**.
$^0F = (^0C \times 9/5) + 32$ 9/5 =1.8

$^0C = (^0F - 32) \times 5/9$ 5/9 = .555

27. Convert 20 degrees Celsius to degrees Fahrenheit.

$20^\circ \times 1.8 + 32 = F$

28. Convert 4 degrees Celsius to degrees Fahrenheit.

$4^\circ \times 1.8 + 32 = F$

Water Treatment Filters

29. A 19 foot wide by 31 foot long rapid sand filter treats a flow of 2,050 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

GPM ÷ Square Feet

30. A 26 foot wide by 36 foot wide long rapid sand filter treats a flow of 2,500 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

Chemical Dose

31. A pond has a surface area of 51,500 square feet and the desired dose of a chemical is 6.5 lbs per acre. How many pounds of the chemical will be needed?

43,560 Square feet in an acre

51,500 ÷ 43,560 = _____ X 6.5 =

32. A pond having a volume of 6.85 acre feet equals how many millions of gallons?

33. Alum is added in a treatment plant process at a concentration of 10.5 mg/L. What should the setting on the feeder be in pounds per day if the plant is treating 3.5 MGD?

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal

Q=AV Review

34. An 8 inch diameter pipe has water flowing at a velocity of 3.4 fps. What is the GPM flow rate through the pipe?
Q = 1.18 CFS x 60 Seconds x 7.48 GAL/CU.FT = 532 GPM
A = .785 X .667 X .667 X 1 = .349 Sq. Ft.
V= 3.4 Feet per second

35. A 6 inch diameter pipe delivers 280 GPM. What is the velocity of flow in the pipe in Ft/Sec?
280 GPM ÷ 60 seconds in a minute ÷ 7.48 gallons in a cu.ft. = .623 CFS

Q = .623
A = .785 X.5 X .5 =.196 Sq. Ft.
V = 3.17 Ft/Second

Collections

36. A 24-inch sewer carries an average daily flow of 5 MGD. If the average daily flow per person from the area served is 110 GPCD (gallons per capita per day), approximately how many people discharge into the wastewater collection system?

5,000,000 divided by 110 =

37. Using a dose rate of 5 mg/L, how many pounds of chlorine per day should be used if the flow rate is 1.2 MGD?

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal

38. What capacity blower will be required to ventilate a manhole which is 3.5 feet in diameter and 17 feet deep? The air exchange rate is 16 air changes per hour.
.785 X 3.5' X 3.5' X 17' X 16 = _____ CFH

39. Approximately how many feet of drop are in 455 feet of 8-inch sewer with a 0.0475 ft/ft. slope?

SLOPE = $\frac{\text{Rise (ft)}}{\text{Run (ft)}}$ **SLOPE (%)** = $\frac{\text{Rise (ft) X 100}}{\text{Run (ft)}}$

455' X 0.0475 =

40. How much brake horsepower is required to meet the following conditions: 250 gpm, total head = 110 feet? The submersible pump that is being specified is a combined 64% efficient.

(250 X 110) ÷ (3960 X .64)

41. How wide is a trench at ground surface if a sewer trench is 2 feet wide at the bottom, 10 feet deep and the sides have been sloped at a 4/5 horizontal to 1 vertical (3/4:1) ratio?

(3/4:1) or 3 ÷ 4 = .75 X every foot of depth

42. A float arrives in a manhole 550 feet down stream three minutes and thirty seconds from its release point. What is the velocity in ft/sec.?
Velocity ft/sec = distance ÷ time

550' ÷ 3 **min stop convert min to sec. 3 X 60 = 180 + 30 = 210 sec**
550' ÷ 210 sec = _____ fps

43. A new sewer line plan calls out a 0.6% slope of the line. An elevation reading of 108.8 feet at the manhole discharge and an elevation of 106.2 feet at a distance of 200 feet from the manhole are recorded. What is the existing slope of the line that has been installed?

SLOPE = Rise (ft) / Run (ft)

SLOPE (%) = Rise (ft) X 100 / Run (ft)

44. A triangular pile of spoil is 12 feet high and 14 feet wide at the base. The pile is 75' long. If the dump truck hauls 9 cubic yards of dirt, how many truck loads will it take to remove all of the spoil?

Given the base and the height of a triangle, we can find the area. Given the area and either the base or the height of a triangle, we can find the other dimension. The formula for area of a triangle is:

$A = \frac{1}{2} \cdot b \cdot h$ Or $A = \frac{b \cdot h}{2}$ where b is the base, h is the height.

14' X 12' ÷ 2 X 75' = _____ cuft (27cuft/cuyrd)

45. A red dye is poured into an upstream manhole connected to a 12 inch sewer. The dye first appears in a manhole 400 feet downstream 3 minutes later. After 3 minutes and 40 seconds the dye disappears. Estimate the flow velocity in feet per second?

Velocity ft/sec = distance ÷ time
Make sure and convert time and average it.

46. Calculate the total dosage in pounds of a chemical. Assume the sewer is completely filled with the concentration. Pipe diameter: 18 inches, Pipe length: 420 feet, Dose: 120 mg/L.

Figure out the volume first.

.785 X 1.5' X 1.5' X 420' X 7.48 =_____ convert to MG

Pounds per day formula = Flow (MGD) X Dose (mg/L) X 8.34 lbs/gal

Answers

1. 7.48 X 10 = 74.8
2. 800 ÷ 8.34 = 95.92 gallons
3. 1372320 or 1.3 MGD
4. 610 X 1441 = 878400 or 0.87 MGD
5. 550 ÷ 60 = 9.167 gpm
6. 9.167 X 3.785 = 34.695 Liters
7. 630 Area 4712 gallons
8. 18,750 cu. ft. X 7.48 = 140250 gallons
9. 140250 X 3.785 = 530846 Liters
10. 10 feet deep
11. 528462 or .5 MG
12. 1.166 Gallons X 3.785 = 4.412 Liters
13. 15 cfs
14. 11.49 cfs
15. 1.8'
16. .58875 cfs
17. 533 gpm
18. 3.2 ft/sec
19. 46.9 gal
20. .002 kg
21. 94.9 lbs/day
22. $950.12
23. .387 MG
24. 6567.75
25. 2 hrs
26. 4.5 grams
27. 68° F
28. 39°F
29. 3.48 gpm/sqft
30. 2.67 gpm/sqft
31. 7.68 lbs
32. 2.231 MG
33. 306.495
34. 532 gpm
35. 3.2 fps
36. 45454.5 people
37. 50.04 lbs
38. 2615.6 cfh
39. 21.61 ft
40. 10.85 bhp
41. 17 ft
42. 2.62 fps
43. .013 or 1.3%
44. 26 trucks
45. 2 fps
46. 5.55 lbs

Scratch Paper

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Water Treatment, Second Edition



Water Treatment Summary Exercise (Review)

This is not your final assignment. This is a review of the water treatment material. Answers are in the rear of this section.

The Hydrologic Cycle

The water on the planet today is the same water that has been on the planet since the beginning. The water that you drank today most likely has been drunk before many years ago. The planet never gets any new water, instead the water cycles from one place to another.

As the water cycles, it goes through many processes. These processes are nature's way of purifying the water.

Give a brief definition of the listed components of the water cycle.

1. **Precipitation:**

2. **Runoff:**

3. **Infiltration:**

4. **Percolation:**

5. **Evaporation:**

6. Another term used for plants giving off moisture would be:
A. Condensation
B. Precipitation
C. Percolation
D. Transpiration

7. There are three basic types of water rights, they are:

_____

_____

_____

Source of Water

When you go see your doctor due to illness, they need to know the source of your problem so they can properly treat it. The same is true when treating water. The hydrological cycle shows several attributes of the earth purifying and moving water. To simplify this, we will focus on two categories of source water, Ground Water and Surface Water.

8. A porous material just above the water table describes this source to be surface water.
A. True
B. False

9. As water moves over or below the earth surface the quality of the water is classified as the following **EXCEPT** for:
A. Physical
B. Biological
C. Chemical
D. Radiological
E. Evolutional

10. In the space provided below, list the physical characteristics of water.

_____

_____

_____

Managing Water Quality at the Source

11. In this lesson, you will focus on surface water and the different factors that affect the quality of the water. Many populations have depended on lakes as a source of impounded domestic water supplies. As the population increases, list below brief examples of how the supplies are being used?

_____

_____

12. Several common water quality problems in domestic water supply reservoirs may be related to algae blooms. Which of the following summarizes the problems that can occur?

A. Taste and odor problems
B. Short filter runs at the plant do to clogging
C. Increased pH
D. Dissolved oxygen depletion
E. All of the above

Define the following terms:

13. Anaerobic:

14. Aerobic:

15. During the winter months, which condition is most likely to occur do to cold water conditions on the bottom of the lake?
A. Anaerobic
B. Aerobic

16. The presence of hydrogen sulfide will produce which type of odor?
A. Earthy
B. Fishy
C. Rotten egg
D. Roses

17. What is the definition for Oxidation?

---

18. What does **MCL** stand for?
A. Maximum Containment Level
B. Minimum Contaminant Level
C. Maximum Can-drink Level
D. Maximum Contaminant Level

19. In which Federal Act would you find the MCL for drinking water?
A. SDWA
B. OSHA
C. NEPDES
D. CWA

20. Lakes and reservoirs have intake-outlet structures. In the space provided below, list types of structures and/or screens.

Coagulation and Flocculation

21. Surface water for domestic use will have some form of impurities. It can be in the form of *INORGANIC* materials or *ORGANIC* materials. Given the following illustrations, determine if they are **I**norganic or **O**rganic.

A. Salt is ____

B. Oxygen is ____

C. Dirt is ____

D. Tree leaves are ____

22. Which statement describes ***COLLOIDAL*** matter?
A. Solids that sink to the bottom of a lake
B. Solids that are invisible
C. Solids that float to the top
D. Solids that are very small and repel each other

23. The purpose of using the Coagulation and Flocculation process is to remove the particulate impurities in the water. Which of the two would you use the addition of chemicals?
A. Coagulation
B. Flocculation

24. What is the purpose of flash mixing?
A. Using lightning to shock the water
B. To mix the chemical slowly
C. To mix the chemical in the water rapidly to prevent clumps
D. None of the above

25. List four primary coagulants used in water treatment.

A.

B.

C.

D.

26. Which type of laboratory analysis best simulates the plant process to determine the coagulant dosage?
A. Temperature
B. pH
C. Turbidity
D. Jar Test
E. Alkalinity

27. Flocculation and Flash Mixing are the same process.
A. True
B. False

28. Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable floc particles.
A. True
B. False

29. What is the advantage of minimizing chemical coagulant doses?
A. Less sludge is produced and chemical cost are reduced
B. Shorter settling times
C. Shorter filter runs
D. Big clumps floating to the top

30. What is ***short-circuiting***?

Sedimentation

We used the term ***PRECIPITATION*** in the hydrological cycle. It gives us a fancy word for ***RAIN***. A cloud forms and rain begins to ***FALL*** towards the earth. The same happens to the impurities we coagulated and flocculated. The impurities precipitate and settle to the bottom. This is done in ***SEDIMENTATION*** basins.

31. Depending on the quality of the source water, some plants have PRE-Sedimentation. Give two reasons for this.
A.

B.

32. List some sedimentation basin components.
A.

B.

C.

D.

33. List possible shapes for a sedimentation basin.
A.

B.

C.

34. What is the definition for **Detention Time**?

35. If a sedimentation basin sludge depth increases, what will happen to the detention time?
A. It will remain the same
B. It will increase
C. It will decrease
D. None of the above

36. What does frequent clogging of the sludge discharge line indicate?
A. Failure to properly maintain the sludge discharge line
B. Sludge concentration is too low
C. Sludge concentration is too high
D. This stuff belongs at the wastewater plant

Filtration

Filtration is the last attempt in removing particulate impurities from the water. In the treatment plant we use a mechanical straining for removal; like a coffee filter that keeps the grounds out of the pot. There are two classifications of filtration plants: Direct filtration and Conventional.

37. What is the major difference between a **Direct Filtration Plant** and a **Conventional Plant**?

_____

_____

38. The filtration process removes which type of particles?
A. Silts and clay
B. Colloids
C. Biological forms
D. Floc
E. All of the above

39. List four desirable characteristics of filter media.
A.

B.

C.

D.

40. Evaluation of overall filtration process performance should be conducted on a routine basis, at least once per day.
A. True
B. False

41. Poor chemical treatment can often result in either early turbidity breakthrough or rapid head loss buildup.
A. True
B. False

42. The more uniform the media, the faster the head loss buildup.
A. True
B. False

43. How are filter production rates measured?
A. GPM
B. GPM/sq ft
C. MGD
D. MGD/sq ft

44. Filter media provides several characteristics. List three types:
A.

B.

C.

45. Give a brief description of a **DECLINING-RATE** filter.

_____

_____

_____

46. What does **S.W.T.R**. stand for?

Disinfection

47. Which of the following pathogens are waterborne diseases?
A. Shingella
B. Hepatitis B
C. Giardia lamblia
D. Both A & C
E. None of the above

48. List three benefits of prechlorination.
A.

B.

C.

49. What does organic matter form when it reacts with chlorine?
A. Floc
B. Nitrates
C. THM's
D. Turbidity

50. When the temperature increases, the pressure of the chlorine gas inside a chlorine container will decrease.
A. True
B. False

51. Hypochlorite compounds tend to lower the pH of the water being disinfected.
A. True
B. False

52. Moisture in a chlorination system will combine with the chlorine gas and cause corrosion.
A. True
B. False

53. You can use regular pipe fittings when making connections with chlorine containers.
A. True
B. False

54. Always work in pairs when looking and repairing chlorine leaks.
A. True
B. False

55. When a chlorine leak exist, use water to dilute it.
A. True
B. False

56. How do water temperature conditions influence the effectiveness of chlorine as a disinfectant?
A. The lower the water temperature the easier to disinfect the water
B. The warmer the water the less dissipation rate of chlorine to the atmosphere
C. The higher the temperature the easier to disinfect the water
D. The warmer the water, the longer contact time needed

57. Which of the following chemical must be present for a breakpoint chlorination curve to develop when chlorine is added to water?
A. Iron
B. Ammonia
C. Manganese
D. Organic matter

58. What does the product of **C x T** provides a measure of?
A. Level of disinfectant intensity
B. Rate of chloramine formation
C. Degree of pathogenic inactivation
D. Threat of THM formation

59. What formula would you use to calculate the chlorine feed in pounds per day?

60. List eight parts that are used for a chlorinator.

A.

B.

C.

D.

E.

F.

G.

H.

61. Give a brief description for the use of a fusible plug in a steel cylinder.

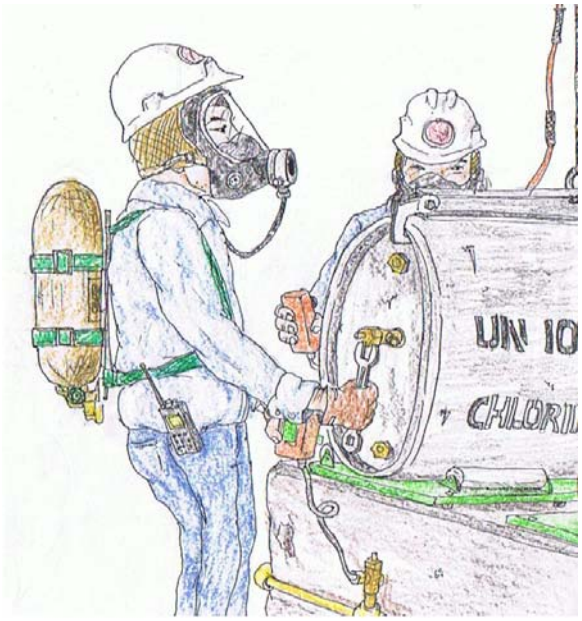
62. What is the maximum rate of chlorine removal in a 150 pound cylinder?

63. What is the most probable cause of leaking joints in gas chlorinator systems?
A. Acid corrosion of joints
B. Back pressure
C. Gas pressure to high
D. Missing gasket

64. How are probes used in the disinfection process?
A. They accurately measure chlorine dosage
B. They measure the liquid chlorine remaining in a chlorine container
C. They provide a direct measure of the disinfecting power of the disinfectant
D. They quickly measure and record chlorine residual
E. All of the above

65. Which of the following factors influence chlorine disinfection?
A. Microorganisms
B. pH
C. Reducing agents
D. Temperature
E. All the above

66. Why will the engines of emergency vehicles quit operating in the vicinity of a large chlorine leak?
A. Corrosion damage from chlorine
B. Crowds of rubber necks
C. Lack of oxygen
D. To far gone to look back and see why



Exercise Answers

1. When atmospheric moisture falls on land or surface water as rain, snow, hail, or another form of moisture.
2. Water draining from an impermeable or saturated surface into stream channels and/or other surface waters, such as rivers or lakes.
3. Gradual flow of water through porous materials, such as soil.
4. Flow of water through coffee, tea, etc. to create a beverage.
5. Process by which liquids (water, gasoline, etc.) become a gas.
15. Transpiration
7. Appropriative: Acquired water rights for exclusive use
Prescriptive: Rights based upon legal prescription or long use or custom
Riparian: Water rights because property is adjacent to a river or other surface water.
8. False (199) (ground water)
9. Evolutional (40 & 201)
10. Water is a solid below 32 degrees Fahrenheit
Water is liquid between 32 degrees Fahrenheit and 212 degrees Fahrenheit Water is in a gaseous state above 212 degrees Fahrenheit. Other Physical Characteristics: Turbidity, Color, Temperature, Tastes, and Odors.
11. Surface water supplies (lakes, rivers, etc.) are being used for recreational purposes (boating, swimming, etc.), domestic purposes (drinking, cooking, bathing, cleaning, etc.) and agricultural purposes (irrigation).
12. All of the above
13. Anaerobic conditions occur when there is an absence of oxygen. Without sunlight, algae consumes oxygen and releases carbon dioxide, thus removing oxygen from water. When there is an absence of oxygen in water, color and odor problems are likely to occur. Dissolved oxygen can be added to water to combat anaerobic conditions.
14. Aerobic conditions occur when there is a presence of oxygen. When algae absorbs energy from the sun, it converts carbon dioxide to oxygen (photosynthesis), thus adding dissolved oxygen to water. Significant levels of dissolved oxygen in water allows iron and manganese to exist in an oxidized state, which causes these metals to precipitate downward, thus improving water color and odor.
15. Anaerobic Destratification)
16. Rotten egg
17. (Add Oxygen; Remove Hydrogen/Electrons)
Oxidation originally meant a reaction in which oxygen combines chemically with another substance, but now it includes any reaction in which electrons are transferred. Oxidation occurs simultaneously with Reduction (Redox Reactions). The substance which gains electrons is the oxidizing agent
18. Maximum Contaminant Level
19. SDWA (31) (V1; P31)
20. 1. Bar Screens:
    Mechanical – Vary in size and bar spacing. Have raking mechanisms that scrape off debris.
    Non-Automated – have to be manually cleaned.

2. Wire Mesh Screens:
    Made of woven stainless steel, vee-wire, and slotted plates
    Usually have narrow openings, Usually manually cleaned

21.
A. Salt is **I**norganic
B. Oxygen is **I**norganic
C. Dirt is **I**norganic and **O**rganic
D. Tree leaves are **O**rganic Inorganic – No Carbons Organic – Carbons
22. Solids that are very small and repel each other
23. Coagulation
24. None of the above
25. A. Aluminum Sulfate (Alum): neutralizes particles' negative charge; use when pH is 5.0 to 7.5
B. Ferric Chloride: neutralizes particles' negative charge; use when pH is less than 4.5
C. Ferrous Sulfate: neutralizes particles' negative charge; use when pH is 4.5 to 9.5 **D.** Cationic Polymers: positively charged strings that attract particles to from larger particles. Other proprietary coagulants are used in proprietary systems.
26. Jar Test
27. False (are not)
28. True
29. Less sludge is produced and chemical cost are reduced
30. A condition that occurs when some water in a tank or basin flows faster than the rest of the flowing water. This is usually undesirable because it may result in shorter contact, reaction, and/or settling times when compared with presumed or calculated detention times.
31. A. It allows larger particles (sand, heavy silt, etc.) time to settle in a reservoir or lake, thus reducing solid removal loads.
B. It provides an equalization basin, which evens out fluctuations in concentrations of suspended solids (Flow Equalization).
32. A. Inlet Zone
B. Settling Zone
C. Sludge Zone
D. Outlet Zone
33. A. Rectangular Basins
B. Circular Basins
C. Square Basins
34. The actual time required for a small amount of water to pass through a sedimentation basin at a given rate of flow, or the calculated time required for a small amount of liquid to pass through a tank at a given rate of flow.
(Detention Time) = ((Volume in Gallons) * (24 Hrs per Day)) / (Flow in Gallons per Day)
35. It will decrease (Volume in numerator decreases)
(DT) = ((Vol in Gals)*(24 hrs/day)) / (Flow in Gals/Day)
36. Failure to properly maintain the sludge discharge line
37. The sedimentation process or step is omitted from the Direct Filtration Plant.
38. Silts and clay
39. Permeable (good hydraulic characteristics)B. Inert and easy to clean (doesn't react with substances in water)C. Hard and durableD. Free of impurities and insoluble in water
40. True
41. True
42. False (slower)
43. GPM/sq ft
44. A. Permeable (good hydraulic characteristics)B. Hard and durable C. Free of impurities and insoluble in water Also inert and easy to clean (non-reactive with water substances)

45. The rate of flow varies with head loss. Each filter operates at the same rate but can have a variable water level. This system requires a weir (effluent control structure) to provide adequate submergence.
46. Surface Water Treatment Rule
47. Shingella & Giardia lamblia
48. A. Control algae and slime growth B. Control mudball formation C. Improve coagulation
49. THM's
50. False (85, 98, 105, 187) (increase)
51. False (116) (V1; P268-269) (Raise)
52. True (85, 92) (V1; P303-304)
53. False (92, 108) (V1; P295) (cannot)
54. True (V1; P304 & 312)
55. False (Volume 1; Page 314) (do not use)
56. (105) (V1; P263)
57. **ALL;**
58. (Volume 1; Page 273)
E. Level of disinfectant intensity
F. Rate of chloramine formation
G. Degree of pathogenic inactivation
H. Threat of THM formation
59. (211) (V1; P275)
(Chemical Feed in Lbs/Day) = (Flow in MGD) * (Dose in mg/l) * (8.34 Lbs/Gal)
(Lbs/Day) = (Million Gallons/Day) * (Parts/Million) * (8.34 Gals/Day)
60. List eight parts that are used for a chlorinator.
A. Ejector
B. Check Valve Assembly
C. Rate Valve
D. Diaphragm Assembly
E. Interconnection Manifold
F. Rotometer Tube and Float
G. Pressure Gauge
H. Gas Supply
61. This metal plug will melt at 158 degrees Fahrenheit to 165 degrees Fahrenheit in order to prevent—buildup of excessive pressure—and the possibility of cylinder rupture—due to high temperatures.
62. (40 Lbs/Day) * (1 Day/24Hrs) = (1.67 Lbs/Day)
63. Missing or damaged gasket
64. They quickly measure and record chlorine residual
65. All the above
66. Lack of oxygen



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