# DISTRIBUTION BASICS II

## CONTINUING EDUCATION
## PROFESSIONAL DEVELOPMENT COURSE

***Second Edition  40 Contact Hours***

Technical Learning College

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## Library of Congress Card Number TX-6-825-267
### DISTRIBUTION BASICS II

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# Important Information about this Manual

## Disclaimer

This CEU training manual has been prepared to assist employees in the general awareness of the water distribution system and groundwater production system, complex pumping ideas, dangerous excavation techniques, water regulatory sampling and dealing with often-complex procedures and requirements for safely handling hazardous and toxic materials. The scope of the material is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of federal and state regulations and safe working procedures.

This manual will cover general laws, regulations, required procedures and work rules relating to water distribution and sampling. It should be noted, however, that the federal and state regulations are an ongoing process and subject to change over time. For this reason, a list of resources and hyperlinks is provided to assist in obtaining the most up-to-date information on various subjects. You can find these on our website or in this manual. This manual is a guidance document for employees who are involved with water distribution, water quality and pollution control. It is not designed to meet the full requirements of the United States Environmental Protection Agency (**EPA**) or the Department of Labor-Occupational Safety and Health Administration (**OSHA**) rules and regulations.

This course manual will provide general guidance and should not be used as a preliminary basis for developing general water/wastewater sampling plans or water distribution safety plans or procedures. This document is not a detailed water/wastewater textbook or a comprehensive source book on water/wastewater/safety rules and regulations. Technical Learning College makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for guidance and is not considered a legal document. Individuals who are responsible for water distribution, production and/or sampling and the health and safety of workers at hazardous waste sites should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state, and local agencies.

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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.

# CEU Course Description

**DISTRIBUTION BASICS CEU TRAINING COURSE *Second Edition***
Review of water distribution systems and related treatment fundamentals. This course will cover the basic requirements of the Safe Drinking Water Act and general water distribution principles. You will not need any other materials for this course.

**Water Distribution, Well Drillers, Pump Installers, Water Treatment Operators.** 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 certification license or to learn how to do the job safely and effectively, and/or to meet education needs for promotion.

**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 Technical Learning College's correspondence courses have complete registration and support services offered. Delivery of services 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/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 number assigned to the student.

**Instructions for Written Assignments**
The Distribution Basics Second Edition CEU Training course uses a multiple choice answer key. If you should need any assistance, please email all concerns and the final test to: info@tlch2o.com.

You may write your answers or type out your own answer key. TLC would prefer that you utilize the answer key found on the TLC website under Assignments and e-mail the answer key to TLC, but it is not required. You may also fax the answer key. Please call us a couple hours later to ensure we received your 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.

**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 and the student will forfeit all fees and the appropriate agency will be notified.

**Grading Criteria**
TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice.

**Required Texts**
The Distribution Basics Second Edition CEU Training course will not require any other materials. This course comes complete. No other materials are needed.

**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.

**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.

You will have 90 days from receipt of this manual to complete it in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70% or better is necessary to pass this course.

## 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 environmental education field,*

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

*To provide opportunities for TLC students to learn and practice environmental educational 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 environmental education,*

*To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.*

## TABLE OF CONTENTS


| | |
|---|---|
| Recent Backflow Situations | 14 |
| Common Cross-Connection | 16 |
| Backpressure | 19 |
| Backflow Responsibility | 21 |
| Types of Assemblies | 25 |
| Water Distribution Section | 35 |
| Distribution Valves | 37 |
| Meters | 61 |
| Water Theft | 62 |
| System Layouts | 65 |
| Distribution Pipes | 69 |
| Joints & Fittings | 73 |
| Water Main Installation | 76 |
| Water Softening | 77 |
| Water Filters | 80 |
| Safe Drinking Water Act Summary | 85 |
| Primary Drinking Water MCLs | 93 |
| Secondary Drinking Water MCLs | 99 |
| New EPA Rules | 101 |
| Water Treatment System | 119 |
| Aquifer | 120 |
| Groundwater Section | 123 |
| Water Well Reports | 137 |
| Water Bearing Zone | 143 |
| Casing Driver Methods | 153 |
| Choice of Casing | 165 |
| Water Demand | 185 |
| Disinfection of Reservoirs | 188 |
| Hydropneumatic Tank | 191 |
| Waterborne Pathogens | 203 |
| Protozoan Diseases | 205 |
| Waterborne Diseases | 206 |
| Bacteriological Monitoring | 207 |
| HPC | 213 |
| Periodic Chart | 237 |
| pH | 239 |
| Chlorine Section | 241 |
| DPD Residual Method | 246 |
| Chemistry of Chlorination | 253 |
| Chlorinator Parts | 261 |
| Troubleshooting Hypochlorination | 265 |
| Disinfection Policy | 267 |
| Alternant Disinfectants | 268 |
| Amperometric Titration | 269 |
| Chlorine Dioxide | 271 |

| | |
|---|---|
| Fluoride | 275 |
| Water Quality | 279 |
| Corrosion Control | 285 |
| Alkalinity / pH Adjustment | 287 |
| Activated Carbon | 288 |
| Hydraulic Section | 289 |
| Pump Fundamentals | 318 |
| Pump Definitions | 321 |
| Pump Categories | 327 |
| Basic Pump | 329 |
| Centrifugal Pump | 341 |
| Motor Coupling and Bearings | 349 |
| Couplings | 365 |
| Excavation Safety | 377 |
| Shoring System | 383 |
| One Call Center | 387 |
| Confined Space | 391 |
| Glossary | 415 |
| Microorganisms | 453 |
| Conversion Factors | 509 |

Hand digging, getting soaked with water and mud, being run over from traffic are just a few tasks and major portions of repairing the distribution system. We hope to be able to teach you about the system. You will understand the distribution system and water quality as well. We welcome your comments and digital photographs.

Before any excavation, always determine the location of the other buried utilities, before tapping a main for a new service connection, the operator should call Bluestake or One-Call centers.

## 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 unauthorized water usage that is being used in the fire line.

Yes, people can steal water through a fireline. I personally would never drink water out of a fireline but some people will do just about anything just to save a small amount of money.

## 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 sodium nitrate contamination that sent 19 people to the hospital.

**New York 1994**
A 8-inch reduced pressure principle backflow prevention 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 homeowner's 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.

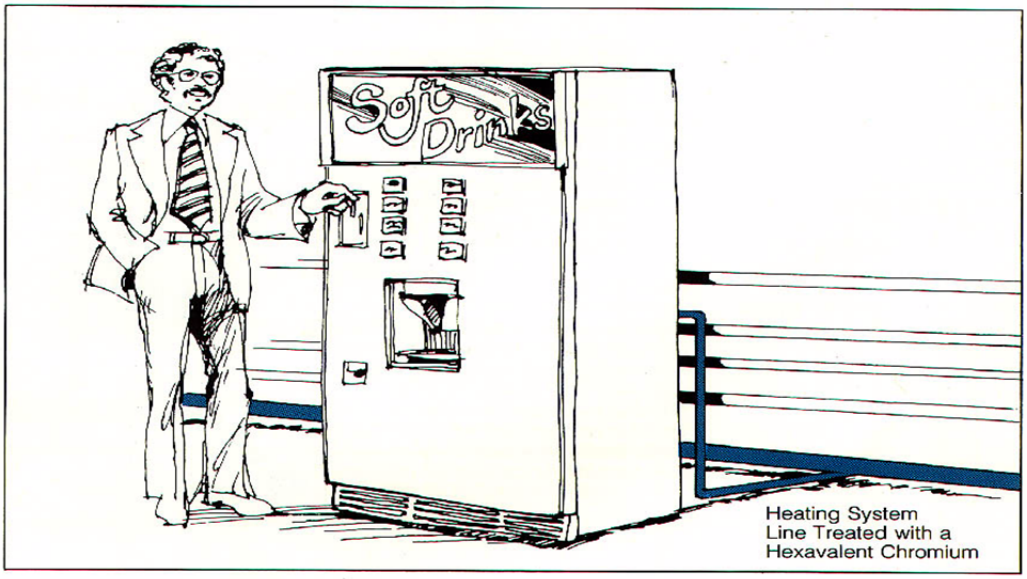
**Indiana 1994**
A water main break caused a drop in water pressure, allowing anti-freeze from an air conditioning unit to backsiphon into the potable water supply.

**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.

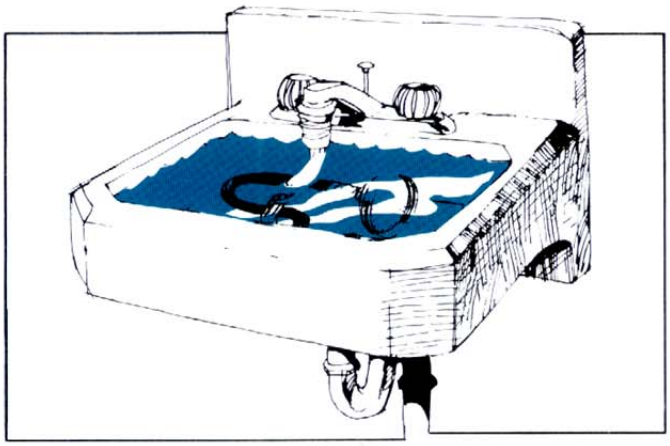
**CONTAMINATION:** To make something bad. To pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

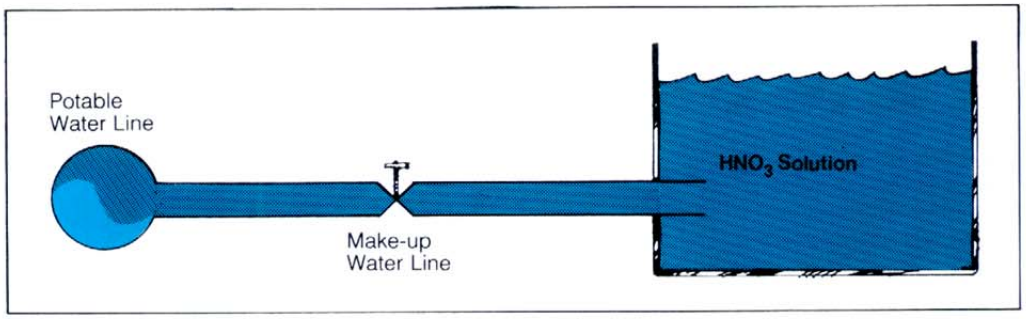
**CORROSION**: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

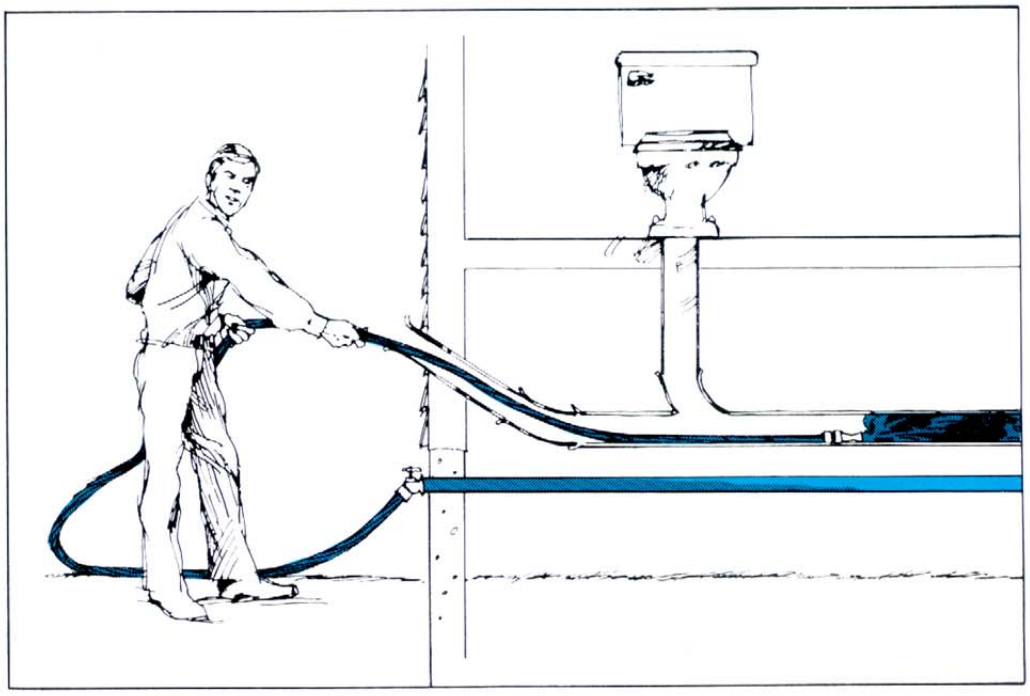
**CROSS-CONNECTION:** A physical connection between a public water system and any source of water or other substance that may lead to contamination of the water provided by the public water system through backflow. This also might be the source of an organic substance causing taste and odor problems 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 substance.

## Common Cross-Connections



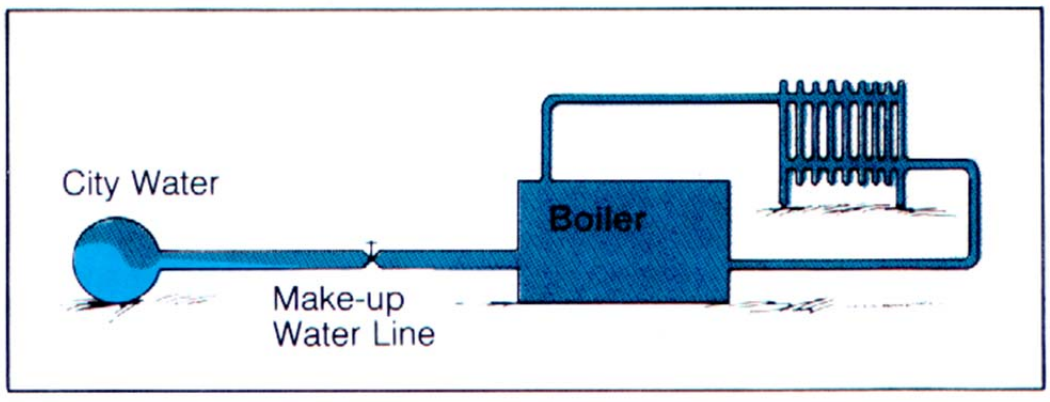


## Backflow

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.**

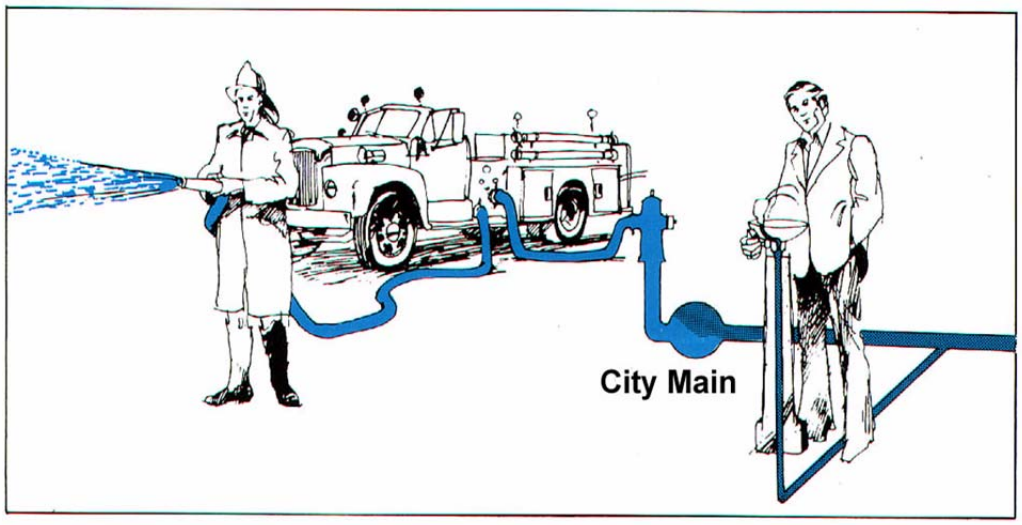
**Backsiphonage**




Backpressure Example

## Backsiphonage

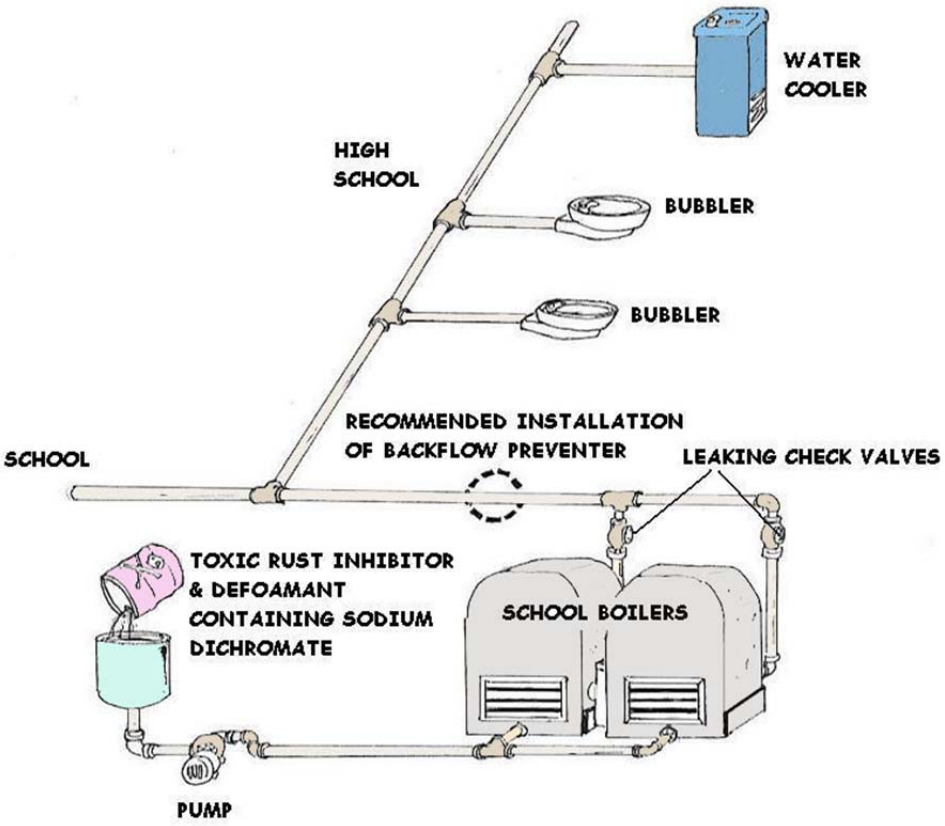
Backsiphonage is backflow caused by a negative pressure (i.e., a vacuum or partial vacuum) in a public water system or consumer's potable water system. The effect is similar to drinking water through a straw. Backsiphonage can occur when there is a stoppage of water supply due to nearby firefighting, a break in a water main, etc. Hoses are the greatest source of backsiphonage problems.



## Backpressure

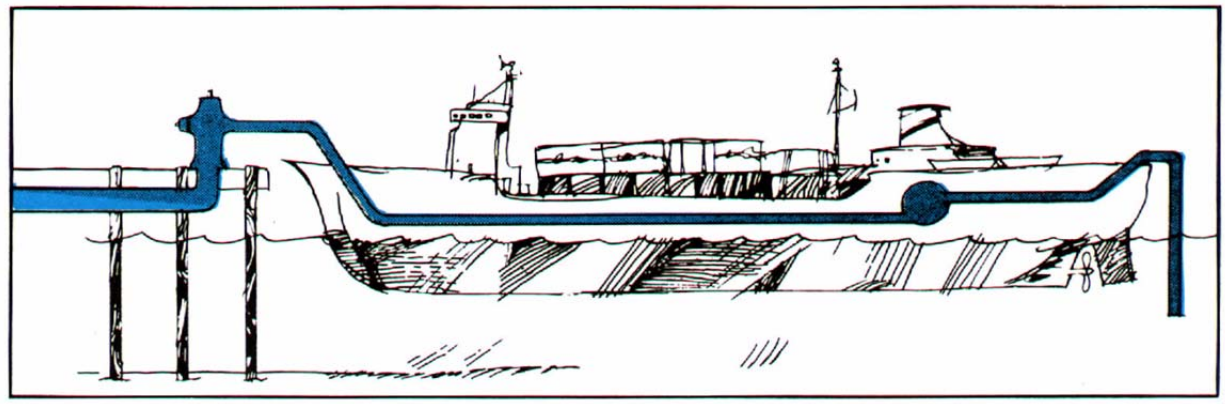
Backpressure is backflow caused by a downstream pressure that is greater than the upstream or supply pressure in a public water system or consumer's potable water system. Backpressure (i.e., downstream pressure that is greater than the potable water supply pressure) can result from an increase in downstream 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, elevation, 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



## Backflow Review Statements

**Backflow Condition:** A continuous positive pressure in a distribution system is essential for preventing a backflow condition or 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 liquid, 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. To reverse the natural and normal directional flow of a liquid, gases, or solid substances back into the public potable (drinking) water supply. This is normally an undesirable effect.

**Backsiphonage 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 its delivery 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.

**Why do water suppliers need to control cross-connections and protect their public water systems against backflow?**
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 foreseeable 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 poses 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 or *Contaminant* and Low or *Pollutional***

**Two Classification of Protection**
**Containment Protection or *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 or *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 it 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).

Various Reduced Pressure Principle Backflow Assemblies.

This RP was covered with 3 foot high grass. The grass was thriving because the RP was leaking. No one noticed, not even the customer that was used to paying an additional $150 each month for the leak. Remember, every drop counts, find and stop all leaks. Any leak makes the Distribution Section and/or water department look bad.

We have trained more than 20,000 operators in continuing education. Let us help you keep your license with a TLC continuing education course. We are here to help you in your professional career.

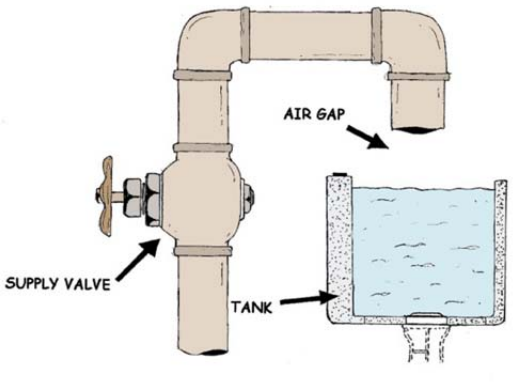
We know the training material; we have worked it; we have field experience; and we can teach you everything you need to know. We care for you and your career. We want to be known for service and education.

# Types of 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 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.




What should a potable water line be equipped with when connected to a chemical feeder for fluoride?
*Air gap or vacuum breaker.*

Air Gap Separation: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

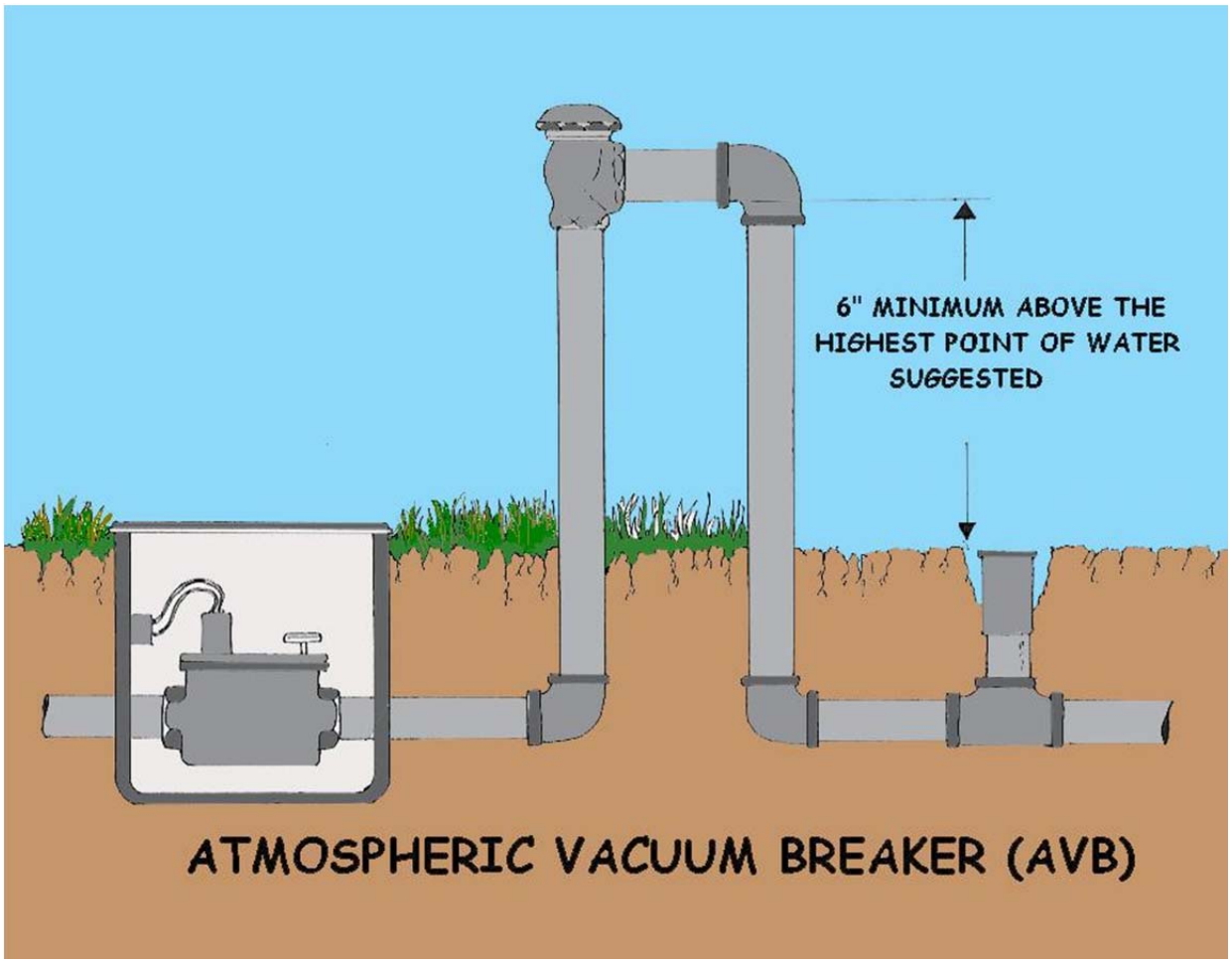
Which of these ice machine drains are approved air gaps?

## 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 to prevent backflow caused by backsiphonage only 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)

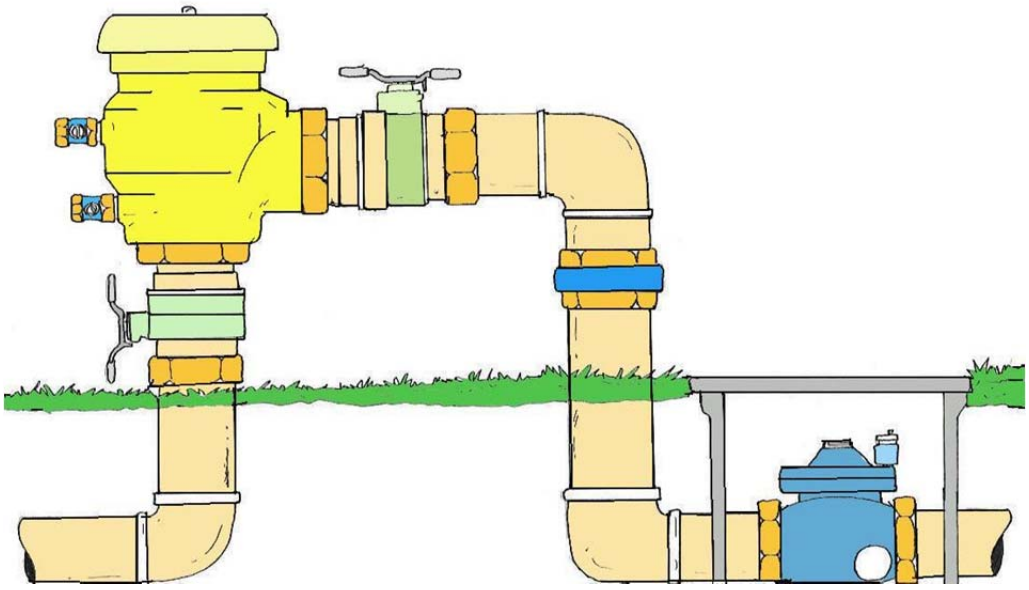
(Note: hazard relates to the water purveyor's risk assessment; plumbing codes may allow AVB for high hazard fixture isolation).



## 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

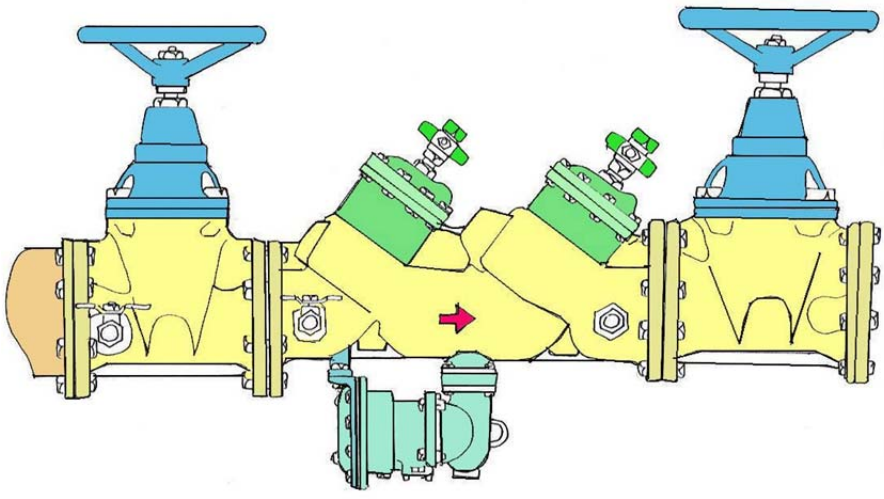


## Double Check Valve Assembly (DC)

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.

## Reduced Pressure Backflow Assembly (RP)

The reduced pressure principle 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.



REDUCED PRESSURE BACKFLOW ASSEMBLY

## 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 usually notify the property owner, asking them to comply. If the property owner does not voluntarily test their device, the City may be forced to turn off water service to that property.

State law requires the City to discontinue water service until testing is complete.

**Troubleshooting Table for Cross-Connection Problems**
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.

## BACKFLOW AWARENESS EXERCISE

1. Define the term BACKFLOW?

2. Define the term BACKPRESSURE?

3. Define the term BACKSIPHONAGE?

4. Why is backflow a concern?

5. Do you believe backflow is a reasonable concern to you? Why?

6. When should a water supplier cause a backflow-prevention assembly to be installed?

***Define the following abbreviations:***

7. AG

8. RP

9. PVB

10. DC

11. What does your State use for a reference or standard for determining what type of backflow assembly can be used? Please provide the name/title or reference of this Rule or Regulation.

12. What State agency is responsible for backflow protection?

13. Are single family residences in your State required to have a backflow assembly?

14. What is the standard or description for an Air Gap?

15. Give one example of an Air Gap that you have seen?

16. Give two examples of how a PVB can be used?

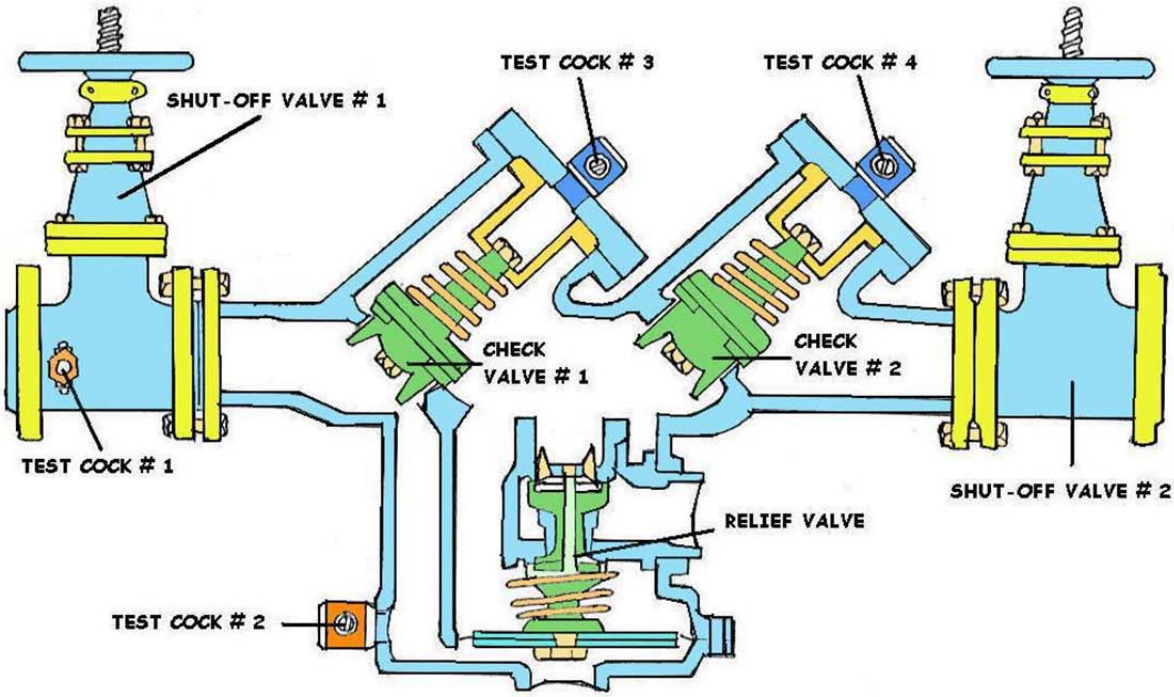
17. Give one example of a backflow prevention assembly, manufactures name, model number, and type of assembly.

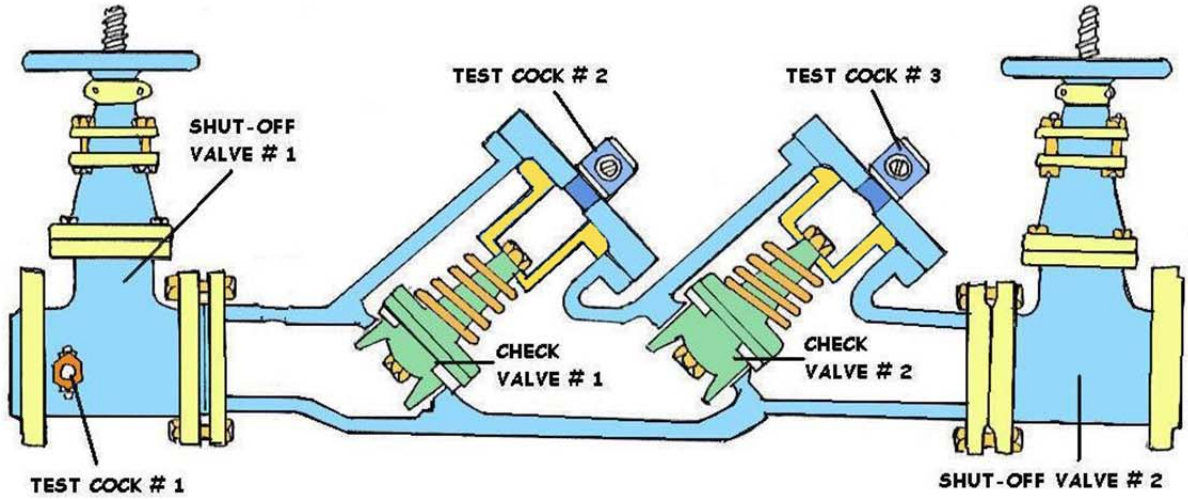
18. Explain Pascal's Law?

19. Explain Bernoulli's Principle?

20. Explain in detail a backflow/cross-connection occurrence. If you are unfamiliar with a backflow/cross-connection occurrence, please use the library or the Internet and you will be able to find several occurrences. We would prefer an actual report of a backflow occurrence that you know of or have seen.

## REDUCED-PRESSURE BACKFLOW ASSEMBLY




## DOUBLE-CHECK BACKFLOW ASSEMBLY

A water service worker installing a new copper water service line on an asbestos cement water main. Notice the bronze saddle with a corporation stop, a compression type fitting and a locking nut to secure the copper pipe to the corp. Bottom photo, the saw blade hole saw type tapping machine which was used to tap the main for the new service. This was completed with the water main under pressure so that other customers on the main did not have their water service disrupted due to the new service.

**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 (friction loss) and the carrying capacity in a pipe. Crenothrix bacteria or Red-Iron bacteria will live and thrive in the bioslime in this type of tuberculation. Now, for dealing with this bacterium, there are two methods: 1) the fast method, super chlorinate and flush forever. Or, 2) replace the line with a nice and new plastic water main. It is up to your supervisor, but remember the nasty bacteria in the water. No one that knows about it would ever drink water from the house service. Biofilms are the result of a complex interaction among microorganisms. The organisms form microcolonies and secrete extracellular material that makes them highly resistant to biocides. Nasty for sure!

## Water System Design and Valves

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. The purpose of a hydropneumatic tank is to provide air for the water system.

Looking inside of a booster pump station, notice the PRV and air relief valve.

**Commonly found 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.

Two different styles of Gate Valves.
Top photograph is valve ready for a gate valve replacement. Bottom photograph is OS&Y commonly found on fire lines. (Outside Screw and Yoke) As the gate is lifted or opened, the stem will rise.

Gate valves should be only used in the distribution system for main line isolation.

## 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.

## Classification of Valves

There are two major classifications of water valves: **Rotary and Linear**. Linear is a fancy word for up and down or blade movement.

**Gate Valve *Linear Valve Our primary Linear valve***
**The most common valve in the distribution system. Primarily used for main line shut downs. Should be exercised on annual basis.**

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.

I always liked to listen to the Valve Key when shutting down a Gate valve. You will easily hear it sing as you shut the water off or leak by. It is very easy to create a water hammer with opening or closing a Gate valve. Always take your time when operating a Gate valve or any valve. I know that most of you will not listen to me and you will end up breaking plastic water services and customer's water lines at first. Next, you'll move up to water main breaks. We like to blame the Fire Department or Street Sweepers for water hammers, and they should be blamed, but most water hammers are created by water personnel. Yes, I said it. A great example is watching a rookie shut down or open a fire hydrant. These young rookies like to turn the hydrant on or off as fast as possible, like the Firemen do. Pretty soon, the hydrant starts chattering and pumping. The ground feels like an earthquake and the rookie pretends that nothing is happening. We've all done this and if you haven't, you've probably never worked in the field.

## Problems

### Valve Jammed Open

Dr. Rusty recommends that opened valves should not be jammed-tight on the backseat.

Always back the valve-off a quarter turn from the fully opened position.

Note that motor operated valves coast inevitably to the backseat by tripping on a limit switch. Valve should not be back seated on torque.

### Valve Jammed Closed

Variations in the temperature and/or pressure of the working fluid are often the cause of a valve failing to open.

Thermal binding can occur in high temperature situations depending on the seat and wedge material, length of exposure and closing torque applied. Thermal binding can cause galling on the valve sealing surfaces as well as on the guides.

A valve can lock in the closed position when high pressure enters the cavity and has no way to escape. This is known as over-pressurization.

### If Excessive Torque is Needed to Work the Valve

Variations in the temperature and/or pressure of the working fluid are often the cause of a valve failing to open.

Thermal binding can occur in high temperature situations depending on the seat and wedge material, length of exposure and closing torque applied. Thermal binding can cause galling on the valve sealing surfaces as well as on the guides.

A valve can lock in the closed position when high pressure enters the cavity and has no way to escape. This is known as over-pressurization. We will cover this in a later section.

Single direction sealing gate valves have a nameplate on the side of the valve that has a relief hole or pressure equalizer. This should be the high pressure side when the valve is closed.

Here is a nasty 4-inch broken gate valve with serious tuberculation. The valve is broken in the closed position. The rust particles are sharp and can easily cut the water service worker. The flange bolts or Tee bolts were cut off to replace this valve. The rubber gasket will leave a black ink-like stain on your clothes and in the water line as well. You will see lots of nasty stuff in the top portion of a valve. Some engineers or big shots refer to this area of the valve as the "Angular space". If they really knew that this space contained nasty particles or debris and sediment they would never visit your Yard or facility again.

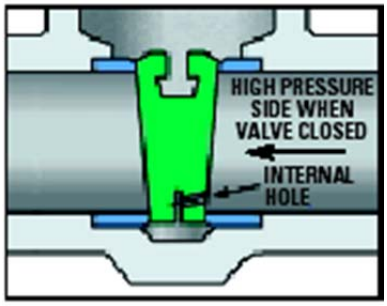
One practice that I am not sure about is the common procedure of only removing the bonnet or removing the guts of a closed valve. I guess that sometimes this practice is necessary, but I don't like removing the guts and packing of cement and a redwood plug in the stem hole but it happens.

Dr. Rusty's advice, "This is a difficult job because of mud and water lines under pressure, be super careful of rust particles cutting your skin. Get in line at the Doctors or Health Provider's facility and get all of your shots, especially Tetanus and Hepatitis. I know some of you will fight this but the facts are that you will probably be infected with something nasty. Best advice, obtain your water treatment certs or get a job promotion and get out of the hole."

Gate valve storage procedures: Always store a gate valve with the gate up or opened. Not like in this picture. Sunlight will give these rubber components a good shot of Vitamin D and sunburn, destroying the rubber. I like to keep the valves covered, open position and clean. I know that some of you don't care because these valves are so damn heavy and bother-some. Get over it and quit making $800.00 bird nests! We are professionals and must remember the final outcome. We provide drinking water to the public.

## Knife Gate Valve

Always follow standard safety procedures when working on a valve. Install the valve so that the arrows on both sides of the body are in the direction of positive pressure differential.




The preferred orientation is with the stem vertical and the handwheel pointing up. The opposite orientation is not recommended, because fiber and dirt can build-up in the bonnet.

Ductile pipe cement-lined iron pipe shown above. I've seen thousands of dollars of pipe that is dropped or moved with the front bucket of a backhoe and destroyed. This destroys the interior protection of the pipe, causing leaks which will start in a few years. I know that some of you welcome this as job security. These nitwits need job security, but water professionals do not need crappy work to keep them employed. Always protect and store all types of pipe in a pipe rack and covered. This goes for the proper storage of rubbers as well.

Flex Coupling-sometimes referred to as a Dayton-used to join pipes or to "cut-in a valve". You will learn that you can use different sizes to join pipe or even file out the inside diameter to adjust to larger pipes like ACP. This flex coupling only has three bolts. I like four or more for work with larger pipes. Professor Rusty's trick--When working on a water line, I like to turn the valves on slowly to fill the water main as the flex couplings are being tightened. This allows the air to escape and for you to find leaks. It also allows debris in the main to flush out.

Here is a four-way pipe cutting tool used for iron pipe. Be careful not to break the wheels by over tightening. I personally like 4-Ways because of the nice cut. You will learn to recognize the distinct snap of cut pipe. The only drawback to these cutters is cutting a small section out of the main. You may need to make two or three more cuts and break the section out with a cocking hammer. It will easily cut Ductile, galvanized, and even plastic. Plastic pipe cutters utilize sharper cutting wheels. Rookies like to thread the pipe rather than cut the pipe. It is fun to watch and to tease these rookies about it, especially if they just finished jumping a stop with the valve closed or no ball. Good times for sure in the crazy Distribution field.

Photograph on right-difficult to see- these are pipe crimpers. These will easily and effectively stop flow in copper or plastic pipe in tubing less than 2 inches. The only problem is dealing with the crimp when you are finished. I suggest placing a flex coupling over the crimp in plastic and completely cutting the crimped area out when done in copper pipe.

Top photograph-two gate valves blew out-you can see the kickers or thrust blocks in the background. Bottom photograph- a tapping machine and a new gate valve. These tapping machines are very, very expensive. I can't believe the cost of a new one. Even buying a used one will set you back more than a new car.

Some days are nothing but hand-digging in the worse possible situations, other days everyone needs to come out and see what's going on. The best thing is to obtain the most education you can and promote up the ladder or find a technical or managerial job. You cannot endure 20-30 years in the hole without one or more injuries.

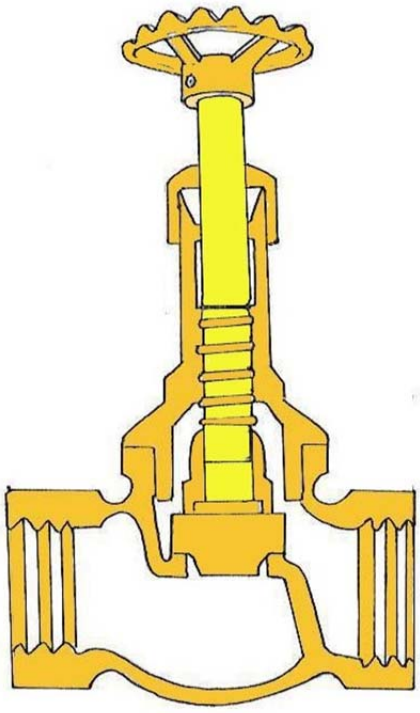
## Common Rotary Valves

## Globe Valve *Rotary Valve*

It is primarily used for flow regulation, and works similar to a faucet. 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 stem, with renewable seatring valves. A Check Valve spring loaded disc resulting with most advanced design features provides 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.



GLOBE VALVE

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.

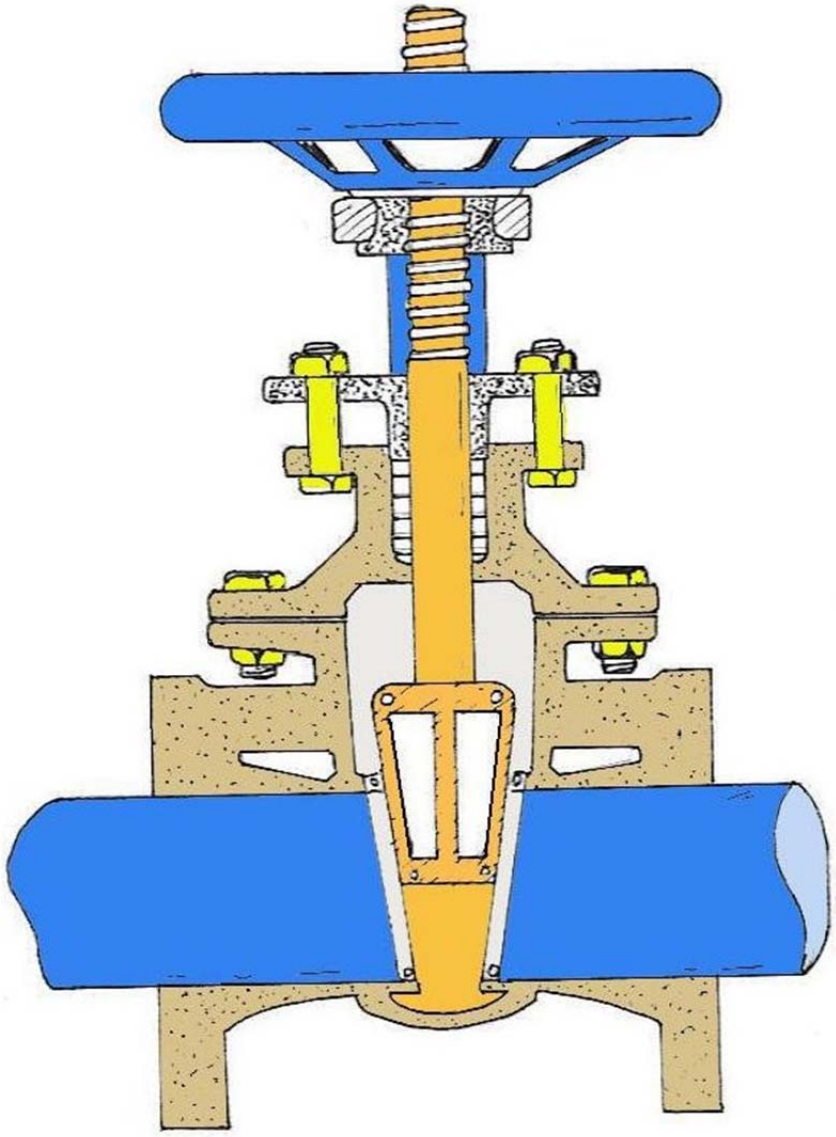
**If the valve packing compression is too tight:** Verify the packing bolt torque and adjust if necessary.

**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 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-assemble. 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:** If you suspect that the valve components are damaged or faulty 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.



RISING STEM VALVE

## Ball or Corporation Stop  Rotary Valve  *Small Valves 2 inch 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.  It is the valve 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 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 or a small leak, but pipe dope, Teflon dope or tape makes a nicer job and makes for an easier removal.

## 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 by 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 types of valves usually found on large transmission lines. They may also have an additional valve beside it, known as a "*bypass*" 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, ladder or valve blocking.

# ACTUATION METHODS

- Standard Handwheel
- Chainwheel Operated
- Square Nut
- Pneumatic
- Electric

## 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 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.

**If the actuator/shaft adaptor is misaligned:** Remove the actuator mounting and realign.

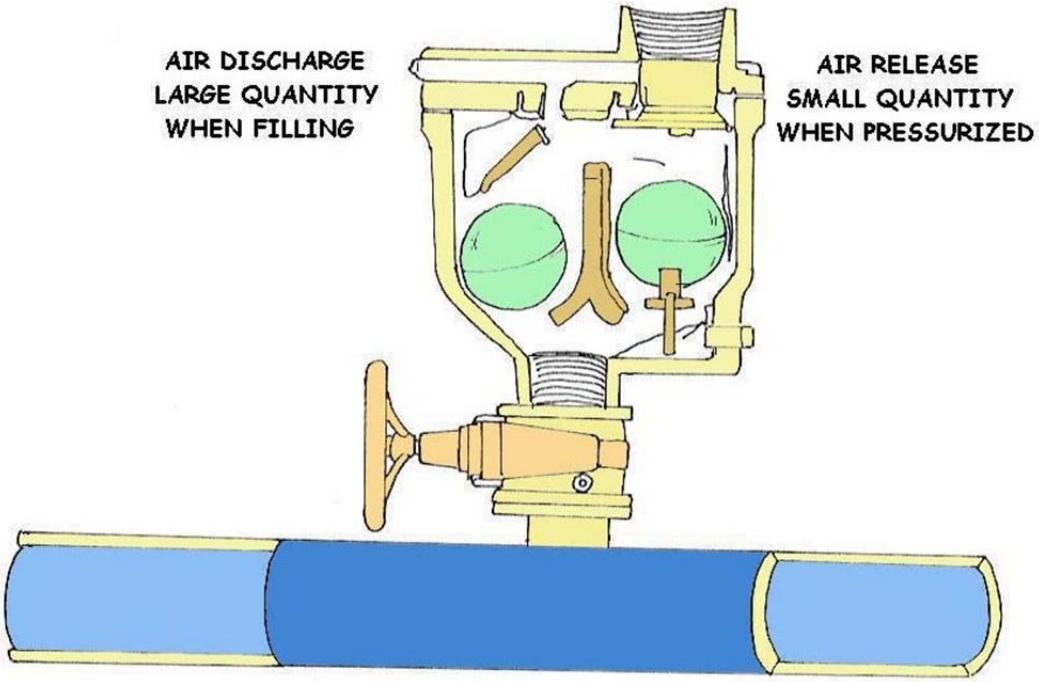
**If the valve has a pneumatic actuator, the air supply may be inadequate:** Increase the air supply pressure to standard operating level. Any combination of the following may prevent the valve shaft from rotating.

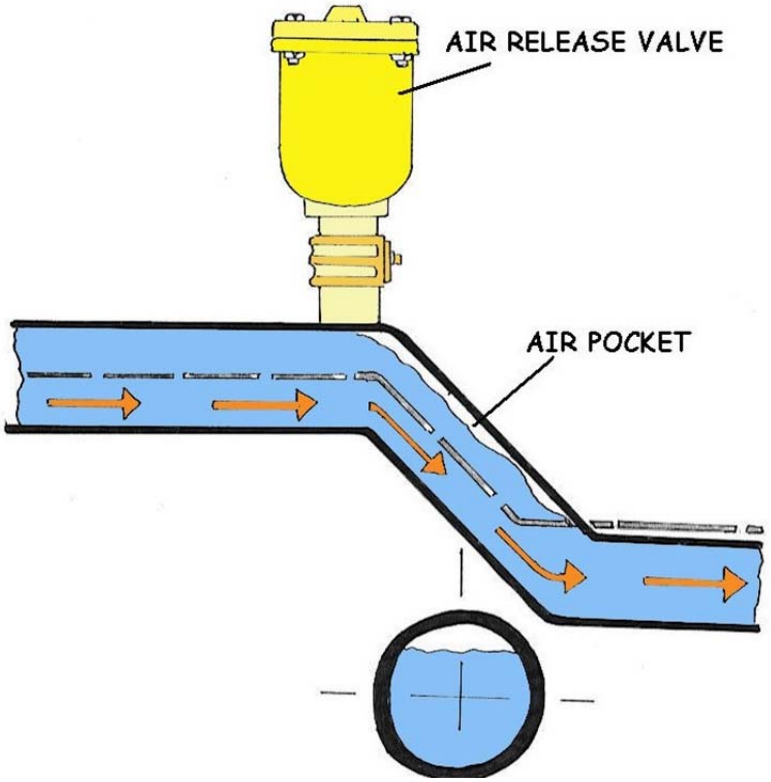
**If the actuator is not working:** Replace or repair the actuator as required. Please contact specialized services or an outside contractor for assistance.

**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 valve and a worker inside the water main preparing the interior surface. Notice, this is a Permit Required Confined Space. A Hot work permit is also required.

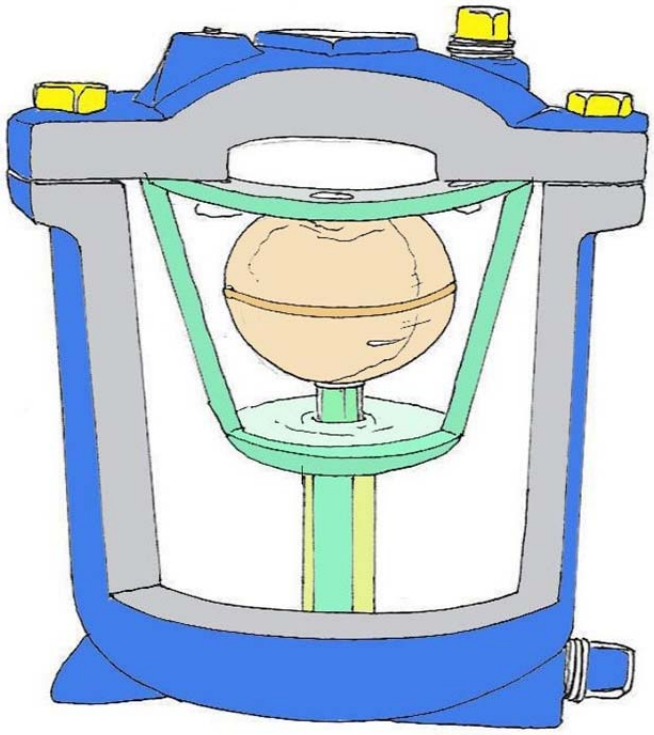
# COMBINATION AIR VALVE



# Why use automatic air valves?

- ❑ **Increase flow capacity**
- ❑ **Reduce pumping costs (less electricity)**
- ❑ **Lessen the effect of water hammer.**
- ❑ **Prevent vacuum damage, such as pipeline collapse, seal failure, contamination and cross connection.**
- ❑ **Keep the lines full to reduce corrosion of the pipe.**

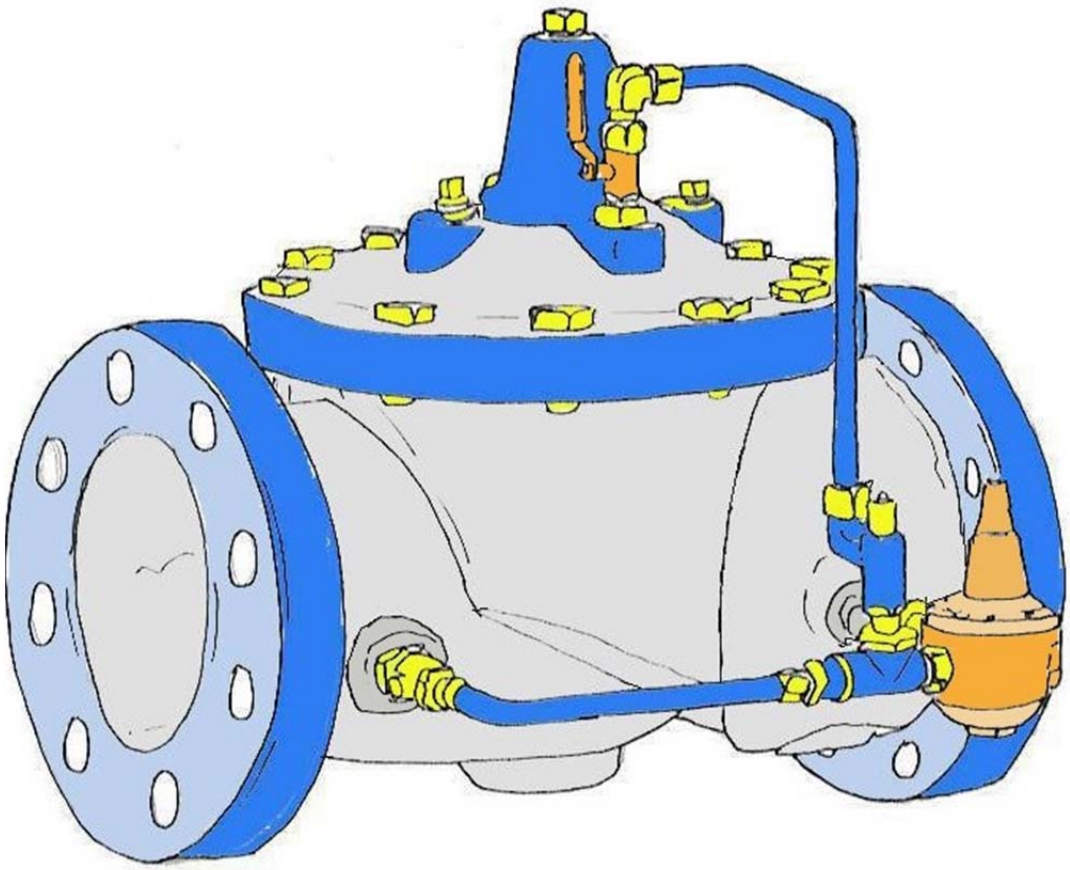


INTERNAL VIEW OF COMBINATION AIR VALVE

## Pressure Reducing Valves *Rotary Valve*

### 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 hold 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: time based (to reduce the pipe pressure at low demand times, e.g. at night) or flow modulated, 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).

## 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.).

**Valve Exercising Machine →**

**Hydrants** are designed to allow water from the distribution system to be used for fire-fighting purposes.

Left photograph-- the 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”. Right photograph-- an “Airport Runway” type of hydrant.

## More on 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. Of equal 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 should be accomplished:

- The accuracy of all valves and valve boxes are 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.

## Distribution System Hydrant Maintenance/Flushing

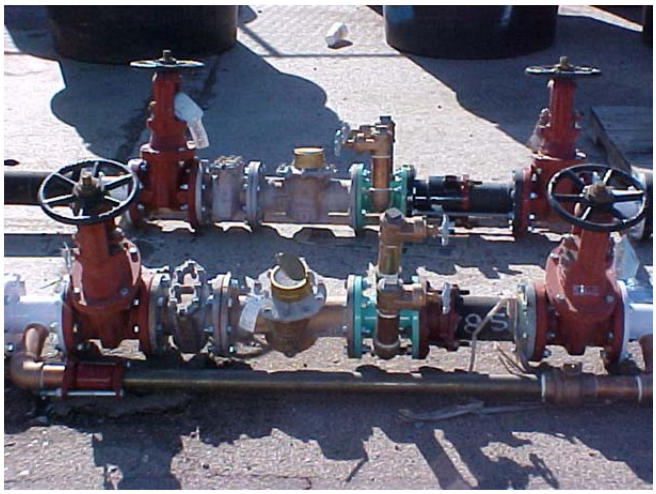
Fire hydrants provide not only fire protection, but also a method of moving large amounts of water out of various portions of the water system if microbiological and/or chemical contamination occurs and an emergency is declared. As a result, fire hydrant maintenance is conducted on al fire hydrants to assure their viability at all times.

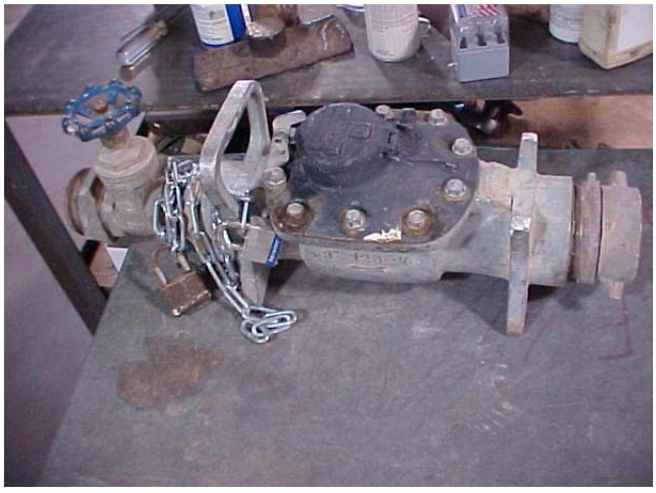
***Fire hydrant maintenance includes the following specific procedures:***

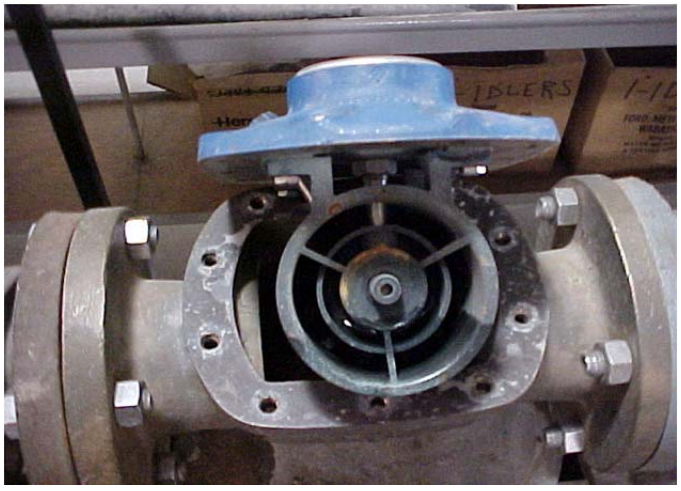
- All fire hydrants are inspected for leakage and repairs are made when necessary.
- The fire hydrant is fully opened and the ease of operation is noted.
- The hydrant flow is directed to waste. During this procedure, care is taken to direct and/or disperse the flow to minimize property damage.
- All fire hydrant nozzle caps are inspected for thread damage and lubricated to provide ease of operation.
- All fire hydrant nozzle cap thread gaskets are inspected and replaced as necessary.
- If a fire hydrant is found to be inoperable, a tag is placed on the hydrant, and the "***out of service"*** is immediately reported to the Fire Department.
- Accurate records related to the maintenance procedures performed on the fire hydrants are maintained by the water department.

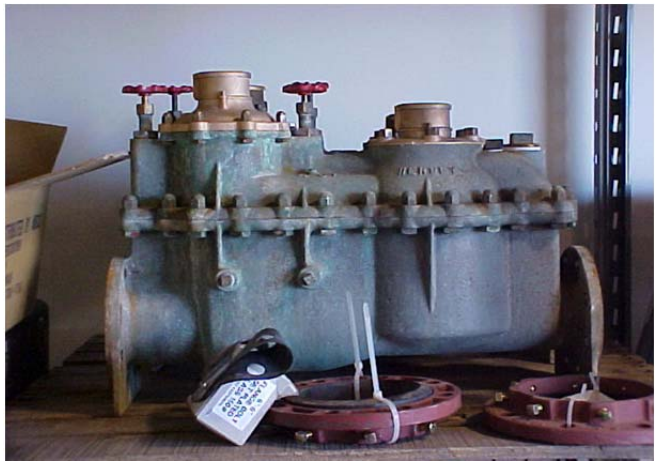
## Water Meters

Record the flow of water in a part of the distribution system.
Bypass, Compound, Turbine or Propeller meters.









## Water Meters

It is important to account for the water produced and supplied. A master meter should be installed on each source, with service meters placed at each point of use. These should be read and recorded periodically. Totals from the master meters should be compared to totals from the service meters to compute the amount of water lost in the distribution system. This information is important in locating and eliminating leaks and unauthorized taps.

Losses of 10 to 20 percent are not uncommon in many distribution systems. Also, it has been shown that a system which is not metered is likely to have a water usage up to three times as great as a metered system. Un-metered water users tend to water freely and have little incentive to repair plumbing leaks.

Computerized handheld electronic meter reader “station”

## Water Theft (*Unaccounted for Water*)

Commonly found methods and devices. Notice diversion with the Semi-truck and dial removal. Customers can be very tricky in water theft.

It is all about deception when stealing water and customers can think of incredible methods to save a small amount of water. I wish these customers could figure how to save gas instead.

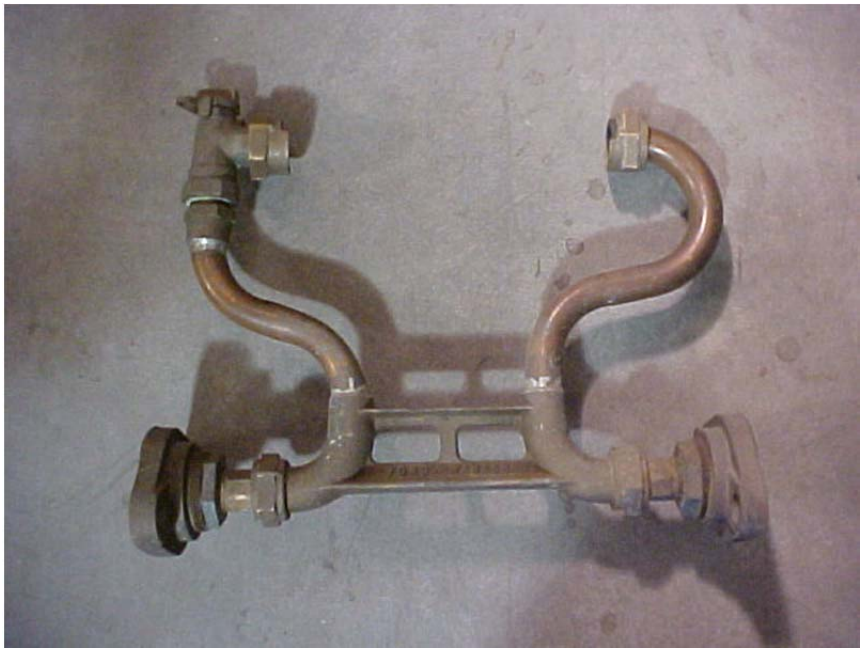
## Meter Shop

Equipment used for meter calibration. Most meters will read lower than normal, never higher. All meters will create “head loss” on the water service except for a “Magnetic Meter”. The large tanks are used to measure the water in gallons that is used to calibrate or check the water meter.

Most water utilities will charge the customer a fee to check the accuracy of the meter.

## 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 fittings. Single check, Poly Pig, 1 inch repair clamp, 4 inch full circle clamp, T- Bolt and a corp. and bronze saddle.

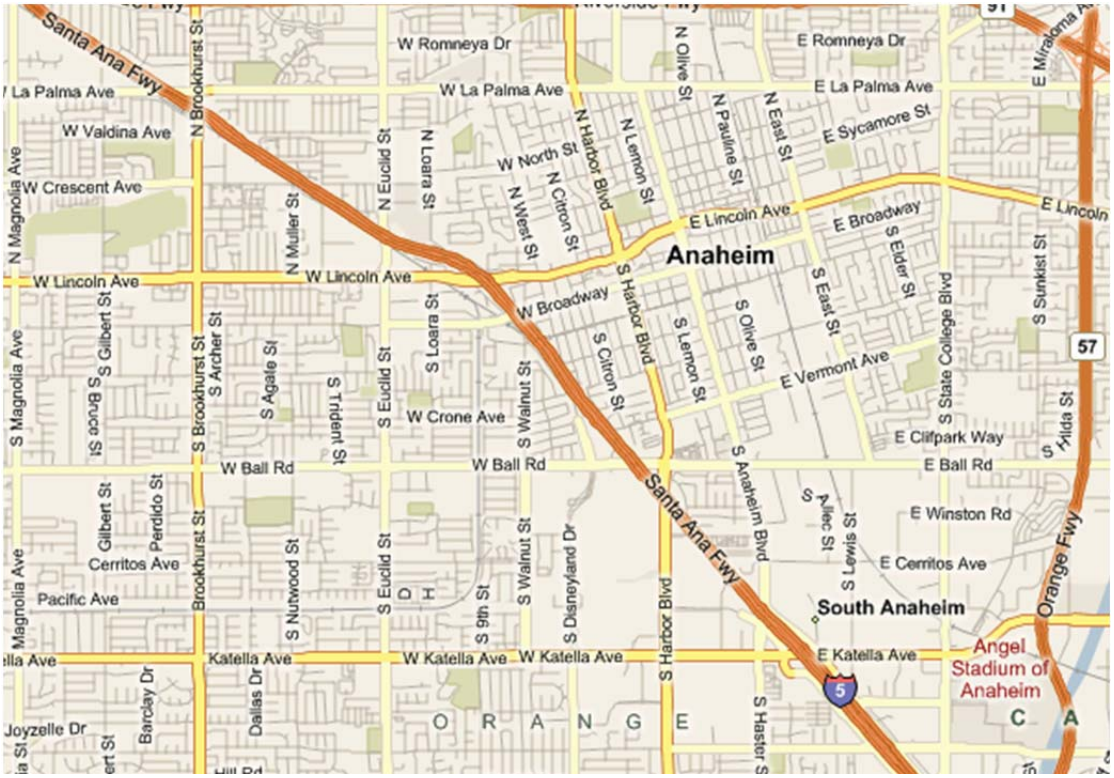
## System Layouts

There are three general ways systems are laid out to deliver water (picture 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.

Rust and debris from cleaning a steel main.

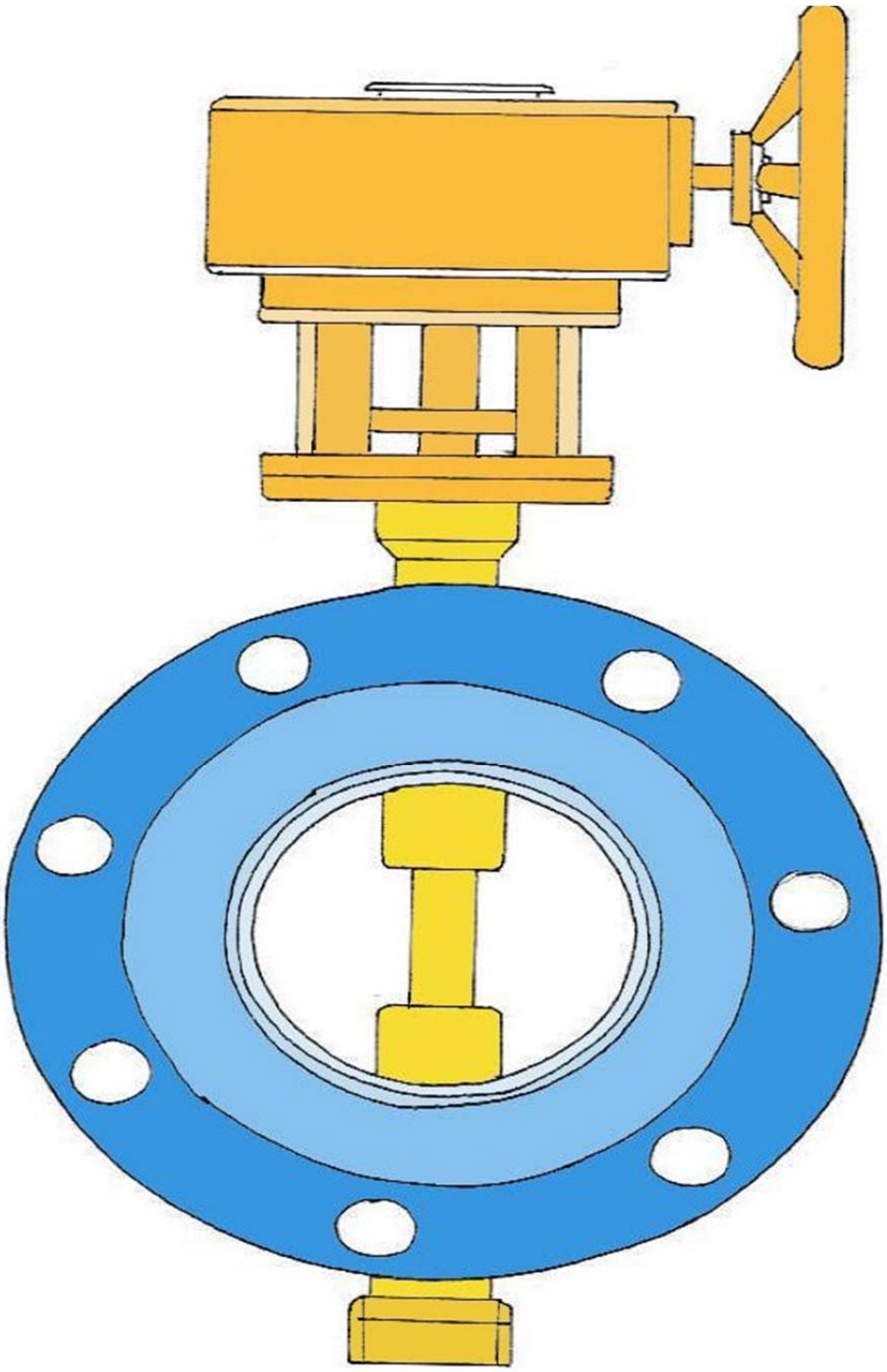
A temporary blow-off at a dead-end line.

## 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 Cause**
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 Solution**
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.



BUTTERFLY VALVE

## 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)**
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.

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.

**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 Pipe or Tubing**

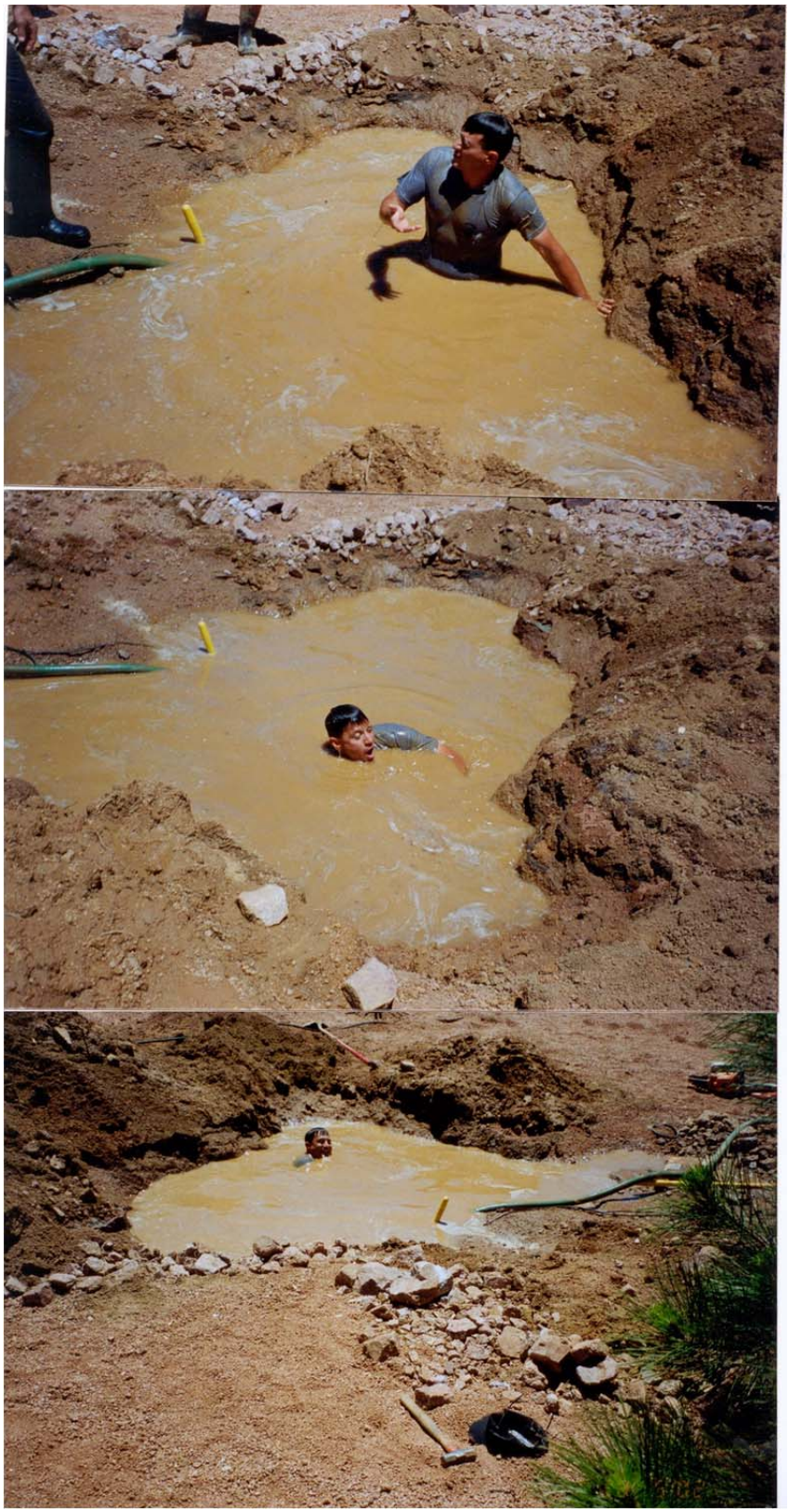
Copper is one of the most widely used materials for tubing. This is because it does not rust and is highly resistant to any accumulation of scale particles in the pipe. This tubing is available in three different types: **K, L, and M.**

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, faster installation will be the result.

Type K copper tubing is available in 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.

Copper Tubing Crimpers. Great if you are unable to get a shut-down. Just place this dude on the pipe. The problem is to fix that crimp when you are finished with the leak. They need to invent an uncrimper.



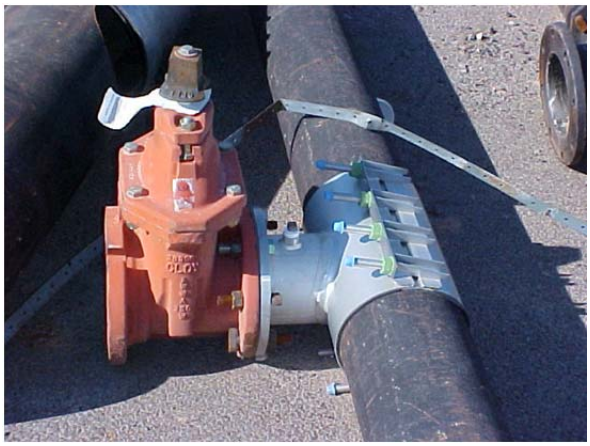
A normal day for a water distribution worker.

## 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



Customers are not inconvenienced by having their water turned off is one of the reason we utilize pressure taps or hot taps. Some of you are lucky to punch a hole with a ball-peen hammer. 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.

**Unions**

There are two types of pipe unions. The GROUND JOINT UNION consists of three pieces, and the FLANGE UNION is made in two parts. Both types are used for joining two pipes together and are designed so that they can be disconnected easily. When 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.

## 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 (PM)**
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 are repaired within twenty four hours after properly locating all underground utilities through the Underground Service Alert or "***Blue Stake*"** procedure.

## 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 insuring 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 high points 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.

## Water Softening

Water softening is a method of removing minerals from water which makes the water 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.

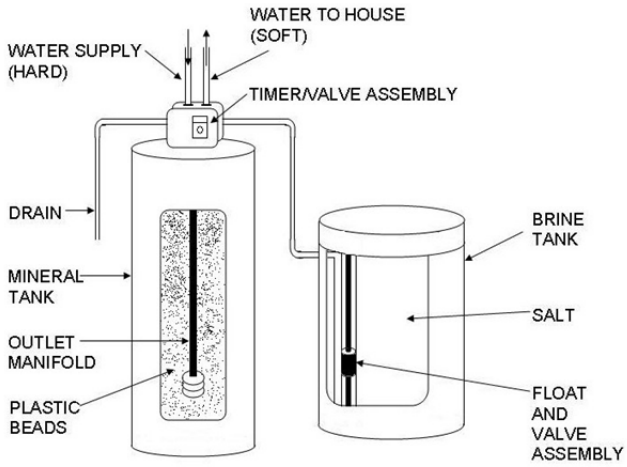
In the *ion exchange process,* the water filters through minerals called *zeolites.* As the water passes through the filter, the sodium ions in the zeolite are exchanged for the calcium and magnesium ions in the water, and the water is softened. After household softeners become exhausted, a strong solution 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.

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 containers hold the resin for the deionization.

**Soften Household Water**

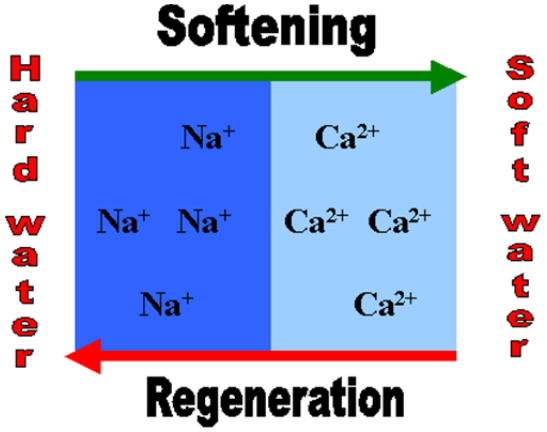
The most common way to soften household water is to use a water softener. Softeners may also be safely used to remove up to about 5 milligrams per liter of dissolved iron if the water softener is rated for that amount of iron removal. Softeners are automatic, semi-automatic, or manual. Each type is available 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.



## Mechanical Water Treatment Softeners

Mechanical water treatment softening units can be permanently installed into the plumbing system to continuously remove calcium and magnesium. Water treatment softeners operate on the ion exchange process. In this process, water passes through a media bed, usually sulfonated polystyrene beads. The beads are supersaturated with sodium. The ion exchange process takes place as hard water passes through the softening material. The hardness minerals attach themselves to the resin beads while sodium on the resin beads is released simultaneously into the water.

When the resin becomes saturated with calcium and magnesium, it must be recharged. The recharging is done by passing a salt (**brine**) solution through the resin. The sodium replaces the calcium and magnesium which are discharged in the waste water. Hard water treated with an ion exchange water softener has sodium added. According to the Water Quality Association **(WQA)**, the ion exchange softening process adds sodium at the rate of about 8 mg/liter for each grain of hardness removed per gallon of water.

For example, if the water has a hardness of 10 grains per gallon, it will contain about 80 mg/liter of sodium after being softened in an ion exchange water softener if all hardness minerals are removed. Because of the sodium content of softened water, some individuals may be advised by their physician, not to install water softeners, to soften only hot water or to bypass the water softener with a cold water line to provide unsoften water for drinking and cooking, usually to a separate faucet at the kitchen sink.

Mechanically softened water is not recommended for watering plants, lawns, and gardens due to its sodium content.

The container behind the salt pallet is a high concentration of salt and water. (Brine)

## Water Filters

Water filters generally come in two forms. Portable ion exchange water filters, and reverse osmosis water filters. Both are used for "*point of use*" drinking water, that is, to filter out harmful or unwanted particles before the water is used for human consumption.

Reverse Osmosis works by forcing the water through a semi-permeable membrane that stops certain particles from passing through.

Portable water filters work using a cartridge containing activated carbon and ion exchange resin. The carbon absorbs and helps reduce the levels of chlorine and chlorine compounds, as well as pesticides, color and other organic substances. This improves taste and appearance. The ion exchange resin works to reduce temporary hardness.

**Activated Carbon Filtration**
Activated carbon has been used for many years to solve water problems. In the beginning, its use was more art than science. Today, however, we understand more about what activated carbon can remove and how it removes impurities.

Activated carbon quickly and effectively removes chlorine from water.

The presence of organic matter in water can cause color, taste and odor complaints. Activated carbon adsorbs organic matter in its extensive network of pores. The adsorption process takes time, so service rates should be limited to 5 gpm/ft (12m/hr) or less for these applications.

A handful of GAC.  Just expensive burnt coconuts shells.

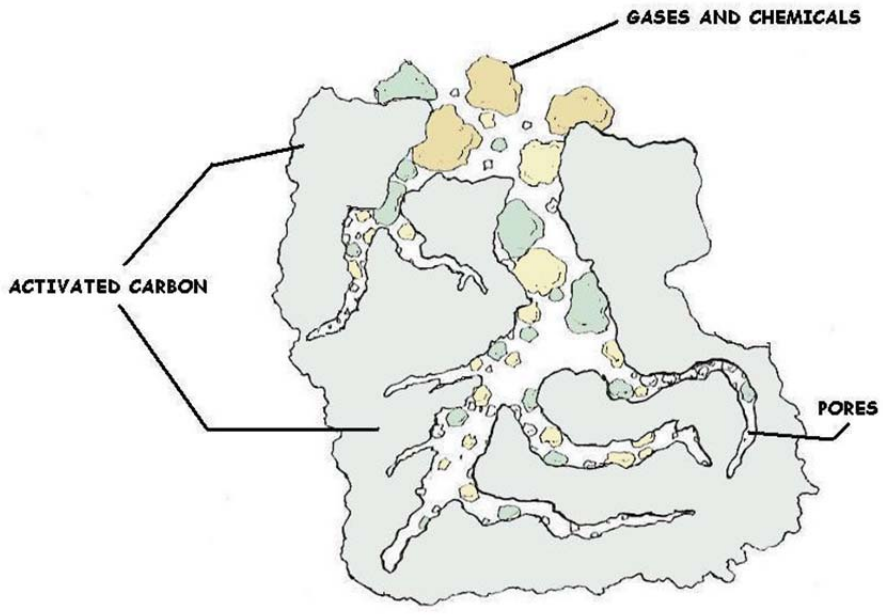
## SOCs and VOCs

Synthetic organic chemicals (**SOC**) include all man-made organics, some of which are volatile organic compounds (**VOC**). Activated carbon can substantially reduce many VOCs such as benzene, trichloroethane and carbon tetrachloride.

Activated carbon also removes SOCs such as Alachlor, EDB and toluene. The EPA is establishing limits for these chemicals in public drinking water supplies.

Before recommending treatment, water suspected of containing any of these and other substances must be analyzed to determine their concentrations and whether they exceed EPA standards.

Activated carbon beds compact with use so they may need occasional backwashing, however, backwash carbon as little as possible to prevent loss of the fragile material. Also, contaminant-laden carbon may migrate toward the bottom of the bed during backwash and reduce filter performance. When operating carbon on turbid water supplies, remove suspended particles with a depth filter before treating it with activated carbon. A carbon filter typically backwashes at 10 gpm/ft (25 m/hr.) for about 10 minutes, followed by a 5 minute down flow rinse. Over a period of several months to two years, the carbon's adsorption capacity diminishes. The exhausted carbon bed should be replaced with fresh carbon. The old carbon should be hauled to an approved disposal facility.




ACTIVATED CARBON ABSORBS GASES AND CHEMICALS

## 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 cost are reduced.

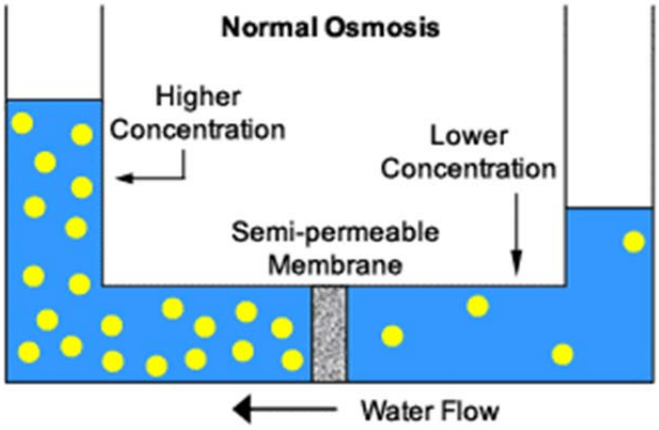
### Description of Membrane Filtration Processes

In the simplest membrane processes, water is forced through a porous membrane under pressure while suspended solid, 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 mm 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. The 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.

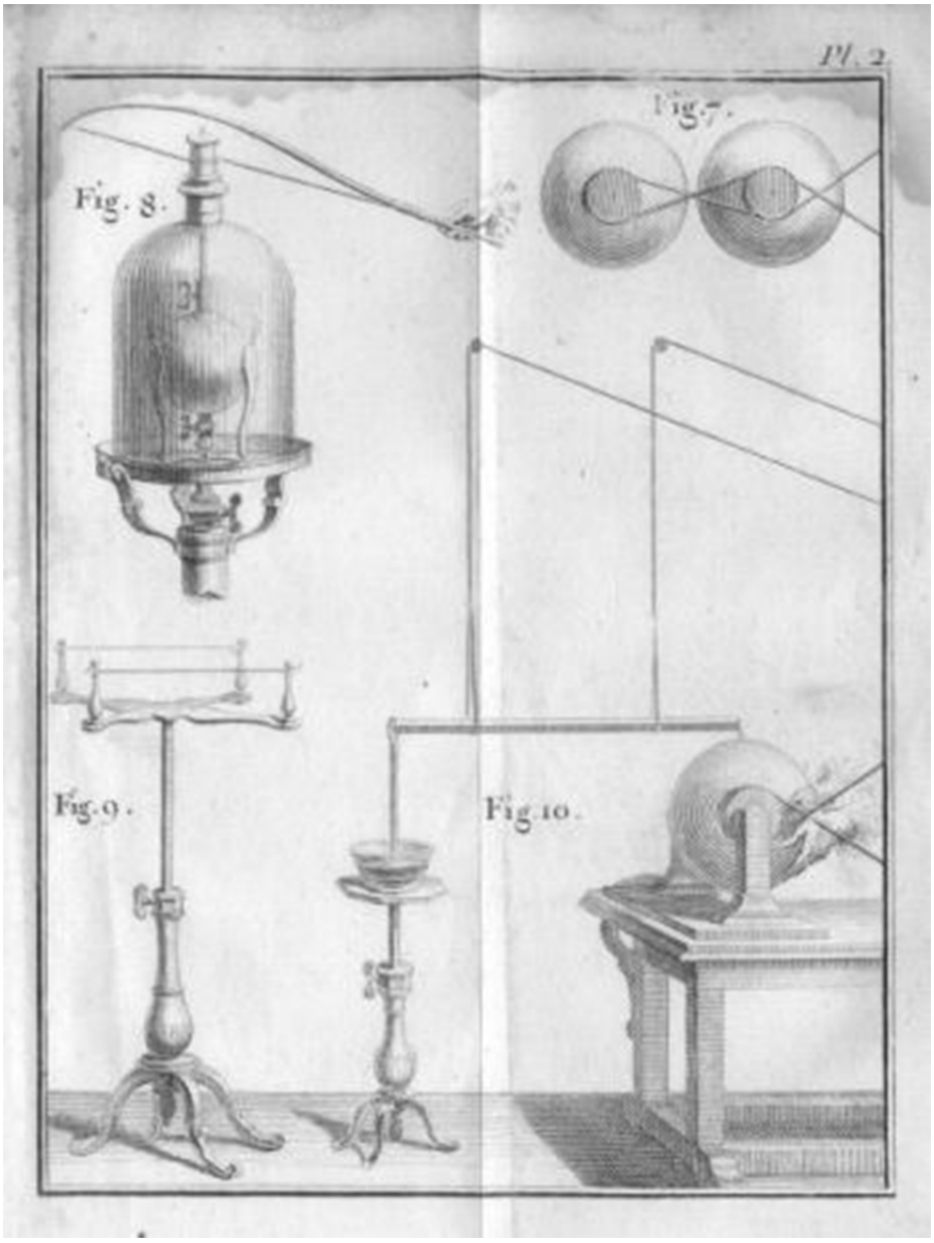
### Nanofiltration

Nanofiltration (**NF**) is a process using membranes 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 MWC 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 most organic chemicals, and radionuclides and microorganisms.




Nollet's first RO machine.

## 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 new 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 additional 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 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 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. Starting in 2001, and 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 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 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 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 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 the EPA to make grants to states to carry out the public water system supervision program. States may also use a portion of their SRLF 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 SRLF 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. 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.

**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 the 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). The 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). 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.

The 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). The 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 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 colonies 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 the EPA to give priority consideration to 24 such projects.

Because of the events of 9/11, we have to prepare for an attack on our water distribution system. This includes preparing for hurricanes, floods and terrorist actions.

Normal well crew, an Electrician, Distribution Foreman and Hydrogeologist working together to provide quality groundwater.

Video screen of a well scan. This picture is from inside a truck cab. Technology today is cutting edge and will only grow. This technology will find itself in new positions in the water department. Nice and easy jobs that you can transfer into and get out of the hole.

Normal work for a distribution repair crew.  It isn't pretty but it pays the bills. These photographs almost looked staged because the workers are too clean for being in a hole.  In the real world, you will be soaked with mud and water.  The top photo looks to be a tapping valve that has broken or blown off.  No shoring or ladder in sight.

# 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 |

| 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 |

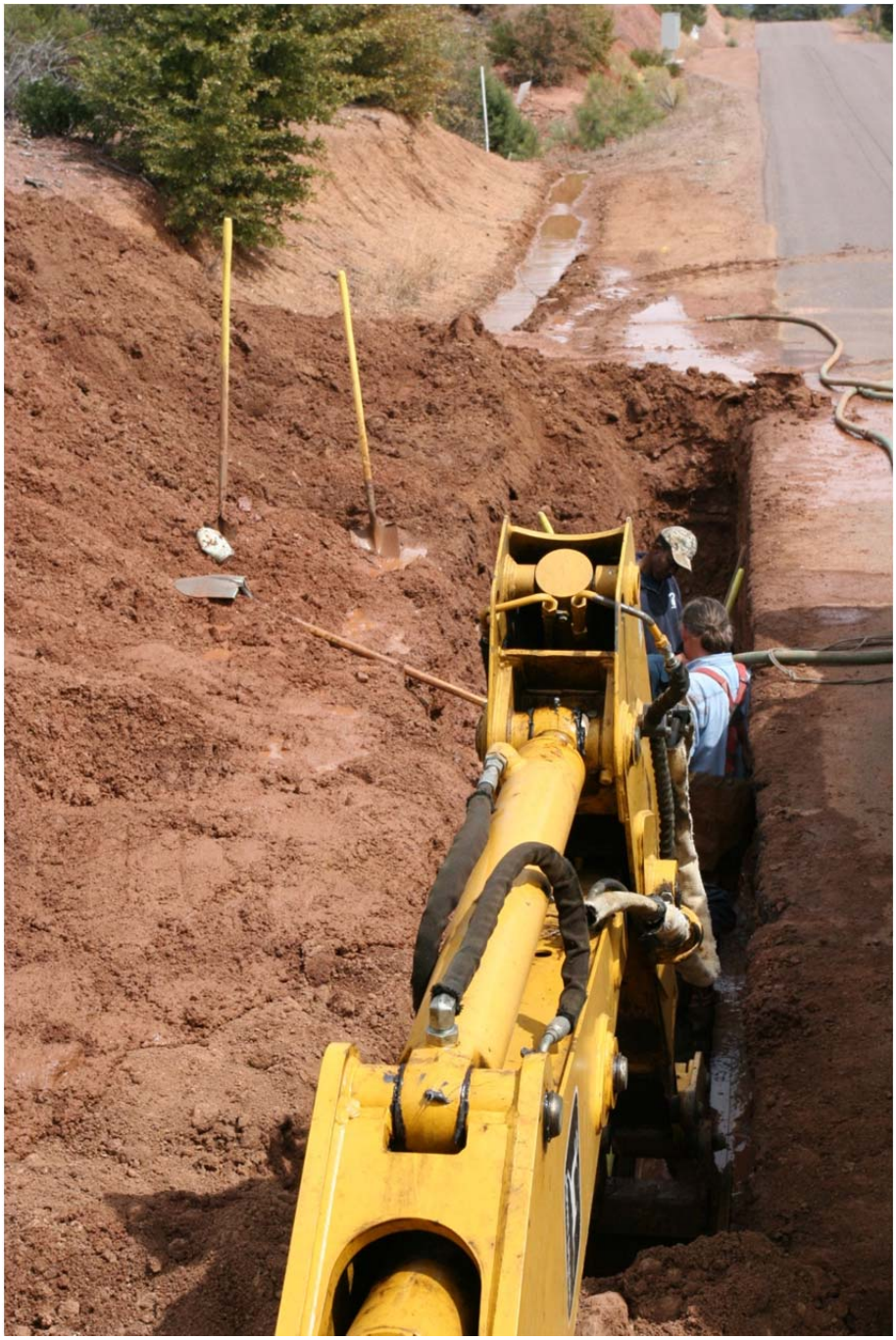
| | | | | |
|---|---|---|---|---|
| o-Dichlorobenzene | 0.6 | 0.6 | Liver, kidney, or circulatory system problems | Discharge from industrial chemical factories |
| p-Dichlorobenzene | 0.075 | 0.075 | Anemia; liver, kidney or spleen damage; changes in blood | Discharge from industrial chemical factories |
| 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 |

We teach this course in both a conventional classroom setting and in a distance based CEU course. We have taught over 20,000 students.



Never work in an unprotected trench and without hard hats or shoring or let an unsafe operator run the backhoe, as in this photograph. You need shoring and a ladder in all trenches, the only thing I see correct, is the spoil is two feet from the edge of the trench.

## 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 |

## Important 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 adequate 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.

# New EPA 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. For most people 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. In January 2001, the EPA revised the standard from 50 parts per billion (ppb), ordered that it fall to 10 ppb by 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 10 ppb 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 10 ppb can be found at www.epa.gov/safewater/arsenic.html.

## ICR

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 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 website.

## Disinfection Byproduct Regulations

In December 1998, 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 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 ppb for water systems serving more than 10,000 people under the Total Trihalomethane Rule finalized by EPA in 1979. The Stage 1 Disinfectant/Disinfection Byproduct Rule standards became effective for trihalomethanes and other disinfection byproducts listed above back in December 2001 for large surface water public water systems. Those 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. 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 new standard replaced the old standard of a maximum allowable annual average level of 100 parts per billion back in December 2001 for large surface water public water systems. The standard became effective for the first time back in December 2003 for small surface water and all ground water systems.

**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 became 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 an annual average of 10 ppb in drinking water. This standard became effective for large public water systems in December 2001 and for small surface water and all ground public water systems in December 2003.

**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 ppm in drinking water.

This new standard became 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.

## 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.

### Disinfectant Review Statements:

Disinfectant residual: The CT values for disinfection are used to determine the disinfection efficiency based upon time and what other parameter?

Bacteria, Virus and Intestinal parasites: What types of organisms may transmit waterborne diseases?

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.

How is the effectiveness of disinfection determined? *From the results of coliform testing.*

The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

What types of source water are required by law to treat water using filtration and disinfection? *Groundwater under the direct influence of surface water, and related surface water sources.*

**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.

pH Strips

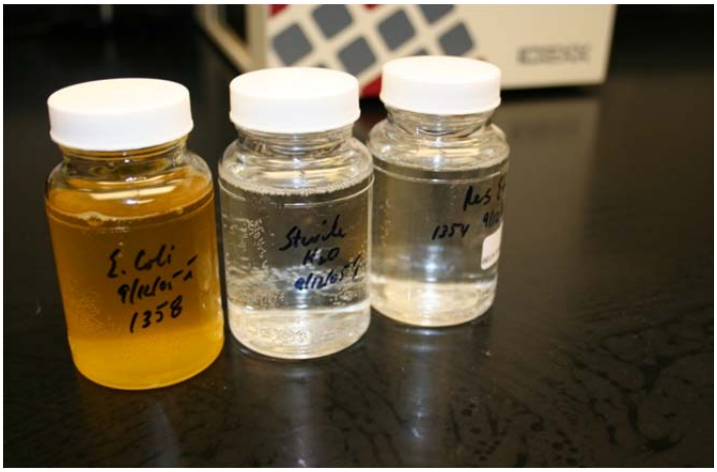
pH is on a scale from 0-14. 7 is considered neutral and acid is on the 0 to 7 side and the base is 7-14. pH is known as the Power of Hydroxyl Ion activity.

Common water distribution sample bottles, 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.

**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.



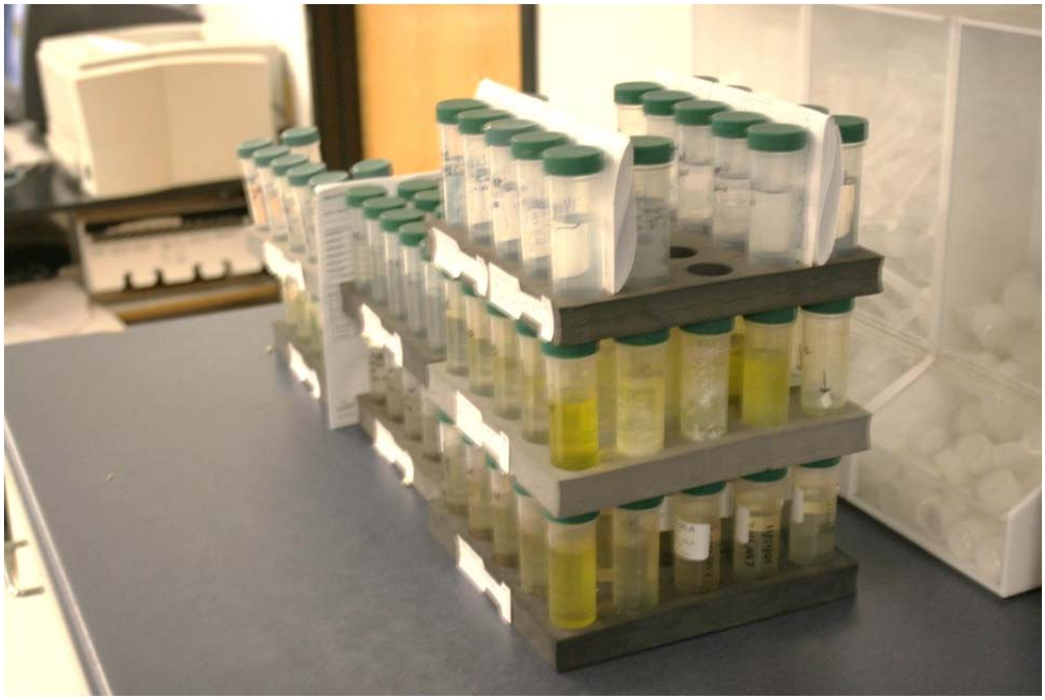

The bottle with the yellow color on the left indicates coliform bacteria is present. If the bottle fluoresces under a black light, fecal bacteria is present.

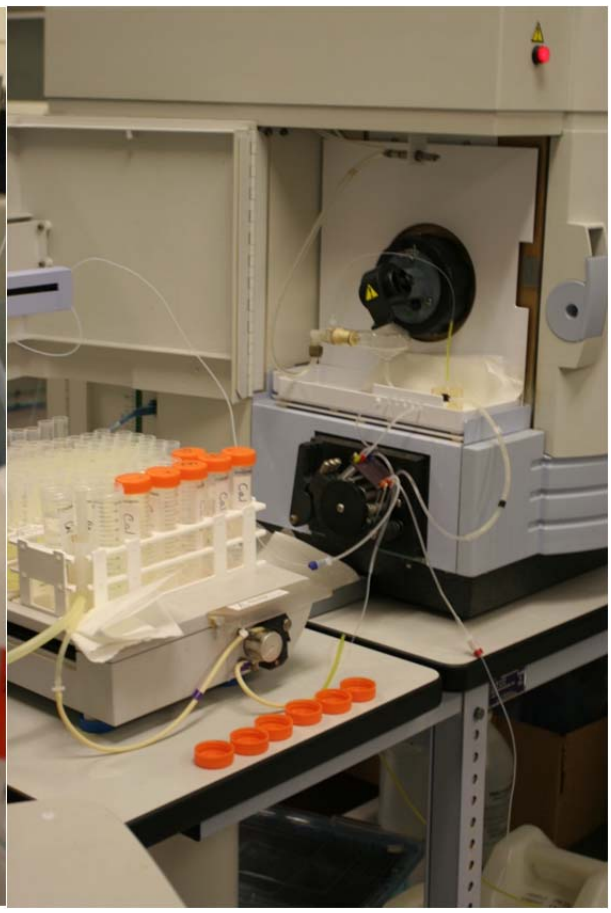
This lab equipment is used for testing parameters in water such as Metals, Pesticides and Hydrocarbons. Often geotechnical water testing that is performed to support characterization regarding the fate and transport of contaminants in soils and sediments. Information such as the grain size distribution 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.

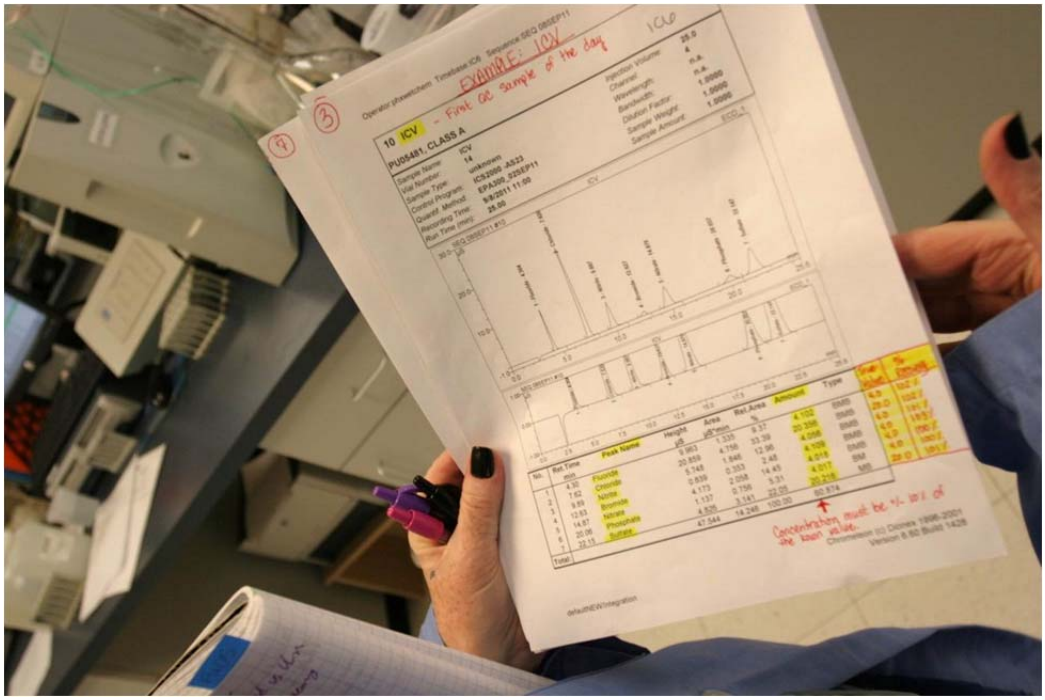
Vapor atomic fluorescence spectroscopy (CVAFS) analytical techniques were designed by the EPA for the analysis of Mercury at low and sub parts per trillion (ppt) concentrations. Low detection limits were developed to support risk assessment, Mercury bioaccumulation in fish is a heightened concern. Thirty-nine 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.





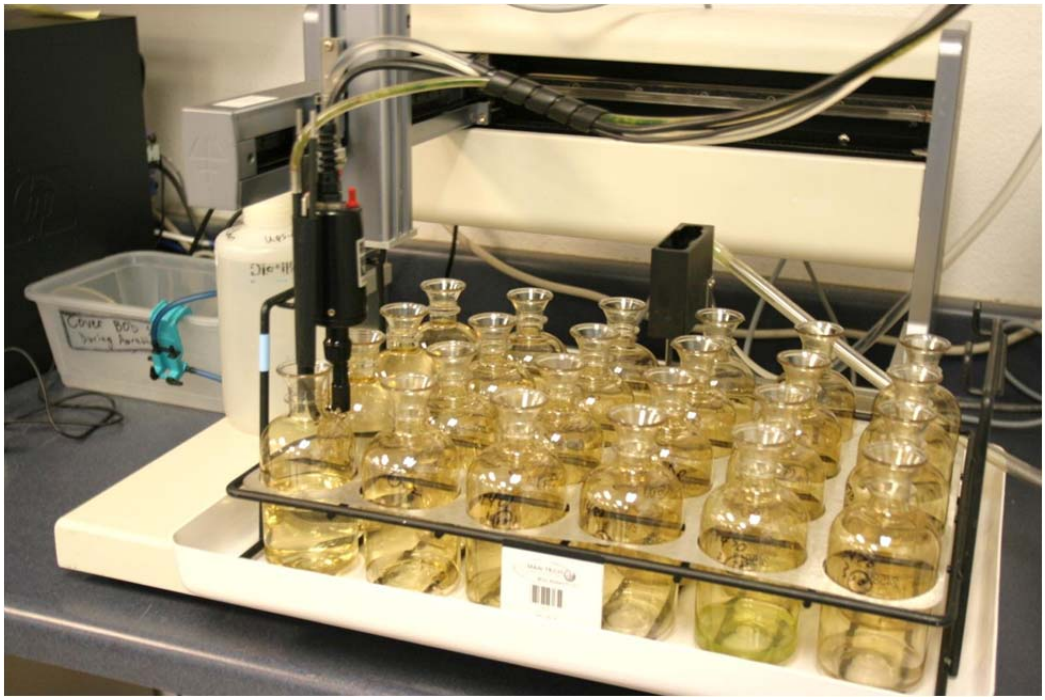
This lab's Quality Assurance Quality Control (QAQC) methods includes spikes, performance samples, replicates, detection limits and blanks.

Prepared samples stored for metal analysis.



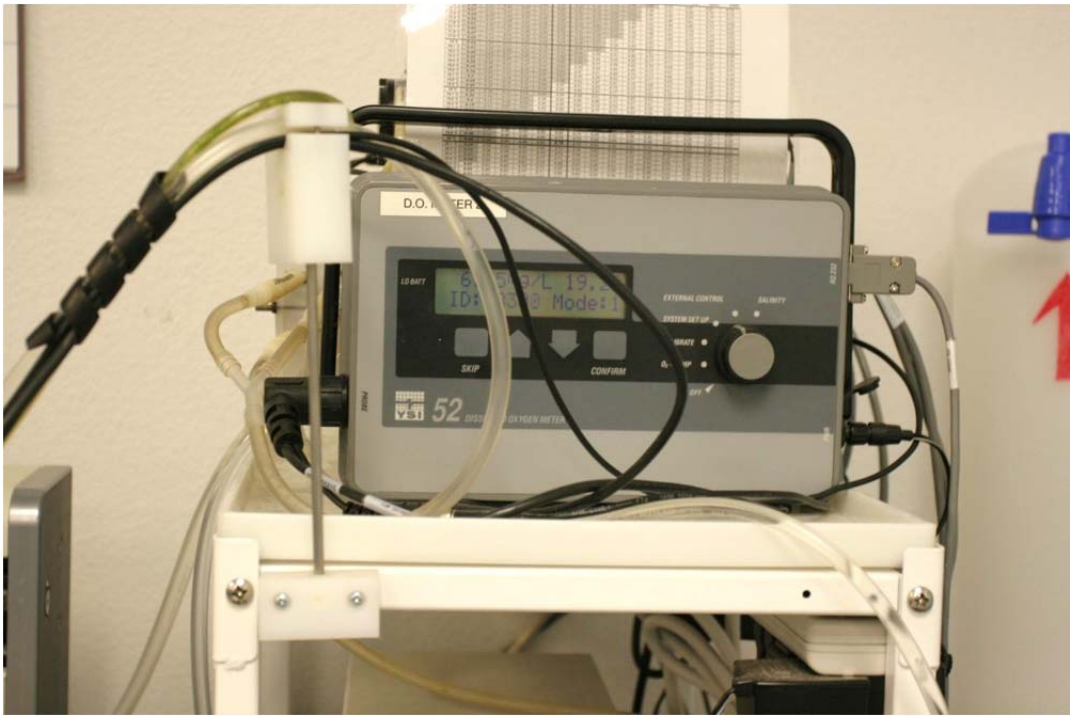

Top Photo: This form shows a typical ion chromatography run will have a standard curve consisting of 4 or 5 points for each ion of interest. A combined ion stock standard is used. The correlation coefficient of the standard curve for each ion should be >.998. The coefficient is calculated by plotting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

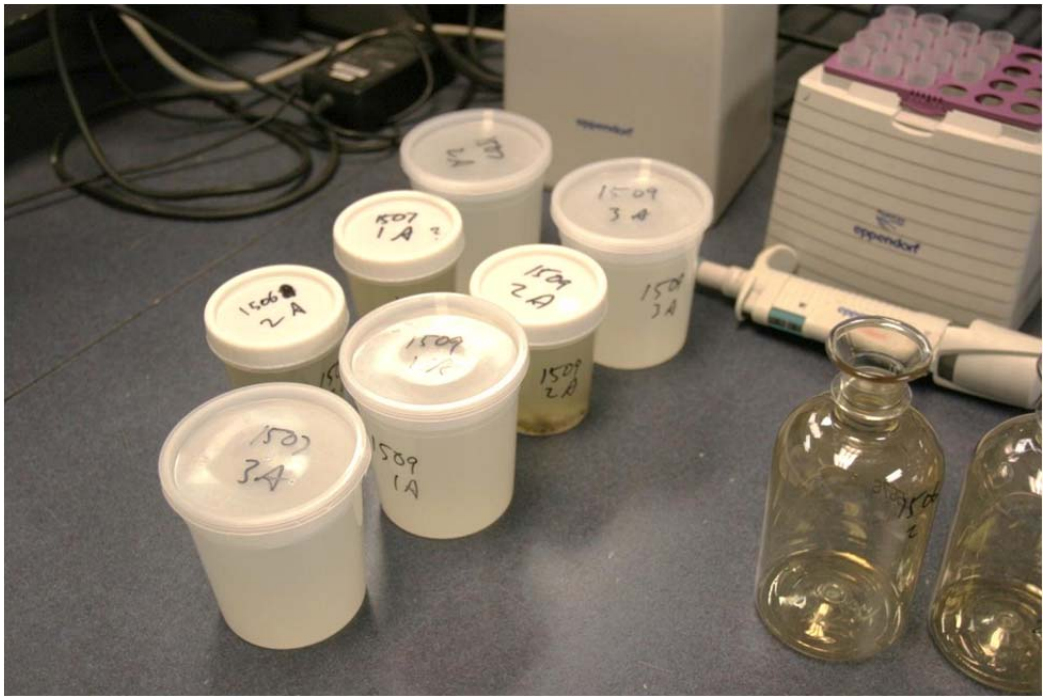
Bottom Photo: Some labs have the luxury of automatic filling dilution water for BOD bottles. If the BOD bottle is filled too rapidly, excessive agitation and bubbling may result in supersaturated water. This device also has the capability of measuring the oxygen level.



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.





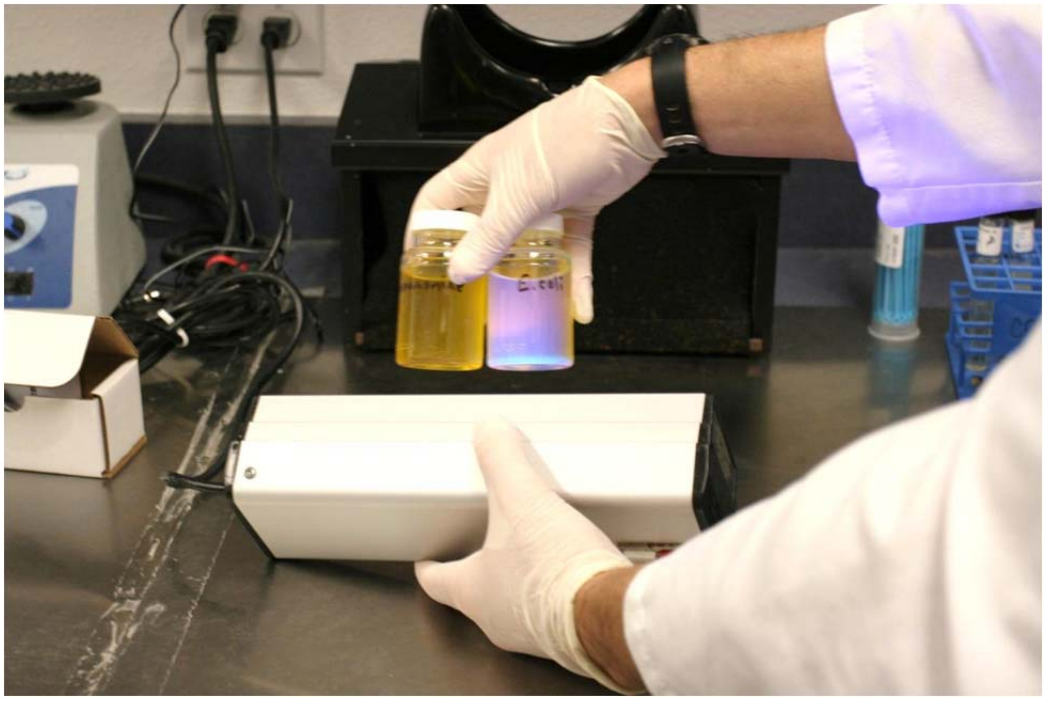

Top Photo: Collecting the seed in a 500 ml bottle and let settle at least 1 hour and up to 36 hours. This will allow settleable solids to settle and help assure the seed is homogeneous.

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.

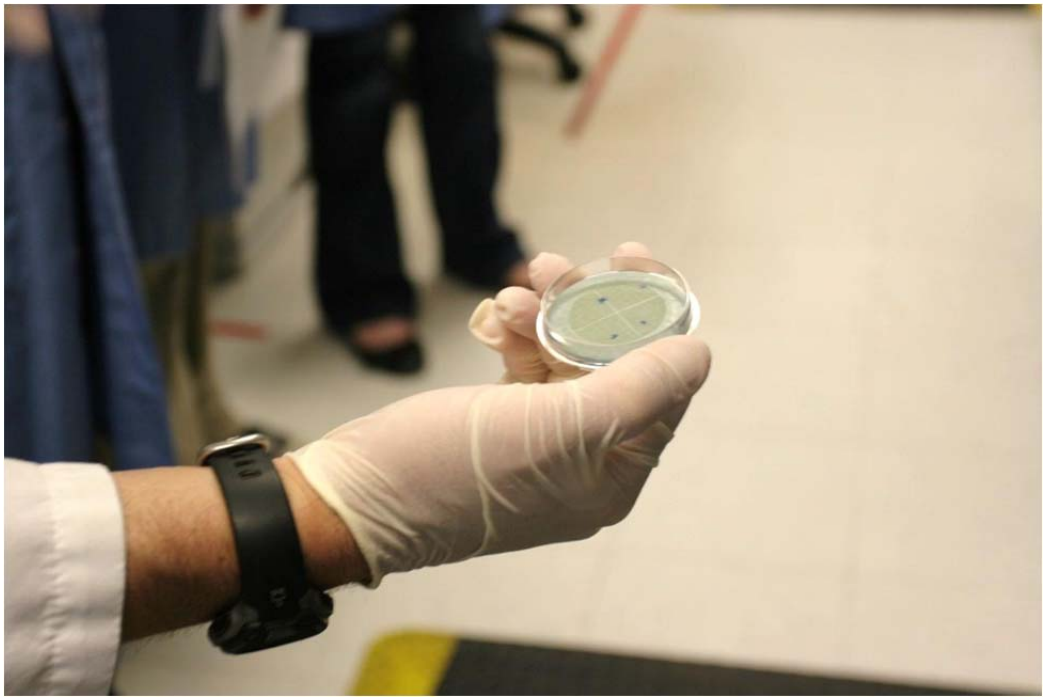
Bottom Photo: Some labs perform a variation of coliform testing this technician is making sure his area follows QAQC standards.

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.



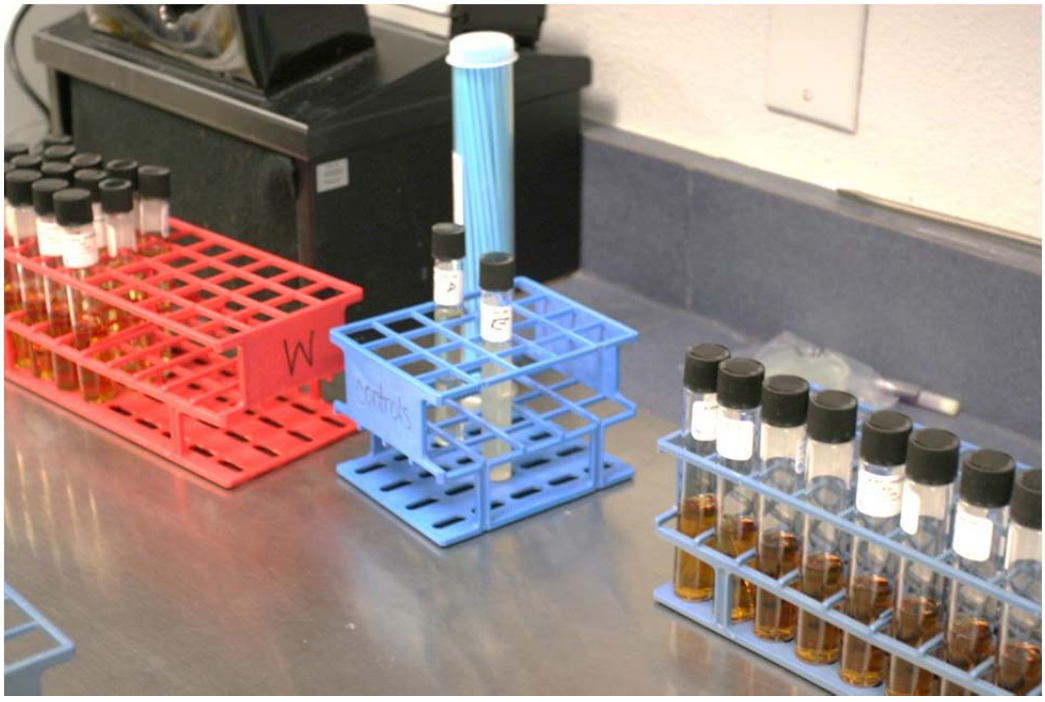
Top Photo: This technician is using Colilert which is a commercially available enzyme-substrate liquid-broth medium (IDEXX Laboratories, Inc.) that allows the simultaneous detection of total coliforms and *Escherichia coli* (*E. coli*). It is available in the most-probable number (MPN) or the presence/absence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

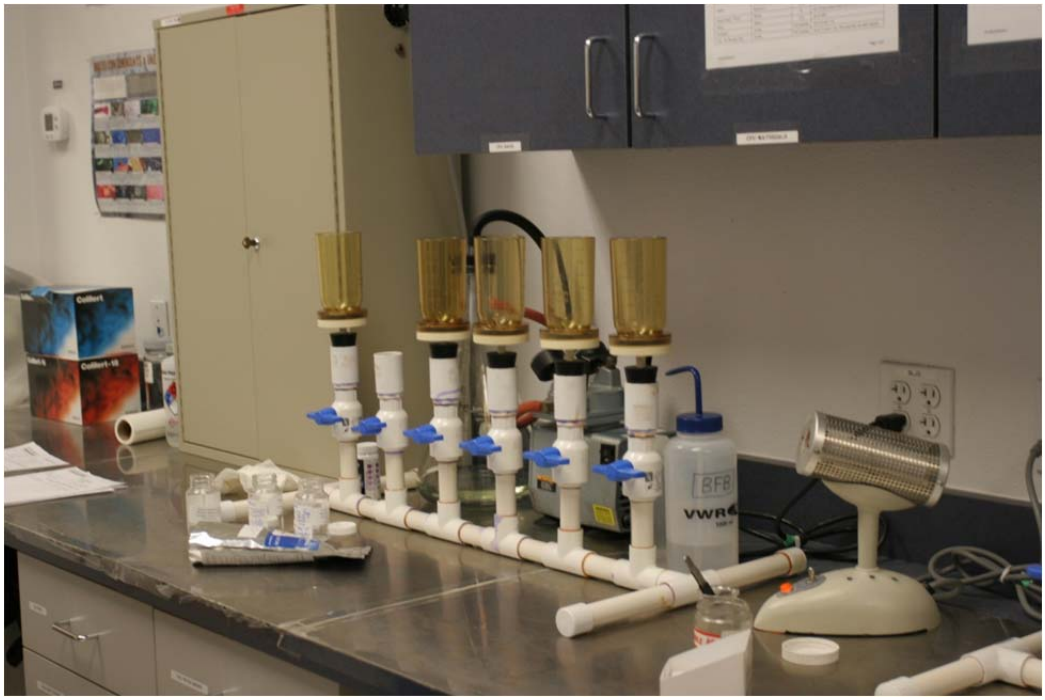
Bottom Photo: Another method is using a petri dish with a filter membrane. The broth and membrane used vary depending on the sample type for water or wastewater.



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 Treatment System

Your heart and lungs play a vital role in keeping you alive. If you don't take care of your body and how your blood circulates, you will die. Our body works very similar to the water system we operate. Our lungs clean the blood exchanging carbon dioxide with oxygen; our water treatment plant treats the water by taking impurities out. Our heart pumps the blood to our lungs and out to other vital organs; our water pump stations deliver the water to our systems and to the customers.

What happens if our arteries become clogged and damaged or we lose circulation? The blood flow will no longer make its way back to the lungs or the lungs will no longer be able to send the purified blood to the vital organs. The same can happen if we have problems with our water transmission lines or distribution lines.

**Water Treatment Basics**
Water is a powerful solvent that is capable of dissolving almost everything it comes in contact with. For instance, water can pick up harmless minerals from the earth, such as calcium, magnesium, carbonates and sulfates. These give the water a pleasing taste as well as beneficial health qualities. This is also because water utilities across the country have in place effective processes to remove contaminants that cause waterborne diseases. The most commonly used processes include filtration, flocculation and sedimentation, and disinfection.

**Flocculation/Sedimentation**
The flocculation process coagulates (joins together) particles with alum and metal salts so that they settle out of the water as sediment. Sedimentation is simply a gravity process that removes flocculated particles from the water.

**Filtration**
Filtration removes remaining particles from the water supply. Those particles may include silt, natural organic matter, iron and manganese, and microorganisms. Filtration clarifies water and improves the effectiveness of disinfection.

**Disinfection (Chlorination, Ozonation)**
Water is then disinfected to ensure that dangerous microbes are killed. Chlorine-based disinfectants or ozone are used because they are very effective. Chlorine-based disinfectants also provide residual protection against biological contamination in the water distribution system. This is a critical step to assure our water is safe all the way to the consumer's tap.

**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

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.

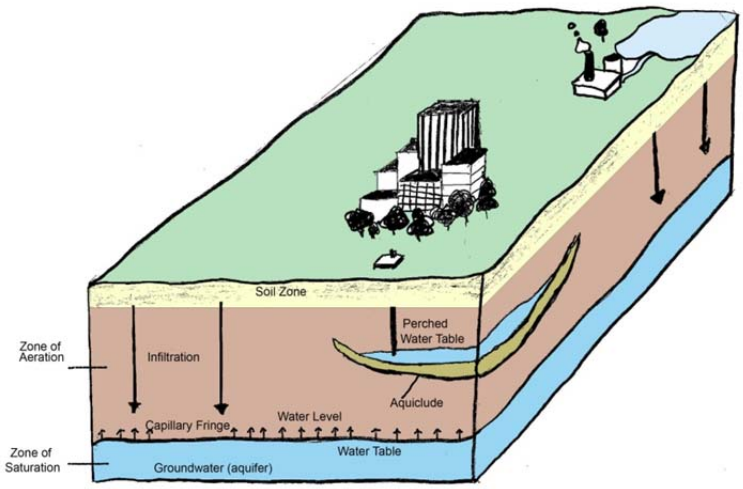
Well with a mineral oil sealed vertical turbine pump.

## Aquifer

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 cracks, joints, or fractures in solid rock, through which groundwater moves. 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*.

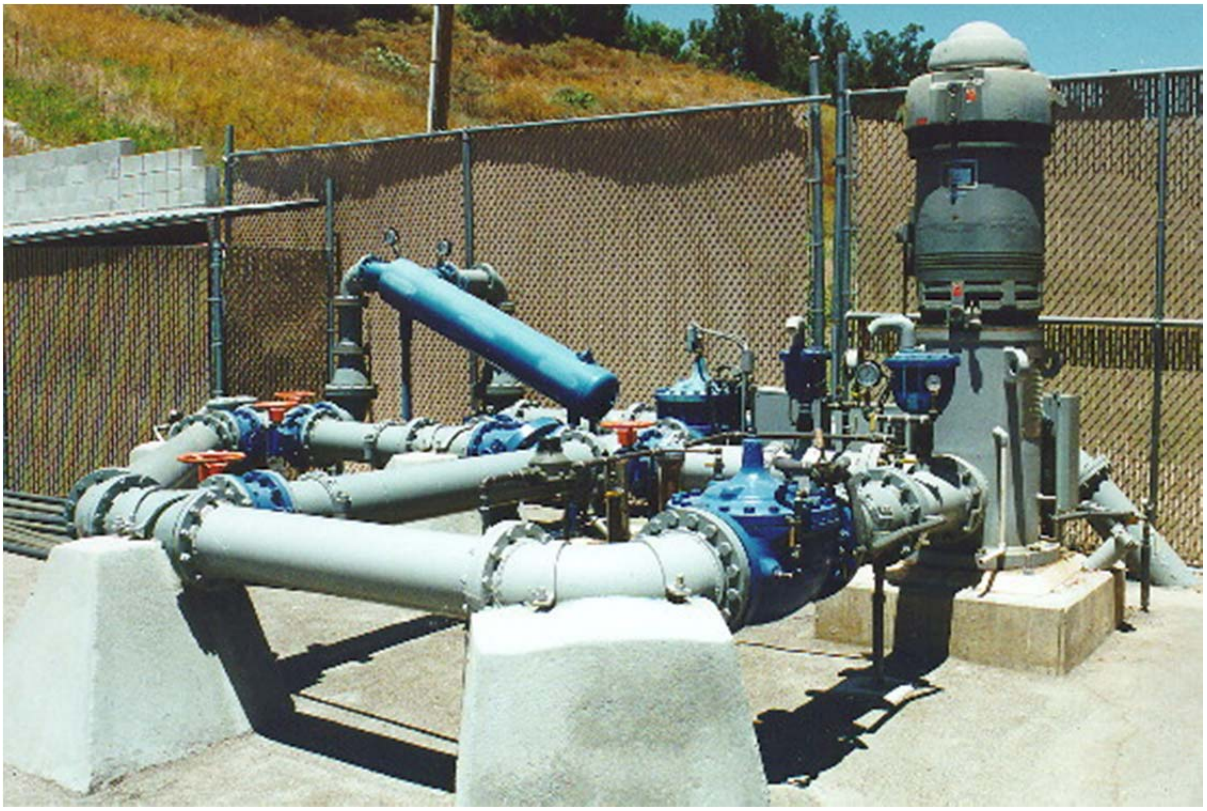
Porous media such as sandstone may become so highly cemented or recrystalized that all of the original space is filled. In this case, the rock is no longer a porous medium. However, if it contains cracks it can still act as a fractured aquifer. Most of the aquifers of importance to us are unconsolidated 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 springs or 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.



Vertical Turbine Well

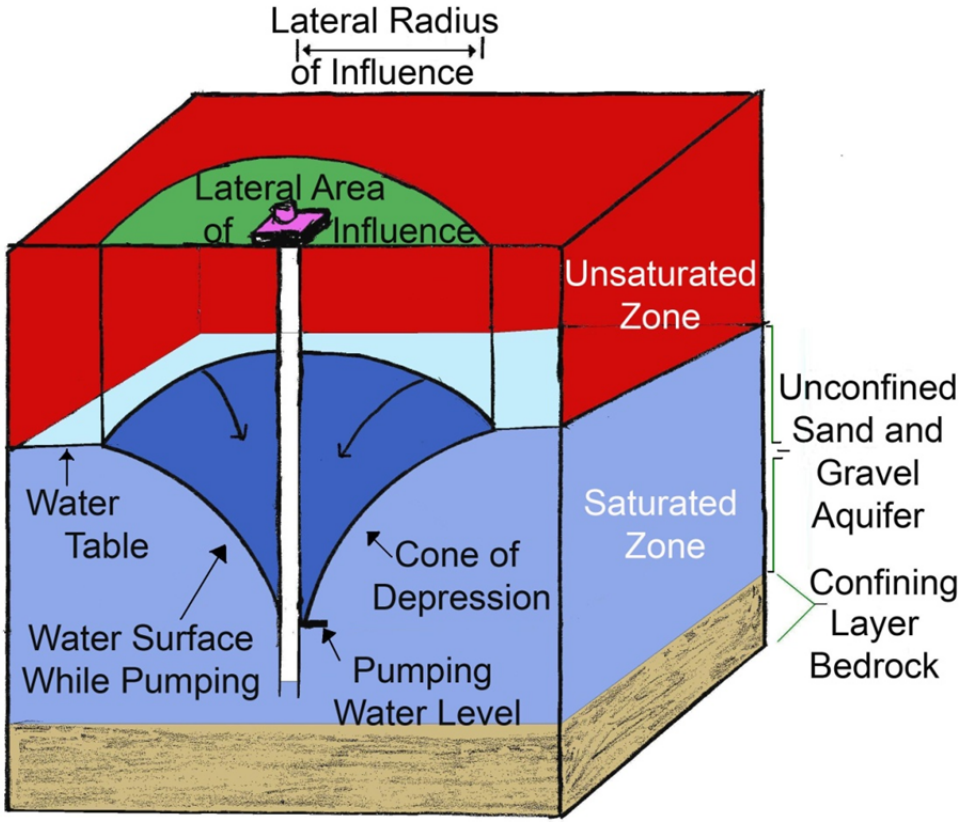
*Unconfined aquifers* are those that are bounded by the water table. Some aquifers, however, lie beneath layers of impermeable materials. These are called *confined aquifers*, or some-times *artesian aquifers*. A well in such an aquifer is called an *artesian well*. The water in these wells rises higher 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.

## 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.

## 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.

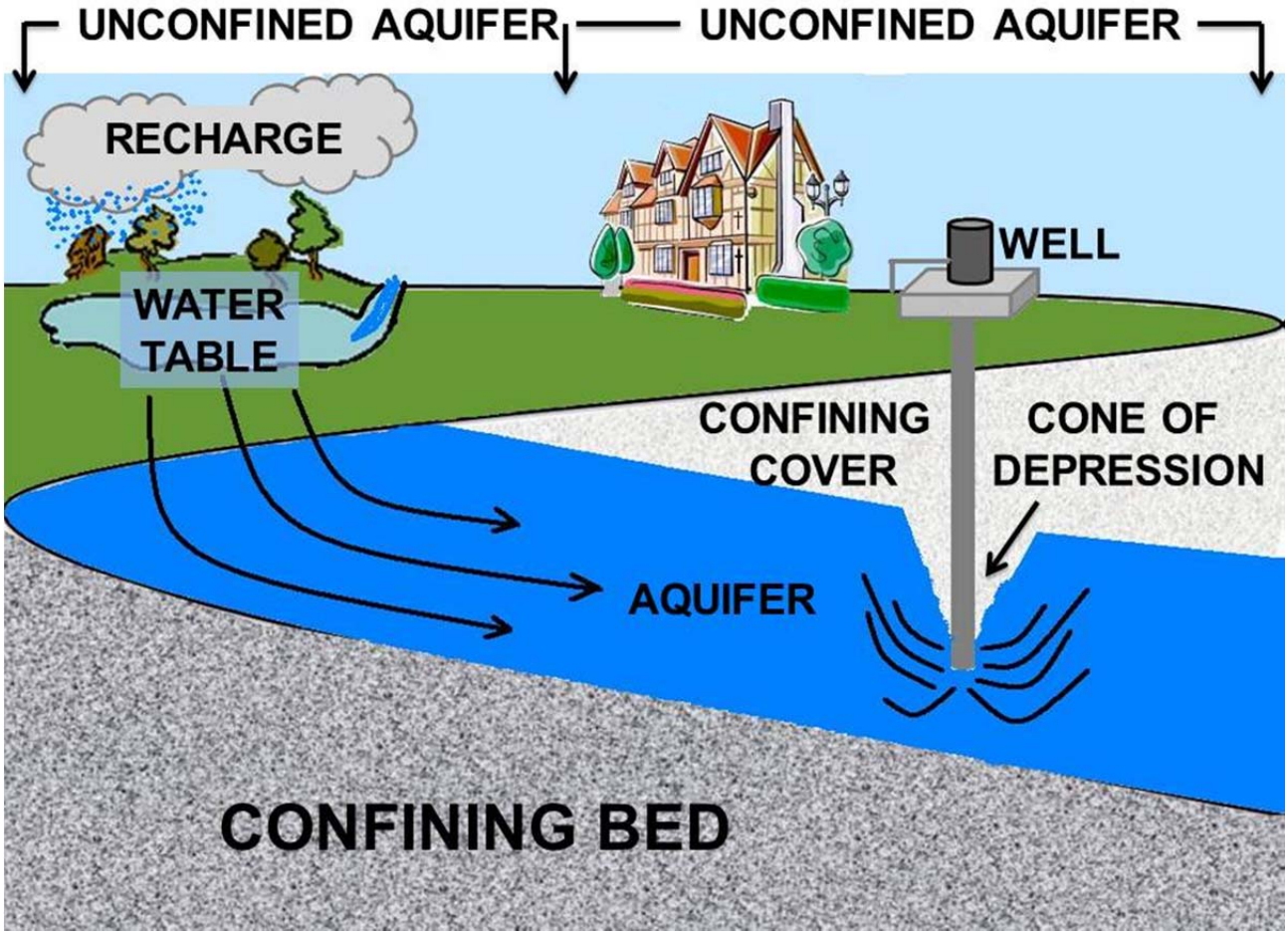
Over the last 10 years, however, public attention has been drawn to incidents of ground-water contamination. This has led to the development of ground-water protection programs at federal, state, and local levels. Because ground-water supplies and conditions vary from one area to another, the responsibility 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.




Aquifer Description

# 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<br>Land disposal of wastes<br>Stockpiles<br>Dumps<br>Sewage sludge disposal | De-icing salt use & storage<br>Animal feedlots<br>Fertilizers & pesticides<br>Accidental spills<br>Airborne source particulates |
| **ABOVE WATER TABLE** | Septic tanks, cesspools, & privies<br>Holding ponds & lagoons<br>Sanitary landfills<br>Waste disposal in excavations<br>Underground storage tank leaks | Underground pipeline leaks<br>Artificial recharge<br>Sumps and dry wells<br>Graveyards |
| **BELOW WATER TABLE** | Waste disposal in wells<br>Drainage wells and canals<br>Underground storage<br>Mines | Exploratory wells<br>Abandoned wells<br>Water-supply wells<br>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.

Although the Clean Water Act does not require states to develop ground-water protection strategies, the legislation does authorize states to take this action. As of 1989, all 50 states have at least begun to develop ground-water protection strategies, and some of these are in advanced stages. Proceeding at varying paces, the states are tailoring their efforts to fit their own perceived needs and budgets.

**Citizen and Community Roles**
In the first three chapters of this guide, you learned how dependent our nation is on ground water to provide water for drinking and other household uses, agriculture, and industry. You also learned a little about the many substances that can contaminate our ground-water supplies, where they can come from, and how difficult and costly it is to try to clean up ground water once it has been contaminated. Finally, you were given some information about current national and state programs to protect ground water. This chapter will focus on what actions you and your community can take to protect your ground-water supplies.

**What Information Do You and Your Community Need?**
Because no two communities are exactly alike in terms of hydrogeologic conditions, resources, or problems, ground-water protection efforts should be tailored specifically to meet the needs of each community. Thus, before you can begin to help your community develops an effective program to manage its ground-water resources; you will need the answers to some very specific questions.

**What Has Your State Done to Protect Ground Water?**
As you saw in Chapter III, the Safe Drinking Water Act requires all states to develop programs to protect public water supply wells from contaminants that could be harmful to human health. Information on your state's wellhead protection program should be available from the agency in your state that is managing this program. (Appendix 2 contains a list of the state agencies managing wellhead protection programs.)

Chapter III also mentioned that all 50 states are in the process of developing comprehensive ground-water protection strategies. Such a strategy can provide you with information on who has what ground-water responsibility in the state and on how any existing state programs fit together. A copy of your state's ground-water protection strategy should be available from the agency in your state that is managing this effort. (**Appendix 2** also contains a list of these state agencies.)

**Does Your Community's Drinking Water Come from Ground Water, and What Information Is Available About Your Community's Wells?**
If your community's drinking water comes from ground water, you will need some basic information about your community's hydrogeologic setting, including the types of soil conditions and geologic formations and the type, location, and depth of the aquifer that stores the ground water. In addition, information on the community's wells will be needed, including whether they are public or private, shallow or deep; their locations; and how they are constructed. It also could be important to know if sites have been identified for future wells.

Potential sources for this information include your local library, your local water supply agency, and your state geological survey, a local office of the U.S. Geological Survey (**USGS**), a county agricultural extension agent, or even the geology or engineering department of a local university or college.

**What Is the Current Quality of Your Ground-Water Supply, and What Actual or Potential Sources of Contamination Are Present in Your Community?**
You will need to know if your water is currently free from bacterial and chemical pollution and what kinds of procedures are in place to test or monitor ground-water quality. Initial information on the quality of your community's ground water should be available from your local water supply agency or your local health department.

Closely related to the issue of ground-water quality is determining whether there are activities in the community that produce or use toxic or hazardous substances and where underground storage tanks are located. Information on activities using or producing toxic or hazardous materials may be more difficult to obtain, but the community right-to-know provisions in the 1986 Superfund amendments may give you a starting point. These provisions require the establishment of state planning commissions, emergency planning districts, and local emergency planning committees. They also require companies that use certain toxic or hazardous substances to report to these committees. Companies also are required to report serious environmental releases immediately. All of this information is required to be available to the public.

Another source of information on environmental releases is available in a data base developed by EPA called the Toxic Chemical Release Inventory that is publicly accessible through the National Library of Medicine. The data include the names, addresses, and public contacts of plants manufacturing, processing, or using the reported chemicals; the maximum amount stored onsite; the estimated quantity emitted into the air, discharged into bodies of water, injected underground, or released to land; methods used in waste treatment and their efficiency; and information on the transfer of chemicals offsite for treatment and disposal.

(To obtain additional information on this data base, see Appendix 2.) On a local level, your community's fire department also may be helpful in providing information on both companies using toxic or hazardous materials and the location of underground storage tanks.

**What Can Your Community Do to Protect Its Ground Water?**
If your community relies on ground water for its water supplies, it has a strong incentive to protect that ground water. Before a plan or program can be developed to protect ground water, it is important to identify existing or potential threats to the ground water. This will generally mean conducting an inventory to learn the location of facilities using, manufacturing, or storing materials that have the potential to pollute ground water.

How your community conducts this inventory will depend largely on the resources available, particularly the number of people available to do the work and funds. A number of communities, however, have had great success in using groups of volunteers to conduct their inventories. For example, the city of El Paso, Texas, has mobilized its senior citizens with the help of the federally funded Retired Senior Volunteer Program (RSVP) and the Texas Water Commission. The inventory of existing or potential threats to the community's ground water may be quite long, and it is unlikely that your community will have the resources to address all of these threats. How do community officials decide which threats are the most serious or set priorities? One way is to assess these threats on the basis of their relative risks to the community's ground water. This requires determining which of the specific pollutants are most likely to be released and reach the ground water in concentrations high enough to pose health risks.

In addition to having an incentive to protect its ground water, your community has a number of powers that can be used for that purpose. These include implementing zoning decisions; developing land-use plans; overseeing building and fire codes; implementing health requirements; supplying water, sewer, and waste disposal services; and using their police powers to enforce regulations and ordinances. A few communities have begun developing their own ground-water protection programs using a variety of management tools based on these powers.
These management tools include:

- **Zoning Ordinances** - To divide a municipality into land-use districts and separate incompatible land uses such as residential, commercial, and industrial; zoning also defines the type of activity that can occur within a district and specifies appropriate regulations that can be used prevent activities that could be harmful to the community's ground water.

- **Subdivision Ordinances** - Applied when a piece of land is actually being divided into lots for sale or development to ensure that growth does not outpace available local facilities such as roads, schools, and fire protection; subdivision ordinances also can be used to set density standards, require open space set asides, and regulate the timing of development, all of which can have significant impacts on ground-water quality.

- **Site Plan Review** - To determine if a proposed development project is compatible with existing land uses in the surrounding area and if existing community facilities will be able to support the planned development; this review also can be used to determine compatibility of the proposed project with any ground-water protection goals.

- **Design Standards** - To regulate the design, construction, and ongoing operation of various land-use activities by imposing specific physical requirements, such as the use of double-walled tanks to store chemicals underground.

- **Operating Standards** - To ensure the safety of workers, other parties, and the environment by specifying how an activity is to be conducted; these can take the form of best management practices (BMPs) that define a set of standard operating procedures for use in a particular activity to limit the threat to the environment (e.g., limits on pesticide applications or animal feedlot operations).

- **Source Prohibitions** - To prohibit the storage or use of dangerous materials in a defined area; these can take the form of prohibitions of certain activities or of restrictions on the use of certain materials.

- **Purchase of Property or Development Rights** - To guarantee community control over the activities on lands that feed water into an aquifer, this may involve outright purchase of the land or of a more limited interest, such as surface-use rights.

- **Public Education** - To build community support for regulatory programs, such as controls on pollution sources in special zoning districts, and to motivate voluntary ground-water protection efforts, such as water conservation or household hazardous waste management.

- **Ground-Water Monitoring** - To assess the quality of local aquifers by sampling public and private wells for selected contaminants.

- **Household Hazardous Waste Collection** - To alleviate the threat to ground water from the disposal in regular trash pick-ups, sewers, or septic systems of household products that contain hazardous substances or other materials that can be harmful to ground water, such as paints, solvents, or pesticides.

- **Water Conservation** - To reduce the total quantity of water withdrawn from ground-water aquifers and to protect against contamination by reducing the rate at which contaminants can spread in the aquifer (e.g., excessive withdrawals from an aquifer located near the ocean can draw salt water into the aquifer and contaminate wells).

**How Can You Clean Up Your Own Act?**
So far, the emphasis has been on how you can help your community to protect its ground water through the development of community-wide policies and programs. But ground-water protection also begins at home. How do your personal habits affect your community's ground water quality? What can you, as an individual, do to protect your community's ground water?

**How Do You Dispose of the Polluting Materials Used in Your Home?**
You may be surprised to learn that the way you dispose of products you use at home can contribute to the contamination of your community's ground water. You may be even more surprised to learn that a number of the products you use at home contain hazardous or toxic substances.

The truth is, however, that products like motor oil, pesticides, left-over paints or paint cans, mothballs, flea collars, weedkillers, household cleaners, and even a number of medicines contain materials that can be harmful to ground water and to the environment in general. (See Appendix 1 for a list of the types of products commonly found around homes and their potentially harmful components.) The average American disposes of approximately one pound of this type of waste each year. So, although the amount of any of these substances that you pour down your drain, put in your trash, or dump on the ground may seem insignificant to you, try multiplying it by the number of people in your community. That amount may not seem so insignificant.

**Don't Pour It Down the Drain!** Anything you pour down your drain or flush down your toilet will enter your septic system or your community's sewer system. Using this method to dispose of products that contain harmful substances can affect your septic system's ability to treat human wastes.

Once in the ground, these harmful substances can eventually contaminate the ground water. In addition, most community wastewater treatment plants are not designed to treat many of these substances. Thus, they can eventually be discharged into bodies of surface water and cause contamination.

**Don't Put It in the Trash!** Community landfills also generally are not equipped to handle hazardous materials. As rain and snow pass through the landfill, the water can become contaminated by these products and eventually carry them into the ground water and surface water.

**Don't Dump It on the Ground!** Hazardous wastes that are dumped on or buried in the ground can contaminate the soil and either leach down into the ground water or be carried into a nearby body of surface water by runoff during rainstorms.

**Do Use and Dispose of Harmful Materials Properly!** There are very few options for disposing of hazardous products used in your home, so the first step may be to limit your use of such products. Whenever possible, substitute a nonhazardous product. When that is not possible, buy only as much as you need.

Larger quantities may be less expensive, but they leave you with the problem of disposing of them safely. Finally, urge community officials to sponsor periodic household hazardous waste collection days if they have not established this policy.

By helping your community to centralize collection of hazardous household wastes for appropriate disposal, you will be helping your community to make a major contribution toward protecting its ground water. The saying "Garbage in, garbage out" applies to more than computer data bases.

**How Do You Take Care of Your Septic System?**
Your septic system is designed to have its effluent discharge into a drainage field where it undergoes some decomposition by micro-organisms in the soil as it works its way down to the ground water. If your system is not pumped out frequently enough, solid materials can leave the tank and enter the drainage field. Any substances poured down your drains also will enter that drainage field and, eventually, the ground water.
To prevent ground-water contamination from your septic system:

- Have your septic system inspected annually and pumped out regularly; no chemical or other additive can be a substitute for this, and these septic system chemicals actually can prevent your septic system from functioning properly

- Be cautious about what you put into your system; substances like coffee grounds, cigarette butts, sanitary items, or fats do not break down easily in septic systems, and chemicals like paints, solvents, oil, and pesticides will go from your septic system into the ground water.

- Limit the amount of water entering your system by using water-saving fixtures and appliances.

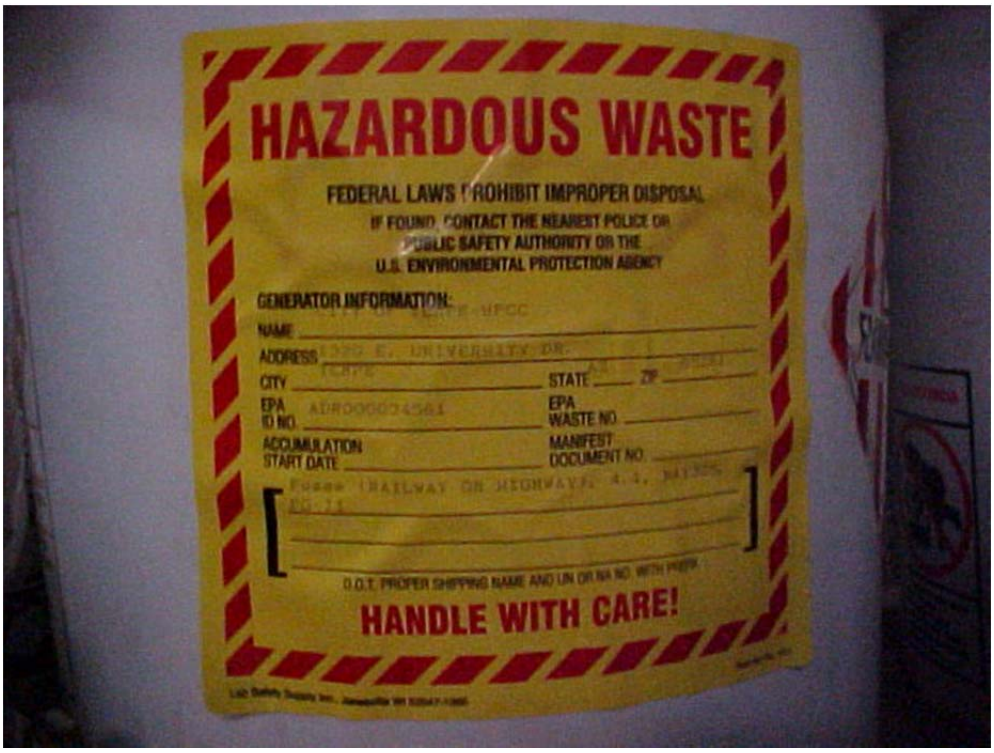
**How Does Your Garden Grow?**
If you are a homeowner, you probably take a lot of pride in your home and the yard surrounding it. You may apply fertilizers to make your grass thick and green, your flowers colorful, and your vegetable crop abundant. You also may use pesticides to keep bugs from ruining what the fertilizers have helped to produce. What you may not know, however, is that many of these fertilizers and pesticides contain hazardous chemicals that can travel through the soil and contaminate ground water. If you feel you must use these chemicals, use them in moderation. This is not a case of "more is better." Your county extension agent can provide information on natural ways to control lawn, garden, and tree pests that can reduce reliance on chemicals.

**What Else Can You Do?**
Get informed and get involved! Around the country, citizens are getting involved in their communities, volunteering their time and energy, and making a difference. If you think one person can't change the system, help form a group. You, alone or as part of a group, can help to educate your family, friends, and neighbors about the importance of ground water to your community. And, after you've cleaned up your own act, you can help your community clean up its act.

## APPENDIX 1. POTENTIALLY HARMFUL COMPONENTS OF COMMON HOUSEHOLD PRODUCTS

| Product | Toxic or Hazardous Components |
|---|---|
| Antifreeze (gasoline or coolant systems) | methanol, ethylene glycol |
| Automatic transmission fluid | petroleum distillates, xylene |
| Battery acid (Electrolyte) | sulfuric acid petroleum solvents, alcohols, glycol ether |
| Degreasers for driveways and garages | chlorinated hydrocarbons, toluene, phenols, dichloroperchloroethylene |
| Degreasers for engines and metal | petroleum solvents, ketones, butanol, glycol ether |
| Engine and radiator flushes | hydrocarbons, fluorocarbons |
| Hydraulic fluid (brake fluid) | hydrocarbons |
| Motor oils; and waste oils | hydrocarbons |
| Gasoline and jet fuel | hydrocarbons |
| Diesel fuel, kerosene, #2 heating oil | hydrocarbons |
| Grease, lubes | hydrocarbons |
| Rustproofers | phenols, heavy metals |
| Car wash detergents | alkyl benzene sulfonates |
| Car waxes and polishes | petroleum distillates, hydrocarbons |
| Asphalt and roofing tar | hydrocarbons |
| Paints, varnishes, stains, dyes | heavy metals, toluene |
| Paint and lacquer thinner | acetone, benzene, toluene, butyl, acetate, methyl ketones |
| Paint and varnish removers, deglossers | methylene chloride, toluene, acetone, xylene, ethanol, benzene, methanol |
| Paint brush cleaners | hydrocarbons, toluene, acetone, methanol, glycol ethers, methyl ethyl ketones |
| Floor and furniture strippers | xylene |
| Metal polishes | petroleum distillates, isopropanol, petroleum naptha |
| Laundry soil and stain removers | petroleum distillates, tetrachloroethylene |
| Spot removers arid dry cleaning fluid | hydrocarbons, benzene, trichloroethylene, 1, 1, 1 trichloroethane |
| Other solvents | acetone, benzene |
| Rock salt (Halite) | sodium concentration |
| Refrigerants | 1, 1, 2 trichloro - 1, 2, 2 trifluoroethane |
| Bug and tar removers | xylene, petroleum distillates |
| Household cleansers, oven cleaners | xylenols, glycol ethers, isopropanol |
| Drain cleaners | 1, 1, 1 trichloroethane |
| Toilet cleaners | xylene, sulfonates, chlorinated phenols |
| Cesspool cleaners | tetrachloroethylene, dichlorobenzene, methylene chloride |
| Disinfectants | cresol, xylenols |
| Pesticides (all types) | napthalene, phosphorus, xylene, chloroform, heavy metals, chlorinated hydrocarbons |
| Photochemicals | phenols, sodium sulfite, cyanine, silver halide, potassium bromide |
| Printing ink | heavy metals, phenol-formaldehyde |
| Wood preservatives (creosote) | pentachlorophenols |
| Swimming pool chlorine | sodium hypochlorite |
| Lye or caustic soda | sodium hydroxide |
| Jewelry cleaners | sodium cyanide |

Chemical separation and recycling of batteries, oils and paint is important to a groundwater protection program. This includes proper pesticide disposal and triple-rinsing pesticide containers. Be carefully on chemical application and always clean-up spills.



# Water Well Reports and Hydrogeology
# Introduction

**Filling in the blanks doesn't just satisfy some agency's requirements. Good well reports also provide hydrogeologists from the public and private sector with valuable information regarding local ground water systems.** *By Dennis Nelson*

***HYDROGEOLOGISTS ARE OFTEN CALLED UPON TO*** evaluate an aspect of a ground water system—for example, the direction of ground water flow, the potential impact of a given land use on ground water, the potential impact of a well on another well or nearby stream, or the "*capture zone*" for a given well.

In order to conduct such an evaluation, the hydrogeologist must have actual or reasonable estimates of the physical and hydraulic properties of the geologic material through which the ground water is moving. In some cases, data may be available in the form of geologic maps, aquifer tests, monitoring wells, or written reports. In many cases, however, the only information available is in the form of well reports (well logs), filed by well constructors at the time of drilling.

The importance of water well reports in hydrogeological investigations cannot be overstated. The information collected by well constructors during and after the drilling of a well is often the only information available to the hydrogeologist. In many cases, it is our only "*window*" into the aquifer. The purpose of this document is to describe the type of ground water information needed to conduct typical hydrogeological assessments, and how the data collected by well constructors is used to obtain this information.

**Hydrogeologic Data**
For hydrogeologists to make reliable assessments about the current and future status of ground water, they need to know where ground water occurs in the subsurface, what the properties are of the various geologic units below the surface, and how fast and in what direction ground water is moving. Obtaining the data necessary for these studies can be time consuming and expensive.

Well reports, however, can provide information that can be used to determine if further data is needed, and if so, what data and from where. In this document, important hydrogeologic parameters that are used will be discussed first, followed by several general examples of how they are used. Finally, how a typical well report can be used to acquire this data will be described.

**Depth to the Aquifer**
It is necessary to identify which geologic unit is the aquifer; i.e., the porous and permeable rock or sediment that contains ground water and the depth at which it occurs. It is often also important to know the type of geologic materials that occur from the surface down to the top of the aquifer.

**Nature of the Aquifer**
The nature of the aquifer can be described as either unconfined or confined. An unconfined aquifer has the water table as its upper surface; there are no significant low-permeability layers between the water table and the surface; and the aquifer is recharged locally, (in the immediate vicinity of the well). The top of the aquifer, the water table, can rise or fall depending on water use and amount of recharge to the aquifer.

A confined aquifer has a low-permeability geologic formation (a confining layer) as its upper boundary; the ground water in the aquifer is under pressure; the aquifer is separated from the surface by the confining layer and generally is recharged at some distance from the well, e.g., in nearby or distant areas of higher topography.

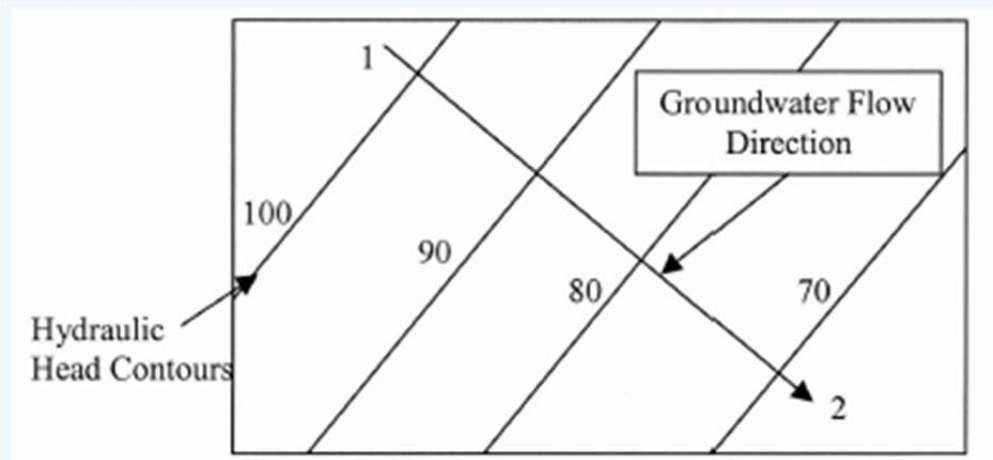


Figure 1.

**Hydraulic Head (h)**
The hydraulic head is a measure of the energy that the water at a certain depth possesses because of its elevation and the pressure exerted through the weight of the water above it. Hydraulic head has units of feet, and generally corresponds to the elevation of water in the well.

Hydraulic head is the driving force for ground water movement either in a horizontal or vertical direction. Ground water moves from where the head is higher to where the head is lower. If we have enough hydraulic head data for an aquifer over a given area, we can contour the head elevation just like the ground elevation is contoured on a topographic map. Ground water will move from high head areas to low head areas and will generally flow in a direction that crosses the contours at a 90º angle (see Figure 1).

The change in hydraulic head (h1- h2) over the distance from point 1 to point 2 (D1,2) is the gradient (I), calculated as

$$I = (h1 - h2)/D1,2$$

In Figure 1, assuming points 1 and 2 represent individual wells, the gradient would be the difference in head between well 1 (~102 feet) and well 2 (~68 feet) divided by the horizontal (map) distance between the two wells.

**Thickness of the Aquifer (b) and Water-Bearing Zones**
To evaluate the amount of ground water moving through the aquifer or its ability to supply ground water to wells, it is necessary to know the thickness of the aquifer. It is also important to be able to identify whether the aquifer is uniform throughout its thickness or consists of one or more discrete water-bearing zones.

**Aquifer Porosity (n)**
The volume of open space relative to the total volume of the aquifer (porosity) and the degree to which these pore spaces are interconnected (effective porosity) controls the volume of water in the aquifer and the amount of water that can be reasonably withdrawn from the aquifer. For a given gradient, the effective porosity strongly influences the velocity in which the ground water is moving.

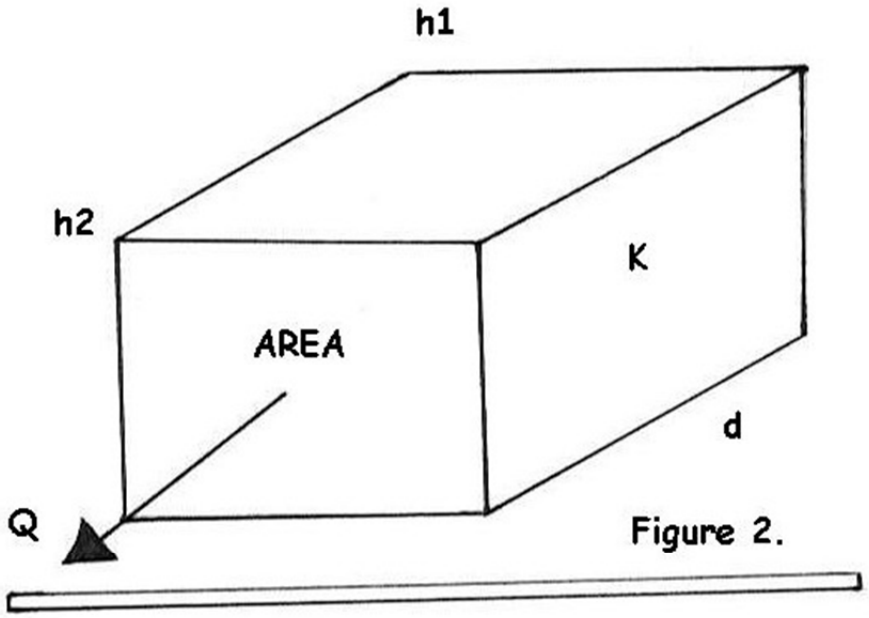



Figure 2.

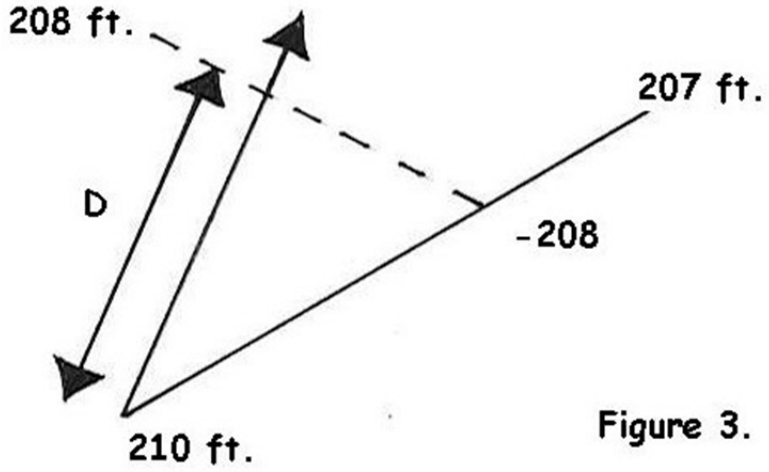



Figure 3.

**Permeability of the Aquifer (K)**

The permeability, or hydraulic conductivity, of the aquifer is a measure of how fast ground water can move through the aquifer. Hydraulic conductivity has units of distance/time, e.g., feet/day, although it does not represent an actual speed.

**Examples of the Use of Hydrogeological Parameters--Is the Aquifer Unconfined or Confined?**

As indicated previously, whether an aquifer is confined or unconfined has important implications for its vulnerability to pollution. The most direct method of determining this characteristic is to compare the hydraulic head to the elevation of the top of the aquifer. Unconfined aquifers have the water table as their upper boundary. The water table is at atmospheric pressure and therefore, when the aquifer is drilled into, the water level in the well remains at the same elevation as the water table. Confined aquifers contain water that is under pressure.

When the aquifer is drilled into, the water level in the well will rise to a higher elevation than that of the top of the aquifer (remember that water seeks its own level).

**Volume Rate of Ground Water Moving Through an Aquifer**
If we wanted to know how much ground water was traveling through an aquifer, we can apply Darcy's law, which states that the rate (Q) is equal to the hydraulic conductivity (K), times the cross-sectional area of the aquifer (A), times the hydraulic gradient (I):

$$\mathbf{Q\ (ft^3/day) = K\ (ft/day)\ X\ A\ (ft^2)\ X\ I\ (ft/ft),}$$

where I = (h1- h2)/d in Figure 2.

Consider a gravel quarry that intersects an aquifer through a thickness of 50 feet and a width of 500 feet. If the aquifer had a hydraulic conductivity of 50 feet/day with a gradient of a 1-foot drop for every 1000 feet of horizontal distance (I = 0.001), what volume of ground water would have to be pumped out of the quarry each day in order to keep it dry?

**Q (ft3/day) = 50 ft/day X (50 feet X 500 feet) X 0.001 (ft/ft)**

**Q (ft3/day) = 1250 ft3/day or approximately 9300 gallons per day**

It is common to combine the hydraulic conductivity and aquifer thickness to yield a number referred to as the transmissivity (T = Kb), a parameter that is more directly related to the volume of ground water flow. Using the transmissivity term, Darcy's law becomes;

$$\mathbf{Q\ (ft^3/day) = T\ (ft^2/day)\ X\ w\ (ft)\ X\ I\ (ft/ft)}$$

**In What Direction Is Groundwater Flowing?**
The direction of ground water flow is from higher to lower hydraulic head. Consequently, if we have wells that produce from the same aquifer, we can estimate the direction of ground water flow. The hydraulic head can be measured by lowering a probe through the observation port of a number of wells, all within the same relative time period, i.e., within a few days of each other.

A minimum of three wells is required to estimate the direction of flow. We can also determine the gradient from these wells. Three wells from the same aquifer have hydraulic heads (elevation of the water table) of 207, 208, and 210 feet.

**What is the direction ground water is flowing and what is the gradient?**
We begin by drawing a line from the lowest (207 feet) to highest (210 feet) value of head. We note that somewhere along that line, the elevation of 208 feet, the intermediate value, must fall. If we assume that the water table has a constant slope, an elevation of 208 feet will occur one-third of the way from 207 to 210 ([208-207]/[210-207]).

Once we have determined where the 208 feet elevation occurs along the line, we can draw a line from that point to the well with the 208 feet hydraulic head. This line represents the 208 feet contour on the water table. As mentioned before, ground water tends to flow directly across, i.e., perpendicular to, the contours from higher head to lower head.

The arrow, then, represents the direction of flow. The gradient can be calculated by measuring D, the distance along the perpendicular from the well, with the 210-foot head to the 208-foot contour using the equation:

$$I = (h2 - h1)/D = (210 - 208)/D$$

Note that the three-point solution works best on wells that are relatively close to one another.

**How Fast Is Ground Water Moving?**
The speed of ground water movement in the down gradient direction can be calculated using a modified version of Darcy's law:

$$V\ (ft/day) = KI$$

This equation assumes that ground water is moving across the entire area of the aquifer, but in the real world, ground water does not flow that way. Ground water is moving only through the pore spaces (actual openings in that area). As a result, we have to include the porosity (n) in this equation: **V = KI/n**

Using the gravel quarry example given before (K = 50 ft/day; I = 0.001; n = 0.25), the velocity of ground water through the aquifer can be determined as follows:

$$V = (50\ ft/day \times 0.001)/0.25 = 0.2\ foot/day$$

**What Is the Drawdown Associated with Pumping of a Well?**
Often we would like to know how the pumping of one well might affect the water level in another. There is a relation between the pumping rate of the well, the transmissivity of the aquifer, the distance between wells, the storage coefficient of the aquifer, and the duration of the pumping event.

The storage coefficient of an aquifer is related to how much water is released from the aquifer as the hydraulic head of the ground water drops. The storage coefficient is slightly less than porosity for an unconfined aquifer (from 0.10 to 0.25) and is significantly less than porosity in a confined aquifer (from 0.01 to 0.000001 or less).

For unconfined aquifers, using the porosity is a reasonable approximation in most cases. No simple expression is available to determine drawdown as a function of distance for a given set of conditions; however, there are a number of computer programs that can perform this calculation with input of the previously mentioned parameters.

**Using the Well Report**
Although most of the proposed questions can best be addressed through more detailed hydrogeologic investigations, we can often make reasonable estimates from available well reports if they have been carefully filled out (see The Well Guy, "*Lithology*," May 2002, Water Well Journal). Well report forms vary from state to state, but most contain data that is relevant to a hydrogeologic investigation. Using typical entries from a well report form, let's examine where we can obtain the data we need.

**Well Location**
For most hydrogeologic studies, the precise location of the well is very important. In many cases, wells are located only to the nearest section or perhaps in a quarter-section. In the latter case, we still only know the location to the nearest 40 acres. Over the last few years, well constructors have been using tax lot information to locate wells. This is an improvement, but depending on lot size, there still may be significant uncertainty.

We hope that more and more well constructors will take advantage of low-cost global positioning system (GPS) technology and begin reporting well location as latitude and longitude. There are 24 satellites positioned above the earth's surface and at any given time off-the shelf GPS units are capable of linking to three or more of these and determining locations within 100 feet or less. Such high precision locations greatly enhance our ability to use the well report data to determine direction of ground water flow, ground water gradients, variation of aquifer properties throughout an area, and so on.

**Well Tests**
Most well reports require the well constructor to perform some level of pump test to evaluate the capacity of the well. If the well constructor has carefully monitored the rate of water production (Q) and drawdown (s) associated with that production over the period of the test (t), the hydrogeologist can often derive useful information regarding the permeability or hydraulic conductivity (K) of the aquifer. The specific capacity (SC) of the aquifer at the well site is defined as the ratio of the discharge of the well to the total drawdown:

$$\mathbf{SC = Q\ (gpm)/s\ (ft.)}$$

The transmissivity of the aquifer can be estimated from the specific capacity through the following relationship:

$$\mathbf{T\ (ft^2/day) = AC\ X\ SC\ (gpm/ft.)}$$

Where AC is a number varying in value depending on the aquifer characteristics.

If the hydrogeologist can determine the aquifer thickness from elsewhere in the well report, the hydraulic conductivity can be derived from this transmissivity value. It must be stressed that the specific capacity data can in no way replace the time-drawdown information acquired from a well-designed constant rate aquifer test. However, it does provide an approximation, and if enough specific capacity data can be found for an area, reasonable estimates can be made.

For information on conducting aquifer tests, see www.ohd.hr.state.or.us/ and click on "***How to prepare for an aquifer test***." So what is a hydrogeologist looking for in specific capacity data? Ideally, the SC test will have been accomplished using a pump over a period of at least four hours. Why four hours? Let's consider a 50 gpm test of 25-foot-thick sand and gravel aquifer. If this test lasts for only an hour, all the water will be derived from within 4.5 feet of the well. This small volume will not be very representative of the aquifer in general. If the test is run over a longer time period, a larger volume of aquifer can be ***"sampled"*** and the resulting hydraulic conductivity estimate will be more representative of the aquifer.

## Depth to First Water-Bearing Zone

There seems to be two ways that well constructors interpret this parameter. Some report the depth at which water is first encountered in the drill hole; while others report the depth where enough water to supply the well is encountered. From the hydrogeologist perspective, the first interpretation is preferred because it tells us where the top of the aquifer is.

It is common to find that an aquifer, i.e., a water-saturated geologic unit, varies in permeability in the vertical sense. For example, consider a 50-foot-thick sand aquifer that occurs at a depth of 30 feet and contains silt in the top 5 feet. The entire 50 feet of aquifer is saturated; however, useful quantities of water can be produced from only the lower 45 feet. First, recognizable water would be encountered at 30 feet, while producible water would not be encountered until 35 feet.

From the hydrogeologist's view, the top of the aquifer is at 30 feet. Why is this so important? In order to determine whether the aquifer is confined or is unconfined, we must compare the elevation of the static water level to elevation of the top of the aquifer. In the case just given, the static water level in a well in this aquifer would be at 30 feet. If we had mistakenly thought that the top of the aquifer was at 35 feet, we may have considered it to be confined when actually it is unconfined.

**Static Water Level**
The driving force for ground water movement is the hydraulic head, and the static water level (SWL) is a measure of that force (head = ground elevation- SWL). If we want to determine the ground water flow direction and the gradient, we may be able to gather that information from well reports. Care must be taken in using SWLs from wells drilled at different times of the year or over a period of years. Careful SWL measurements greatly enhance our understanding of the nature of ground water movement.

Well report forms generally provide space for SWL reporting as a function of depth in a given well. Multiple aquifers exist in most areas and these aquifers may be encountered as one drills deeper into the ground. Identifying where one aquifer ends and another begins is key to identifying the source of ground water to individual wells. Although this often can be determined by careful review of the lithologic log provided by the well constructor, the transition from one aquifer to the next can be indicated by a marked change in the SWL.

A change in SWL is a better indicator that a different aquifer has been encountered than the lithologic description. A progressive change in the static water level with depth can indicate to the hydrogeologist that the area represents a recharge zone (decreasing head with depth) or a discharge zone (increasing head with depth). Identification of recharge and discharge zones may have important implications in ground water protection and identifying the relation between area ground water and local streams.

**Water-Bearing Zones**
A well report that does not indicate where within the 200 feet of open hole the water is actually coming from does not provide enough information to describe how water moves to the well. In some cases, the screened or perforated portions of cased wells provide a clue, but all too often, the screened interval is either significantly greater or less than the actual thickness of the water-bearing zone(s). Arriving at accurate estimates of aquifer parameters or calculating ground water velocity requires us to know the thickness of the water-bearing zone(s). On well reports, if well constructors can identify the depth(s) where ground water is found and estimate the yield from each zone, the hydrogeologist can increase his or her understanding of the ground water system significantly.

**Lithologic Log**
The well log portion of the well report describes what the driller encountered in the subsurface. Clear descriptions of the material drilled through, e.g., the relative proportions of silt/clay in the sand units, the locations of weak (fractured) zones in bedrock, whether a clay unit contains lenses or layers of sand, etc., allow the hydrogeologist to better estimate the potential permeability of these zones. This information also allows the hydrogeologist to better estimate the recharge amount, vulnerability from contaminants from the surface, degree of hydraulic connection to surface water, and so on. Of course, it is not necessary that well constructors be trained geologists. But it is important that their observations, coupled with their experience on a rig, be recorded. Once a hydrogeologist has examined a number of well reports from a given driller, he or she can begin to attach geologic terms to the descriptions provided. Consistency in reporting lithologic character and distribution with depth is very important.

**Contributions of Well Constructors to Hydrogeology**
This document stresses the importance of data that is recorded on well reports and how that data influences hydrogeologic investigations. Filling in those blanks doesn't just satisfy some agency's requirements; it also provides hydrogeologists from the public and private sector valuable information regarding local ground water systems. Well constructors can provide important contributions to the science by making careful observations and measurements when recording that data on the well report.

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His current work focuses on the hydrogeologic identification of the source of ground water-based public water systems (drinking water protection areas), determining the sensitivity of aquifers to contamination, and assisting public water systems and communities in developing drinking water protection plans.

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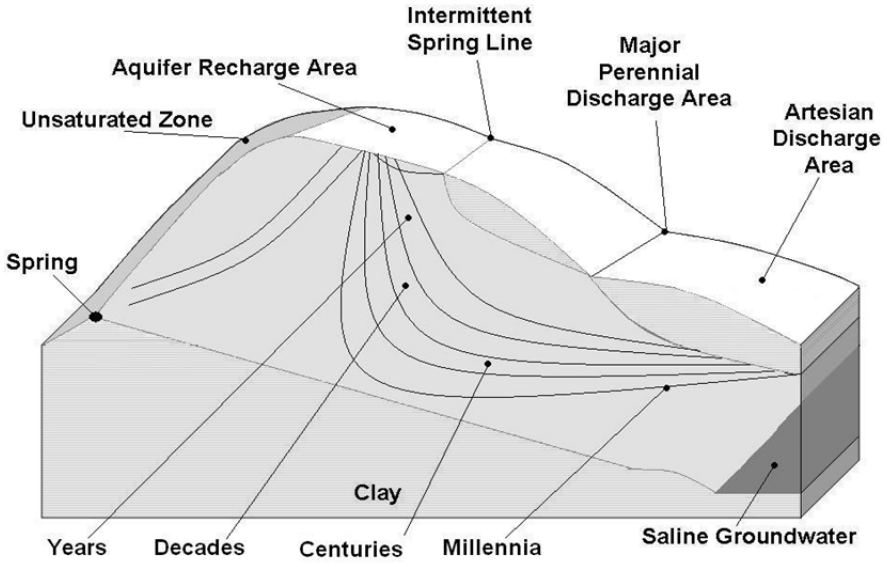
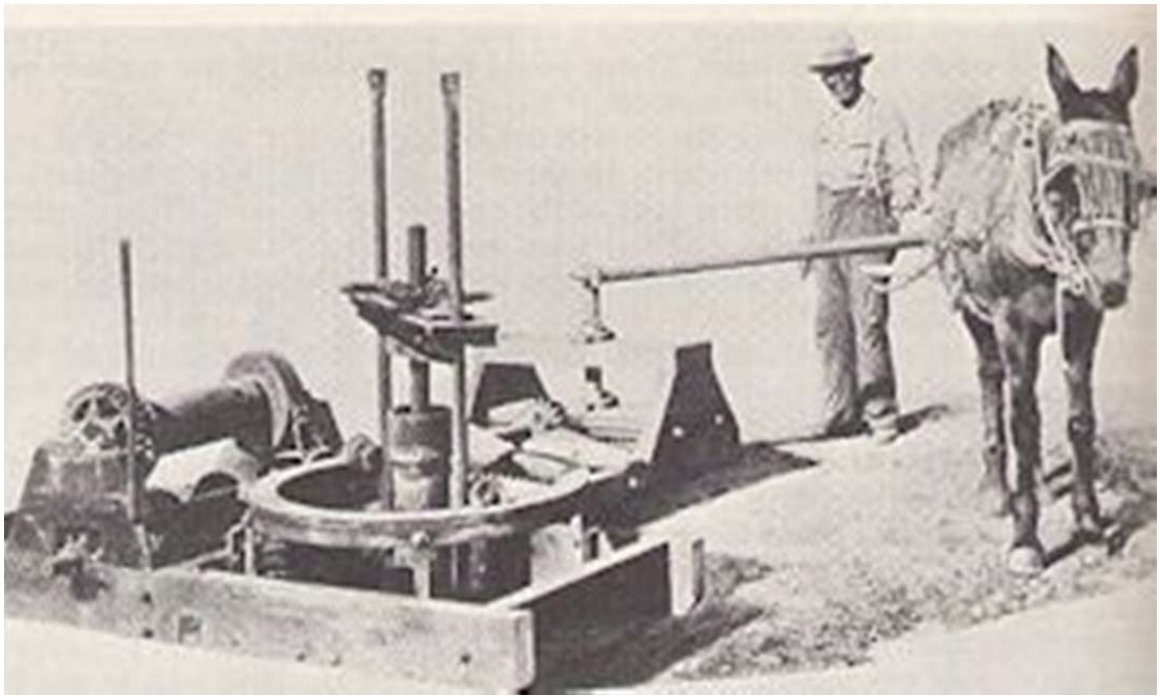




Up until 1940, mules were used as the horsepower to drill wells.

## How Wells are Drilled

Man has been digging holes into the ground to obtain water for thousands of years. Early on, these wells were dug by hand and sometimes using animals. This work could be dangerous and slow requiring many years to complete. In these modern times, wells can be drilled much faster and safer using numerous technologically advanced methods.

Some examples of today's more common well drilling methods include ***rotary, auger, and cable tool*** with many variations of each. ***Drilling fluids*** are often used during drilling in order to keep the borehole open while drilling is done. Drilling fluids ***stabilize*** the hole and aid in the removal of ***cuttings***. Typical drilling fluids may be **water, mud, air, chemical or natural additives, or combinations of each**.

Although each drilling technique may be utilized in different types of geology, each one is better suited for particular types of material. For example, **air rotary with downhole hammer** is particularly suited for ***hard rock*** drilling, while **mud rotary** is better suited for drilling in ***sediment***. No matter what type of rig or method is being used, a highly trained and skilled ***driller*** is required to operate it successfully.

# Basic Rotary Drilling Methods

**Rotary drilling** utilizes a **drilling rig** with a rotating bit and circulating drilling fluid to penetrate into the aquifer. It is the most common type of drilling method used today. Common variations of this method include: ***direct and reverse mud rotary, direct air rotary, and drill through casing driver methods*****.**

**The Rotary Drill String**
Rotary drilling methods use a ***drill string***, which typically consists of a bit, collar, drill pipe and a kelly (if table driven). A ***kelly*** is a section of heavy walled pipe that can be hexagonal, square, or rounded with grooves. The kelly is several feet longer than the drill pipe being used and fits into the table drive much like the splines on an automobile's drive shaft fit into a transmission.

The ***table drive*** turns the kelly and the rest of the drill string connected below as it slips down through the table. Some rotary rigs use a ***top drive*** to turn the drill string and are like a drill press, but larger. A top drive is free to move up and down the ***mast*** of the rig while rotating the drill string. ***Drill pipe*** makes up a majority of the overall length of a drill string and is used in various diameters and wall thicknesses for added strength. Drill pipe can be used in various lengths but are typically 20-foot sections and may be connected to the ***drive unit*** with a ***sub***.

A sub is a length of pipe used to connect pipes and/or act as shock absorber (***floating sub***) between the drill pipes and drive unit. At the end of the drill pipe is the drill collar. The ***drill collar* or *stabilizer*** is typically very heavy and is often ***gauged*** close to the diameter of the bit being used. There are many types of drill collars that are often custom made by the driller by adding metal ribs to heavy drill pipe. The drill collar aids in maintaining a consistent borehole diameter and primarily helps to prevent ***borehole deviation***.

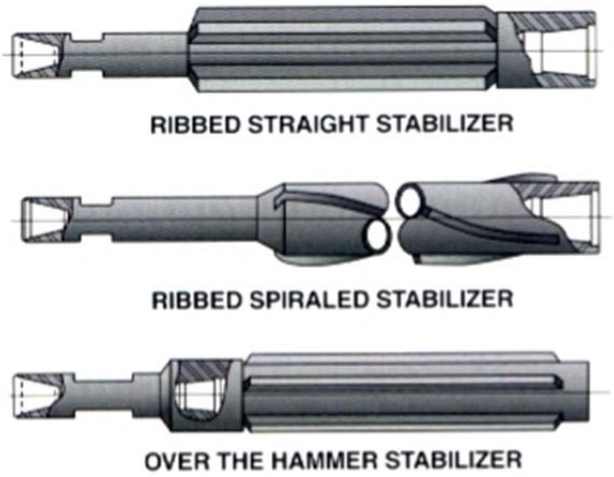
At the end of the collar is the rotary ***bit***. Several types of bits may be used, such as drag bits or roller bits. ***Drag bits*** are typically used in unconsolidated to semi-consolidated sand, silt, and clay-rich formations. Drag bits come in many shapes and sizes and cut with a shearing action aided by the jetting of drilling fluids from nozzles or jets in the bit. Roller bits, such as the common ***tri-cone bit***, typically utilize interlocking teeth or buttons on individual rotating cones to cut, crush, or chip through the formation.

***Roller bits*** are also aided by the jetting of drilling fluids from nozzles or jets in the bit. These bits can be used in consolidated formations and even hard rock applications if equipped with ***carbide buttons***. These types of bits are often referred to as ***roller button bits***.

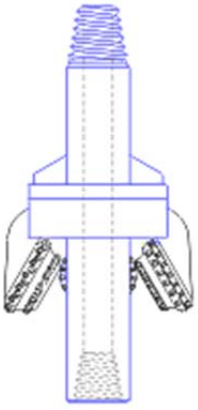
Often an initial borehole needs to be ***reamed*** or made larger. ***Reamers*** are bits that can be used to enlarge, straighten, or clean an existing borehole. Occasionally**, *under reamers*** are used to enlarge deeper sections of an existing borehole without requiring the enlargement of the entire upper well bore.

***Under reaming*** involves the projection of cutting blades beneath permanently installed casing in loosely consolidated sediments. This can allow for the cost effective installation of well screen and gravel pack within deeper loosely consolidated aquifers.

Table Drive (Notice notches for kelly)

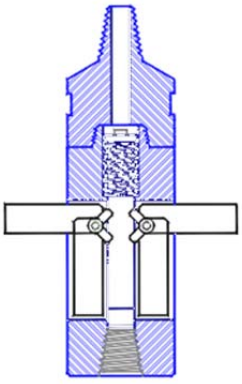


Tricone Roller Bits



Roller Reamer

Drag Bit

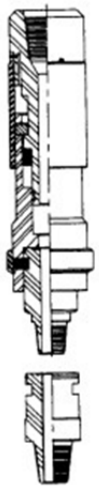


Drag Type Under-reamer

Drill String

Top Drive

Drill Pipe



Floating Sub Assembly

# Direct Rotary Method

Direct rotary drilling methods utilize a rotating bit at the end of a ***drilling string*** with ***drilling fluid*** that is ***circulated*** from the rig through the drill pipe and jets in the bit. Down-force exerted by the drilling rig and/or the weight of the drill string itself is used along with rotating action to force the bit downwards, cutting through the sediment or rock. The drilling fluid that is pumped by the rig's ***mud pump*** and/or ***air compressor*** is jetted out of ports in the bit.

These ports are called ***jets***. The drilling fluid carries **cuttings** up the ***annular space*** between the drill pipe and ***formation*** and into ***mud pits*** or ***containment recirculating systems*** on the surface. The drilling fluid pressurizes the ***borehole*** and helps to keep the hole open while removing cuttings. If this pressure is lost due to ***washouts***, ***voids***, ***caverns***, or any number of other causes, circulation will not be maintained and drilling will likely have to be stopped.

Large drill rigs may utilize the cutting's containment systems that separate the cuttings from the drilling fluid before a pickup pump recirculates the drilling fluid back down the borehole, where the process is then repeated.

Also, one or more temporary mud pits may be dug into the ground adjacent to the rig in order to contain and settle out cuttings from the drilling fluid before recirculating.

**Direct Mud Rotary Method**
Direct Mud rotary drilling rigs use various types of mud or drilling fluid to drill into the ground. Mud is circulated down the drill string and through the bit at the bottom of the borehole. The mud then carries the cuttings generated by the bit up to the surface and into the mud ***recirculating system***.

Soil or formation samples may be collected from the recirculating system as drilling proceeds. A vibrating screen or set of screens called a ***shaker*** may be used in part of the recirculating system on larger rigs. It separates out cuttings from drilling fluid and provides an ideal ***sampling location***. The mud not only removes cuttings but also adheres to and pushes against the borehole walls, minimizes fluid loss, and cools the bit.

The process of building up a film of mud on the borehole walls is important to mud rotary drilling and is called ***mud caking***. Sometimes specially trained personnel are needed to manage the physical properties of the mud to ensure that a proper ***mud cake*** thickness is maintained and that a proper density or weight of mud is used to efficiently drill the well. The ***mud engineer*** will often use bentonite clay and water to make the mud drilling fluid. Sometimes chemical additives such as drilling polymers or gels may be used.

Mud engineers play an important role in ensuring that a mud rotary drilled well can be drilled to the proper depths successfully and ultimately developed for use. Sometimes the loss of mud drilling fluids to cavities in the earth cannot be stopped with a mud cake alone, however. In these instances, ***casing*** or ***grout*** may be installed to permit drilling beyond such zones.

Mud Pump

Typical Rotary Rig

Small Self-Contained Mud System

Constructed Mud Pits

Well Drilling Components and Products

## Reverse Mud Rotary Method

Reverse mud rotary drilling rigs utilize the same process as direct mud rotary with the exception that the mud drilling fluid injection process is reversed. Reverse rotary methods pump the drilling fluid down the borehole to the bit where the cuttings are forced up the drill string and into the containment or recirculating system.

The reverse method is utilized in situations where borehole stability problems are particularly difficult and would otherwise prevent conventional drilling of the well to the total ***target depth***.

This method is particularly applicable to hard rock aquifers in zones where highly fractured or ***weathered*** rock may prevent the efficient flow of drilling fluids up the borehole walls to the surface. Also, fluid losses may be minimized with this method.

Samples are collected in the same way as mud rotary.

**Air Rotary Method**

***Air rotary*** methods utilize compressed air and derived drill cuttings and groundwater as the drilling fluid. Air is forced through the drill string and out the bit where it then mixes with and lifts cuttings and any derived groundwater to the surface.

Once at the surface, the cuttings and groundwater are typically contained in subsurface pits, much like the mud rotary method.

Soil or formation samples may be collected in a bucket or shovel placed beneath the ***table*** of the rig as drilling proceeds, resulting in representative samples. The borehole is kept in a pressured condition while drilling, in order to maintain the circulation of drilling fluid to the surface.

Biodegradable foam or ***surfactant*** (soap) is often added while drilling with air in order to maintain sufficient hole pressurization so that cuttings may be lifted to the surface efficiently while maintaining hole stability.

As in drilling with mud, if this pressure is lost due to washouts, voids, caverns, or any number of causes, circulation cannot be maintained and drilling may not continue.

The air rotary method is particularly suitable to hard rock drilling with a ***down hole air hammer***. The air hammer utilizes compressed air to drive a piston up and down which makes the ***hammer bit*** move up and down while the drill string rotates.

The combined rotating and hammering action generates great rock breaking force and is very valuable for drilling through solid rock or consolidated formations. Conventional air rotary drilling methods utilize roller bits in the same way as those used for mud rotary drilling.

In hard rock or consolidated formations, a roller ***button bit*** may be used when ***drilling pressures*** are too high or borehole sizes are too large for the efficient operation of an air hammer.

Air Rotary Containment Pit
(Notice Foam and Water Truck)

Hammer & Bit

First Pit (heavy with cuttings)

Last Pit (small amount of fines)

Several containment pits installed in series can help cuttings to settle out.

## Drill through Casing Driver Method

The drill through casing driver method drives casing into the borehole as the drill string advances. A ***casing driver*** is a pneumatic device designed to push or pull casing that is typically attached to a top head drive air rotary rig. Heavy gauge steel casing is used with a ***cutting shoe*** installed on the down hole side.

The cutting shoe is a specially designed hardened steel ring that is installed on the casing end. It helps the casing cut its way through the formation as it is forced downward by the casing driver. The drill string is inserted into the casing and the casing is attached to the casing driver. As the drill string penetrates into the ***overburden*** or formation, the casing driver hammers the casing down, following the drill string.

The drill string may employ a hammer or roller bit. The driller pays close attention to the distance between the cutting shoe and the bit and adjusts as is necessary. Cuttings rise to the surface with the injected air through the casing and exit through the casing driver.

The cuttings are then collected near the rig. As the borehole is drilled, the casing advances and isolates the material being drilled from the remaining borehole. As a result, very accurate soil or cuttings samples may be collected as drilling proceeds with this method.

The addition of casing and drill string can continue until ***competent*** formation is encountered. Once the well has been drilled to competent formation, conventional drilling methods may be utilized to continue. The casing driver method is often used to install temporary casing in order to permit the installation of a well in unstable aquifers.

In this instance, the casing driver may be used as a puller to remove the temporary casing following well construction. This method is most useful when accurate formation or soil samples are needed and when drilling in troublesome unconsolidated overburden or formations with numerous cobbles or boulders.

### Cutting Shoe

The Cutting Shoe is welded to the bottom of casing before installation.

A Casing Driver attached to a top drive air rig.

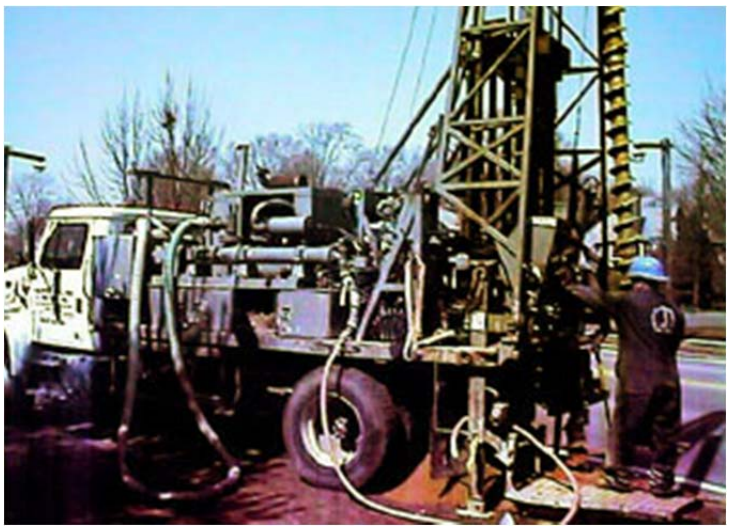
## Auger Boring Methods

Auger boring methods make use of a rotating blade or ***spiral flange***, which may be attached to a ***pilot bit*** and ***cutter head***. Down-force applied by the rig along with the rotating action of the blade and cutting action of the pilot and/or cutter bits facilitates the boring process.

Soil samples may be collected as cuttings rise or are brought to the surface, or they may be collected with ***split spoon*** type samplers.

Augers are capable of boring large diameter holes in excess of four feet in diameter. They are typically used in shallow applications (less than 200 feet) and where stable silt and clay soils or soft materials are dominant.

These boring methods are commonly used to construct large diameter boreholes for the construction of ***surface seals*** around wells through thin and stable overburden sediments which overlie the aquifer below. One of the methods is commonly used in environmental applications for the collection of soil samples. There are three primary types of auger boring methods: ***solid stem, bucket, and hollow stem*****.**

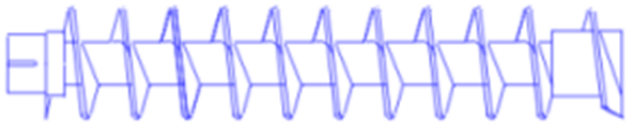


Typical Auger Rig

## Solid Stem Auger Method

The solid stem auger boring method uses a spiral flanged drill pipe driven by either a kelly or rotary drive head, like those used on rotary rigs. The drill pipe may be continuously flanged or just the initial section is flanged. Flanged sections of drill pipe are referred to as ***flighting***. The lower portion of flighting, having the cutter bit attached, makes the initial cuts into the formation, providing the path for the remaining flighting to follow. Larger diameter augers typically employ a single flight and can be used in stable formations to depths of approximately 60 feet. Deeper borings are typically installed with continuous flighting and only in stable formations. Occasionally, the lower flight is removed from the borehole so that cuttings, which accumulate at the bottom of the borehole, may be removed and/or sampled. When boring with continuous flighting, cuttings are brought to the surface by the spiral action of the flighting. Samples may be collected from these cuttings or the flighting may be brought to the surface and samples collected from the ***cutting head***. This method is not suited for applications below the water table and may provide limited soil sample data. However, it may be used to aid in quickly constructing the larger diameter upper sections for larger wells.

**Auger Flighting:**
**Cutting Head**



**Bucket Auger Method**

The bucket auger method essentially combines the rotary and auger techniques. The bucket auger method employs a single, typically large in diameter, bucket auger to drill or bore into the ground. The ***bucket auger*** is a cylinder constructed with auger like blades at its bottom edge. These blades may be armored with various forms of cutting teeth or blades to provide strength and "**bite**". The bucket auger is rotated via a kelly and table drive much like those of rotary rigs. However, bucket auger rigs utilize a ***telescoping kelly***. A telescoping kelly consists of two or more sections of square piping that telescope into each other. This type of kelly allows the rig to drill to depths of 40 feet or more without requiring the addition and removal of drill pipe. When the bucket is filled with cuttings it is closed and brought to the surface where it is swung out to the side of the rig by a specially designed ***swing arm or dumping arm***. At this point the bucket is opened and cuttings are dumped. Soil samples may then be collected and can be considered representative of the section bored. Bucket auger methods typically cannot be used in material containing cobbles and boulders, but is used most often in more stable ***semi consolidated*** silty or clay rich deposits. Large diameter wells up to 4 feet in diameter may be constructed with the bucket auger method, with smaller diameters approaching 200 feet in depth. Occasionally, drilling fluids such as ***bentonite mud*** may be used in order to maintain borehole stability when drilling in questionable materials.

Bucket Auger Rig (notice swing arm)

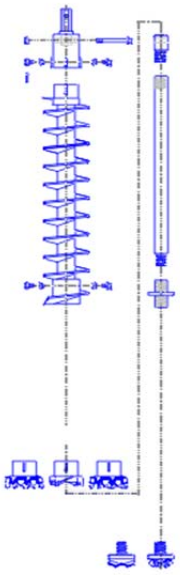
## Hollow Stem Auger Method

The hollow stem auger method has been used in the ***geotechnical*** field for many years for its usefulness in obtaining soil samples. Continuous ***hollow stem flights*** are used with a **pilot** and **cutter head**.

The lowermost flight contains a ***plug*** that is connected to drill pipe that passes through the center of the flights and is ultimately connected to a top drive. The plug prevents soil from entering the auger and is connected to the pilot bit that helps to guide the auger downward during boring.

When the plug is removed, accurate soil samples may be obtained while the flighting remains to keep the borehole open. Samples are typically collected with a ***split spoon sampler*** or core barrel sampler driven into the soil a few feet ahead of the flighting.

The use of larger diameter continuous flights can also permit the installation of well screen and filter media in otherwise relatively unstable formations by its acting as temporary casing. Wells constructed with this method are normally less than 200 feet deep. This method is also limited to relatively soft ground applications with few boulders or cobbles.



Hollow Stem Flighting

←Cutter Head

Split Spoon Sampler →

**What is a significant deficiency?**
Significant deficiencies cause, or have the potential to cause, the introduction of contamination into water delivered to customers. This could include defects in design, operation, or maintenance of the source, treatment or distribution systems. They could also be represented by the failure or malfunction of those systems. The rule requires each state to define and describe at least one type of specific significant deficiency for each of the eight sanitary survey elements.

An example of a source-related significant deficiency could be a well located near a source of fecal contamination (e.g., failing septic systems or a leaking sewer line) or in a flood zone. EPA will develop guidance to help states carry out sanitary surveys and identify significant deficiencies that could affect the quality of drinking water.

## Cable Tool or Percussion Method

The cable tool or percussion method is one of the oldest and most reliable forms of well drilling still used today. This method is adaptable to virtually every kind of drilling environment. As a result, numerous variations in both rig types and methods have evolved over its history. However, it is often used as a method of last resort when time is an issue, due to its typically slow process. Still, the cable tool method can surely succeed where any of the other methods fail.

Cable tool or percussion drilling methods utilize a system of cables and reels to lift and drop a very heavy drilling string as downward progress is made. The weight and force of the bits' impact breaks up the ground and permits a typically slow, but steady, downward movement. Water is used as the primary drilling fluid. As drilling proceeds, cuttings and water mix, forming slurry. This slurry is allowed to pass back and forth through a watercourse or opening within the drill string.

The drill sting is occasionally removed from the borehole through the use of a specially designed ***bailer***. A bailer is a section of pipe constructed with a check valve located at the bottom of the pipe. As the bailer is lowered, it fills with the drilling fluid and cuttings.

When the bailer is raised up, the valve at the bottom of the pipe closes, trapping the slurry inside. The slurry can then be lifted to the surface and the contents dumped into a containment system, where samples may then be collected.

The cable tool drill string is comprised of a ***cable, swivel socket, drilling jars, drill stem, and drill bit***. The primary cable is used to lift and drop the drill string, while the swivel socket provides a rotating mechanism.

The rotation allowed by the swivel socket ensures that fresh cuts are made with each strike of the bit. The drilling jars are used only for additional upward shock to remove the bit, should it become stuck in the borehole.

The drill stem provides the majority of the weight of the drill string and also helps to maintain a straight borehole. It serves the same purpose as the drill collar used in rotary methods. Cable tool bits are normally a wedge shape, although numerous variations may be used for different formations, including carbide button and armored bits for consolidated formations.

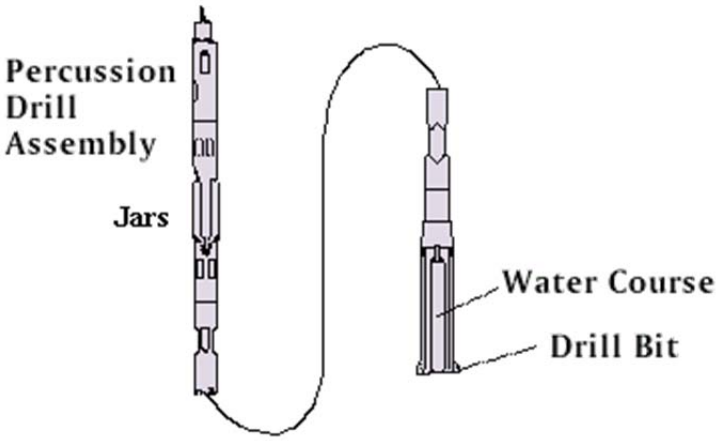
The borehole may remain open or casing may be advanced while drilling, in order to keep the borehole open in ***unstable*** formations. Casing is advance by either pushing it hydraulically, like a large press, or by ***driving*** it down with the drill string or a ***drive block***.

The drive block is a heavy collar type device that attaches over the drill pipe and is lifted up and allowed to fall, striking the casing and forcing it down. An accessory reel called a ***cathead*** is used to lift and drop the drive block with a heavy rope.

Also, a ***drive clamp*** may be attached to the top of the drill stem and serves as a striking surface. A cutting shoe is attached to the bottom edge of the casing to add strength and provide cutting ability. Drilling, casing advancement, and bailing alternate as the borehole gets progressively deeper. If the casing becomes too difficult to advance further and the required drill depth has yet to be achieved, a smaller borehole and casing may be used inside of the outer casing in order to continue. This is called ***telescoping***.

Typical Cable Tool Rig

Sand Bailer



Percussion Bits

Using a video camera to see inside a groundwater well.

## Selecting an Appropriate Well Site

Before a well can be drilled a permit is normally required. The permit helps to ensure that an appropriate location of the well is selected which reduces the possibility of ***contamination***. The ideal well location has good drainage and is higher than the surrounding ground surface.

All possible sources of contamination should be at a lower elevation than the well, and the distances to those contamination sources must be in accordance with the State or Local Water Well Construction Codes.

Surface drainages should not allow surface water to accumulate within a 15-foot radius of the well. A well must also never be located closer than 20 feet to sewers, 100 feet to septic tanks, or 100 feet to sewage seepage fields. (***The "code" refers to the requirements of the well permit process enforced by the State or Local regulating agency***.)

**Well Construction**
Following the drilling of a well, it must be constructed to meet strict standards set by the ***governing agency***. Each State has well construction design criteria for water supply wells. Before a well is drilled, a well drilling permit is normally required to be in hand. The purpose of the well ***drilling permit*** is to ensure that a qualified driller is being used to drill and complete the well to a standard set by the governing agency.

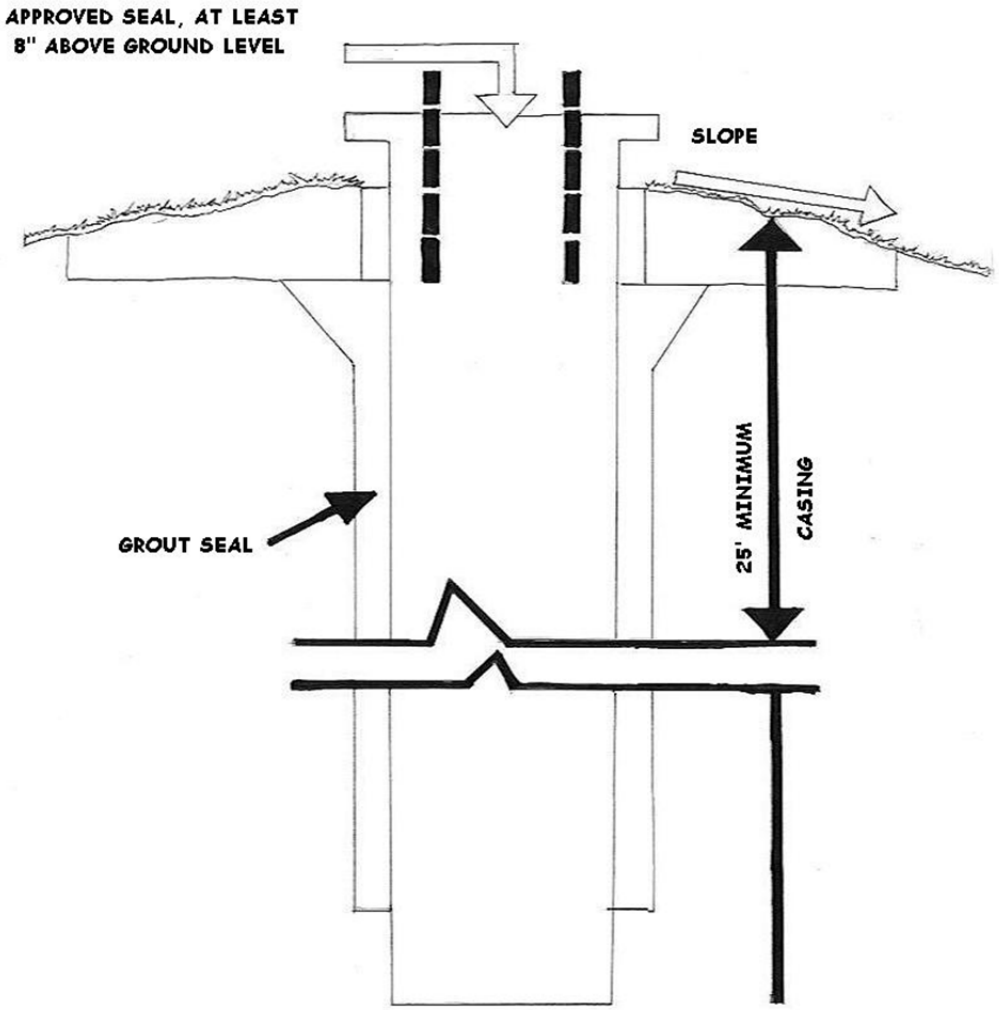
The drilling permit also ensures that the ***regulating agency*** is aware of the location and proposed use of wells and that they are not constructed within close proximity to any activities that may put the water supply at risk, such as a septic tanks or chemical storage areas.

A permit application fee is normally charged. The permit will normally require information about the proposed well's location, depth, diameter, anticipated production rate, sanitary seal, and proposed construction at a minimum.

***Permitting requirements and well construction standards can vary by state and location. As such, well construction specifications presented in this document are general in nature and should not be considered legal in your state.***

***One should become familiar with his state's particular regulations regarding well drilling and construction.***

## WELL PROTECTION




***(EXAMPLE ONLY – CHECK STATE OR LOCAL REQUIRMENTS)***

## Common Well Construction Specifications

Water wells should always be located and constructed in such a manner that they ***yield*** safe water at all times and under all conditions. Contamination of a water supply typically occurs when leachate from sewage systems or surface waters enter a well. Surface water may enter the well through an opening in the top or by seeping through the shallow borehole walls.

Tests have shown that bacterial contamination is usually eliminated after filtering through 10 feet of normal soil. Therefore, construction of the well must ensure that the top and uppermost 20 feet of the well bore are sealed and watertight. This is the primary reason why surface casing and surface seals are so important.

All wells must be constructed with a ***surface seal*** to prevent the infiltration of surface water and/or surface contaminants into the well bore and aquifer. This seal is installed in the upper portions of the well bore between the ***annulus*** and ***surface casing*** and will normally extend to the ground surface around the well.

The seal is constructed by pouring or pumping neat ***cement grout*** and/or ***bentonite*** between the surface casing and the well bore. The installation of the cement or grout between the annulus and surface casing effectively seals off the upper borehole from the surface.

The surface casing used is a solid piece of permanently installed casing, usually steel, that should be of sufficient size to allow the ***completion*** of the well within it. In addition to the surface seal, a ***well seal*** or ***cap*** is always installed with the pumping equipment to ensure no surface water or debris enters the well.

When the well is drilled into the aquifer, the depths of water ***(productive intervals)*** and ***estimated well yield*** are normally ***logged*** by the ***driller*** or ***geologist.*** Sometimes the aquifer's productive intervals may not be known, due to drilling method limitations or a lack of regional ***hydrogeological*** data.

In these instances, specialized ***borehole geophysical logging equipment*** may be used to isolate the areas of optimum production capability and aid in determining the ultimate well design. In addition, preliminary ***pumping tests*** are normally conducted to ensure the well is as productive as originally estimated and to obtain preliminary ***aquifer parameters***.

Following the installation of the well's surface seal, the well is then reamed (if necessary) to accept additional ***blank casing, well screen, and filter or gravel pack***. Once the well has been reamed large enough in diameter for the anticipated flow rate, the appropriate casing can be installed.

The well casing ensures that the borehole remains open and that debris from the formation(s) does not enter the well, thereby protecting the pump equipment and the well itself. Blank casing is normally installed to the depth of the main ***producing zone***.

At this point, ***well screen*** is used and may extend to the total depth of the well or may be used intermittently to total depth with blank casing used through unstable or non-productive areas.

A groundwater production crew, an Electrician, Distribution Foreman, and a Hydrogeologist work closely to deliver groundwater to the public.

## Choice of Casing

The choice of casing is as important as its placement. There are numerous types of casing designed for specific applications. The type of well casing needed is related to the type of aquifer, well depth, water quality, well use, and regulatory requirements. *Stainless steel* casing and screen may be required for one situation, while *PVC* or *low carbon steel* may be acceptable in another. As such, *please check with your regulating agency and well driller to ensure the installation of the appropriate type of casing for your application.*

As with casing, the choice of well screen is as important as its placement. The size of the openings in the casing (*screen slot or perforated opening size*) are dependent on the *grain size* of the filter or gravel pack used. The same applies to applications where a well is *naturally developed* or *naturally packed* (no filter pack is used). As a rule, course grained sediment or fractured hard rock aquifers may be naturally developed, while fine-grained sediment aquifers typically require a filter pack. The selection of screen slot size is normally made based on samples collected from the aquifer during drilling and consideration of the filter or gravel pack grain-size. A *sieve analyses* is often conducted in order to select the optimum size of slot for the application. During a sieve analyses for well screen, determination samples are screened through various sizes of sieves. The *sieve size that retains 40% of total aquifer sample is normally used to select the well screen and associated filter pack material*.

The sieve analyses results will indicate in decimal inches what size slot may be used.

For Example: A sieve analyses indicates that a 40% share of a sample from an aquifer is retained in a .050 sieve. This suggests that the well screen slot size should be .050 inches wide and that a filter pack of .050 or larger may be used within that portion of the aquifer.

However, unless the entire aquifer is uniform in composition, it is always possible that the ideal slot size for one interval may not be ideal in another. This is why the collection of samples during drilling is so important. It is not unusual to have a single well-constructed with several different slot sizes over variable intervals. It is still possible though to identify a single slot size that may be effective throughout the screened interval by varying the filter pack size and adjusting the slot size to the smallest observed 40% retention sieve analyses result. Not only are there numerous types of casing and slot sizes, but there are also many different types of well screen. A few of the more common types of well screen are: *wire wrapped*, *continuous screen*, *slotted*, *louvered*, and *perforated screens*.

All except wire wrapped are available in various types of metal or PVC composition. Again, the appropriate selection depends on local regulations, use, type of aquifer, depth, water quality, location and possibly much more. Therefore, *please refer to your driller and regulatory agency for the proper selection or recommended well screen*. As a rule, wire wrapped screen or continuous screen is normally used in municipal applications where a *high yield* is obtained from *unconsolidated* to *semi-consolidated* formations.

Slotted and perforated screens are stronger and less expensive than wire wrapped screens and are best suited to deep applications, where borehole stability is a concern, and in domestic applications. Louvered screen is used in high yield production wells but particularly in filter packed wells and may help where *cascading water* is a problem.

**Louvers**
The louvers deflect groundwater above *pumping levels* back into the annulus or filter pack so that *air entrainment* and corrosion within the well are minimized. Air entrainment occurs when cascading water drops into the pumping water level creating turbulence and making bubbles. These bubbles may get drawn into a *vortex* created by the pump and then included in the water pumped from the well.

Once the casing and screen specifications are determined, they may be installed into the well. Due to weight, casing is often installed with a drill rig. If a well is *telescoped,* the driller will install the largest diameter portions first. Gravel or filter packs can then be installed. A bentonite or *cement plug* is often installed in the bottom of the borehole before the filter pack is installed, effectively sealing the bottom of the casing and borehole. If certain intervals of the well need to be isolated from others, *inflatable packers* and bentonite or cement grout may be used. The inflatable packer is used to seal off a portion of the annulus to prevent the mixing of the seal material and the filter pack.

These types of seals are commonly used for wells constructed within confined aquifers so that they may be isolated to prevent cross connection with other aquifers or formations. Well *centralizers* are normally installed on the screen and casing before installation. The centralizers are a type of banding or metal offset that, when installed, ensures the casing and screen do not rest up against the borehole walls.

The centralizers will minimize the potential of *bridging* during the installation of filter media and grout. When complete, the well casing is *capped* and normally must terminate at least 12 inches above ground level. Once the well construction is completed it may be developed.

Wire wrapped screen being installed in a well.

# Specialized Well Construction Information

***(Please check with your regulating agency and well driller to ensure your well is properly constructed)***

**Fractured Formations**

Wells obtaining water from fractured formations such as limestone or granite are susceptible to contamination. Contaminated water can move rapidly through these types of formations. Therefore, proper well location and construction are very important when drilling wells in these types of formations. When the ***overburden*** overlying the upper bedrock formation is less than 30 feet thick, the well casing should extend to a depth of at least 40 feet below ground level.

The annular space between the well bore and the casing should also be pressure grouted. Where the well is drilled to obtain water from a formation located below a fractured formation, the casing should extend at least through the fractured formation and be seated in firm rock or clay. Where the overburden overlying the upper bedrock formation is greater than 30 feet thick, the casing should be fitted with a drive shoe and driven to a firm seat in the bedrock. The annular space around the casing can then be sealed with Bentonite grout or neat cement grout.

**Auger Drilled Wells**

As opposed to smaller diameter drilled wells, auger wells are generally constructed at locations where aquifers (water bearing geologic formations) are both shallow and low yielding. An aquifer that yields only 1 gallon per minute will provide 1,440 gallons per day. Auger wells range in depth from 30 to 100 feet.

To compensate for low-yielding aquifers, large diameter auger wells serve as storage reservoirs to provide water during periods of high demand. An auger well with a diameter of 3 feet, a total depth of 50 feet and a water depth of 30 feet, contains approximately 1,600 gallons of water.

***There are two recommended methods for the construction of auger wells.***

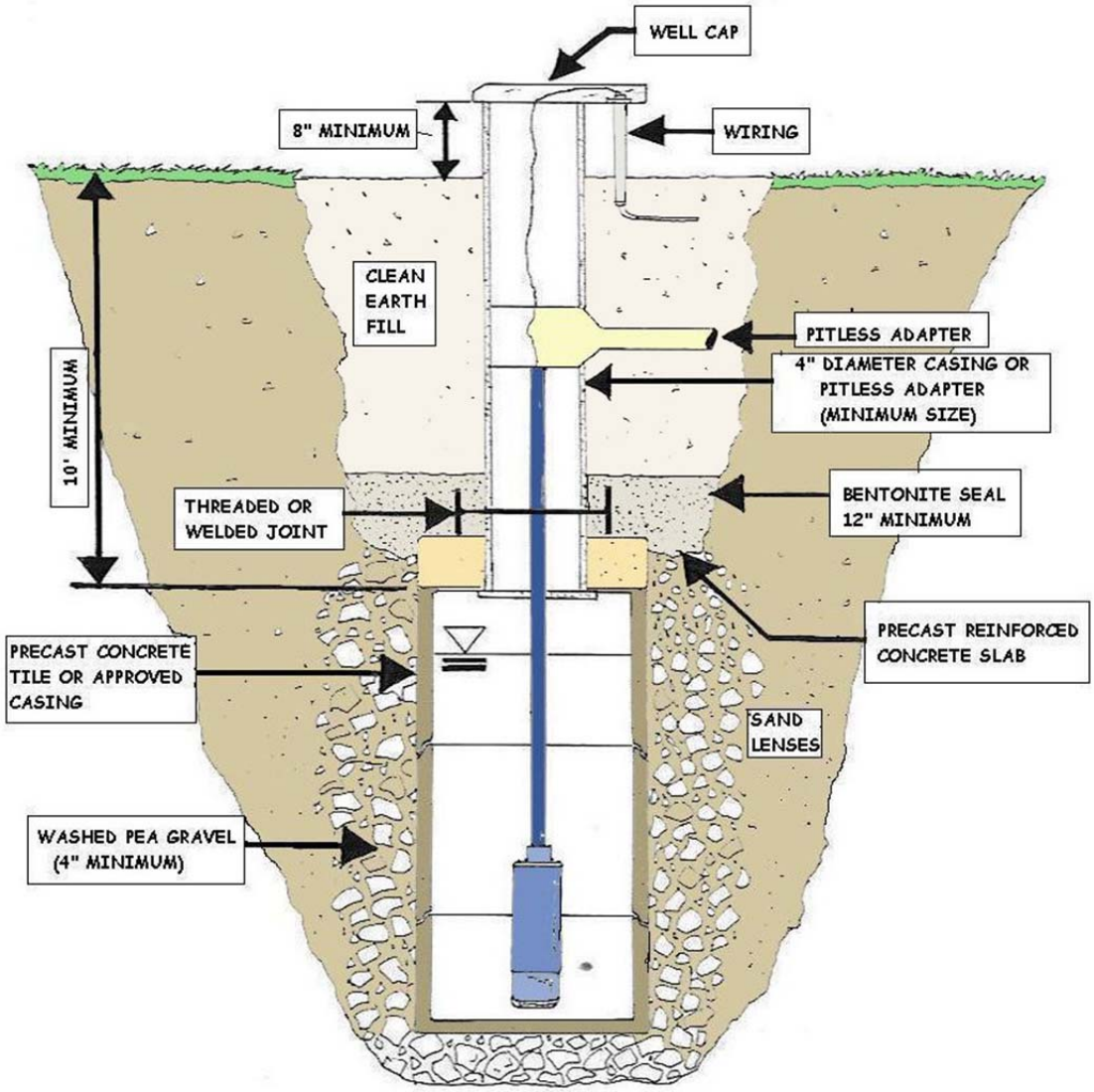
**1) Auger (bored) Well with Buried Slab Construction**

Auger wells are usually constructed utilizing the buried slab method. With this method, the upper well casing shall extend to a depth of 10 feet or more below ground surface and be firmly imbedded in a uniformly tapered hole that is formed when the reinforced concrete buried slab is manufactured, or shall be connected to a pipe cast in the concrete slab. The upper well casing should be at least 4 inches in diameter and extend from the concrete slab to at least 8 inches above the finished ground surface.

A bentonite seal that is a minimum of 12 inches in thickness shall be installed over the buried slab the entire diameter of the borehole. The earth fill on top of the buried slab and around the upper well casing should be well compacted and mounded to drain away from the well.

Sand or gravel cannot be used as fill on top of the buried slab. The lower concrete casing is normally constructed using pre-cast concrete sections ranging in diameter from 2 to 3 feet. The diameter of the well bore hole below the buried slab must be at least 4 inches greater than the outer diameter of the well casing, and the annular space (opening between concrete casing and well bore) must be filled with pea gravel to the well bottom.

The discharge pipe exits the well below grade through an approved *pitless* well adapter. A pitless well adapter is a mechanical device attached to the well casing pipe, usually below frost level, that permits water to pass through the wall of the casing and provides protection to the well and water from contamination. An approved vented well cap or seal should be properly installed on top of the well casing. As an alternative, the discharge pipe can exit at the top of the well casing through an approved well seal. If the pump is located away from the well, the buried pipe leading to the pump from the well must be encased in a pressure discharge line at system pressure.




***(EXAMPLE ONLY – CHECK STATE OR LOCAL REQUIRMENTS)***

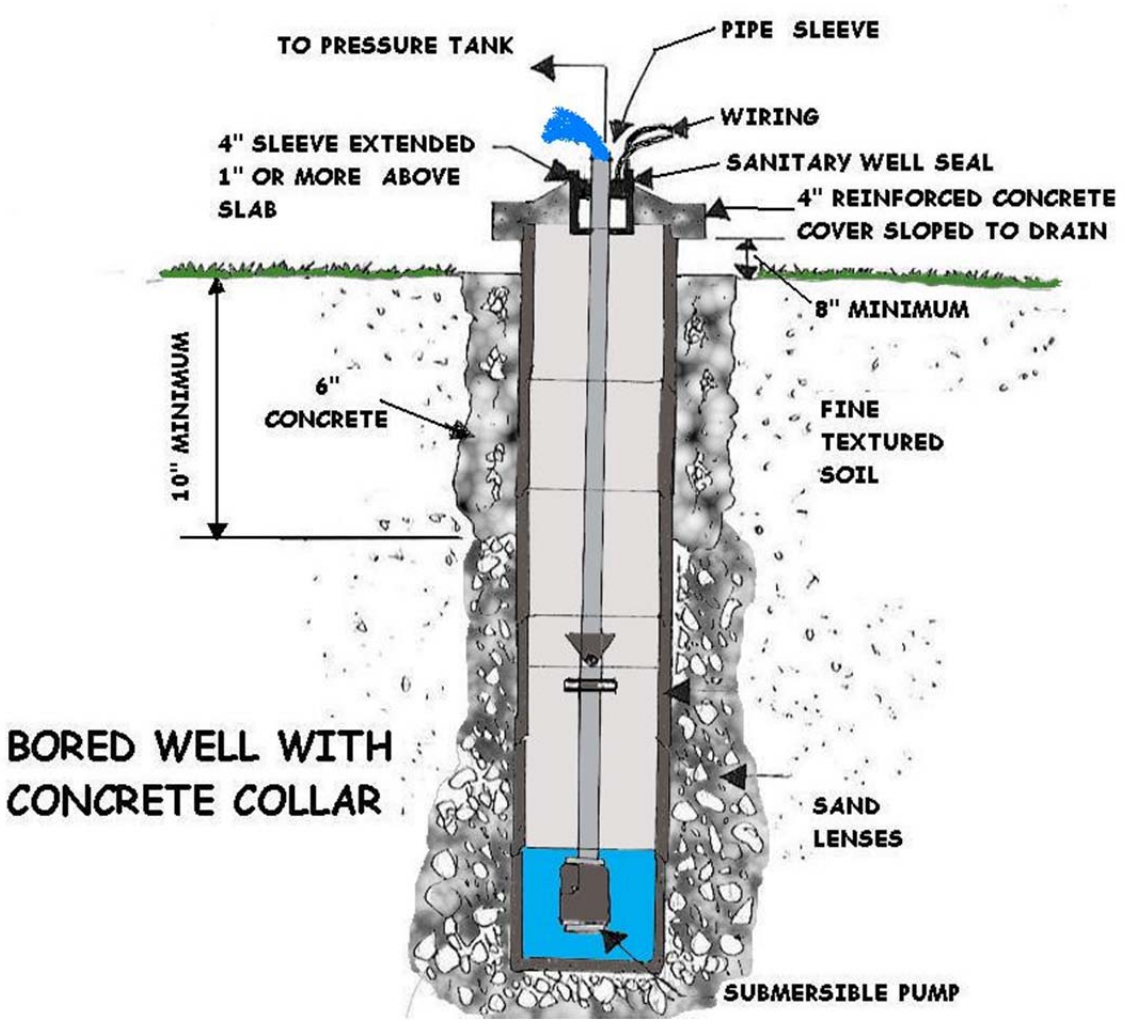
## Auger (bored) Well with Concrete Collar

For auger wells not finished with a buried slab, the concrete casing also ranges in diameter from 2 to 3 feet. The annular space between the excavation and the installed casing should be grouted with concrete that is at least 6 inches thick and poured without construction joints from a minimum of 10-20 feet below ground level to the ground surface. The diameter of the well bore hole below the grouting must be at least 4 inches greater than the outside diameter of the well casing and the annular space should be filled with pea gravel to the well bottom.

The casing should extend at least 8-12 inches above the finished ground surface. The cover slab must be at least 4 inches thick, without joints, adequately reinforced and with a diameter sufficient to extend to the outer edge of the casing.

Adequate sized pipe sleeve(s) should be cast in place in the slab to accommodate the type of pump or pump piping proposed for the well.

A watertight joint must be made where the slab rests on the well casing. If a manhole is installed, it should consist of a curb cast in the slab and extend 4 inches above the slab. A watertight cover must be provided over the manhole and should overhang the curb at least 2 inches. The discharge pipe must exit the well in a watertight manner at the top of the well casing through an approved well seal.



**Why is EPA taking a risk-based approach to protect drinking water provided by ground water systems?**
An evaluation of data on outbreaks and the occurrence of waterborne viral and bacterial pathogens and indicators of fecal contamination in ground water supplying public water system (PWS) wells indicate that there is a subset of ground water systems (GWS) that are susceptible to fecal contamination. Therefore, in 1996, Congress amended the Safe Drinking Water Act (SDWA) to require that EPA take a targeted risk-based approach to require GWSs that are identified as being at the greatest risk of contamination to take action to protect public health. Previously, the 1986 Amendments to the SDWA had included a provision that would have required all PWSs using ground water to disinfect. This would have posed a great implementation challenge for approximately 147,000 GWSs and states.

**What types of pathogens can be found in water provided by ground water systems?**
Ground water that is susceptible to fecal contamination may contain harmful viruses or bacteria. Viral pathogens found in GWSs may include enteric viruses such as Echovirus, Hepatitis A and E, Rotavirus and Noroviruses (i.e., Norwalk-like viruses) and enteric bacterial pathogens such as Escherichia coli (including E. coli O157:H7), Salmonella species, Shigella species, and Vibrio cholerae. Ingestion of these pathogens can cause gastroenteritis or, in certain rare cases, serious illnesses such as meningitis, hepatitis, or myocarditis. Health implications in sensitive subpopulations may be severe (e.g., hemolytic uremic syndrome) and may cause death.

**What causes contamination of ground water?**
Viral and bacterial pathogens are present in human and animal feces, which can, in turn, contaminate drinking water. Fecal contamination can reach ground water sources, including drinking water wells, from failed septic systems, leaking sewer lines, and by passing through the soil and large cracks in the ground. Fecal contamination from the surface may also get into a drinking water well along its casing or through cracks if the well is not properly constructed, protected, or maintained.

**Does this rule address private wells? If not, how does EPA help protect them?**
This rule does not address private wells because they are not under the jurisdiction of the Safe Drinking Water Act and are therefore not subject to EPA regulation. EPA has provided outreach material to states and homeowners to help them understand how to manage individual wells. EPA recommends that well owners periodically test their water for microbial and chemical contaminants and properly maintain their well. Information is available on EPA's Private Wells Web site.

**What are the basic requirements of the rule?**
The risk-targeting strategy incorporated into the rule provides for:

- regular sanitary surveys of public water systems to look for significant deficiencies in key operational areas;
- triggered source water monitoring when a system that does not sufficiently disinfect drinking water identifies a positive sample during its Total Coliform Rule monitoring and assessment monitoring (at the option of the state) targeted at high-risk systems;
- implementation of corrective actions by ground water systems with a significant deficiency or evidence of source water fecal contamination to reduce the risk of contamination; and,
- compliance monitoring for systems that are sufficiently disinfecting drinking water to ensure that the treatment is effective at removing pathogens.

## 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.

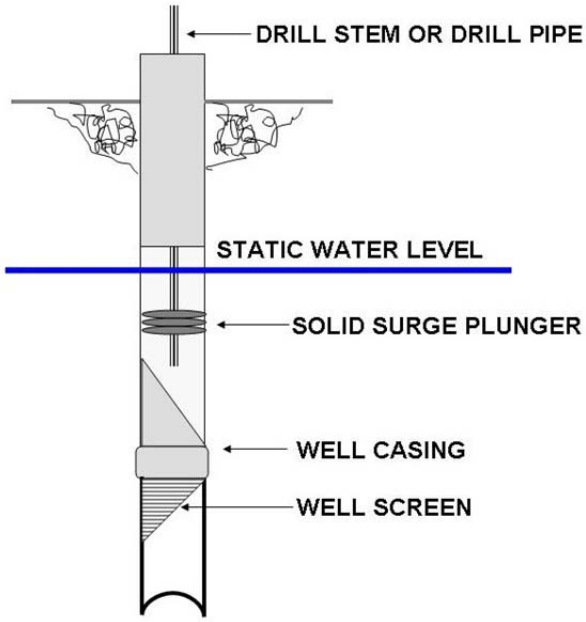
Air lifting development is most often done with a rotary drilling rig through the drill string. Sometimes special air diffusers or jets are used to direct the bursts of air into preferred directions (see jetting). Piping is inserted into the well and intermittent blasts of air are introduced as the piping 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.

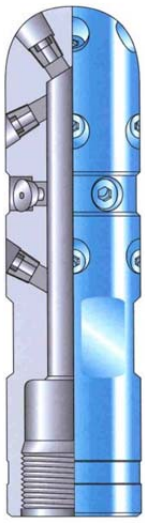
**Rotary Rig**

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.)

## Pump Selection

A drill rig in the snow.

Basically, a well is a hole drilled into an aquifer. A pipe and a pump are used to pull water out of the ground, and a screen filters out unwanted particles that could clog the pipe. Wells come in different shapes and sizes, depending on the type of material the well is drilled into and how much water is being pumped out.

**Three Basic Types of Wells**

- **Bored** or **shallow wells** are usually bored into an unconfined water source, generally found at depths of 100 feet or less.
- **Consolidated** or **rock wells** are drilled into a formation consisting entirely of a natural rock formation that contains no soil and does not collapse. Their average depth is about 250 feet.
- **Unconsolidated** or **sand wells** are drilled into a formation consisting of soil, sand, gravel, or clay material that collapses upon itself.

## 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.

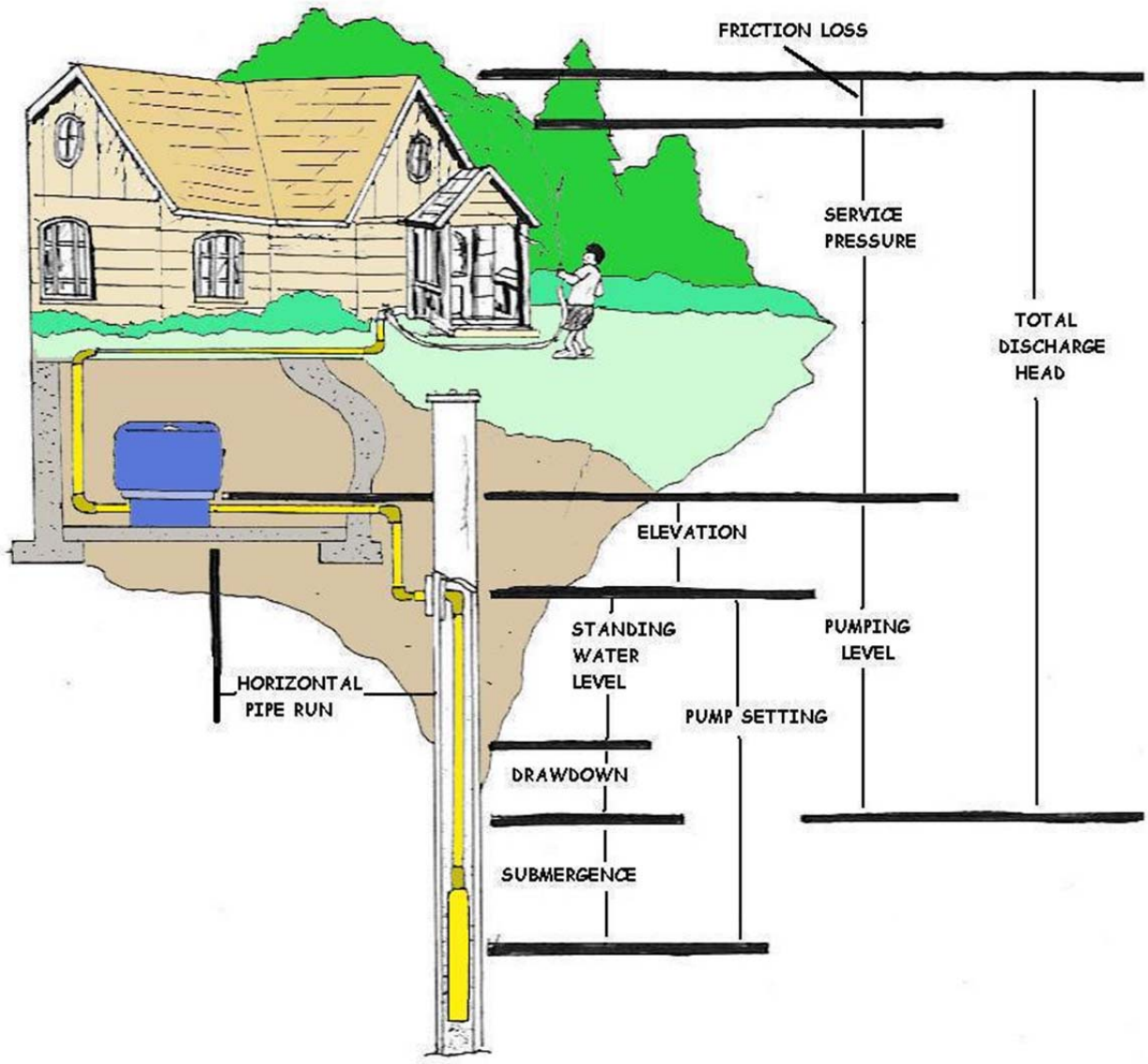
**For example:** A municipal supply well has been tested and determined to yield 500gpm. The well was constructed with 10 inch casing that has been perforated from 200 to 500 feet below the ground surface within an unconfined aquifer. The static water level has been measured at 100 feet while the drawdown 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.

Preparing an explosive charge to ‘hydrofract” or loosen or dislodge any debris or corrosion inside an existing well casing. This explosive material is made in 25 or 50 foot lengths and has a blasting cap to start the explosion. Believe it or not, you cannot hear the explosion, since it is deep underwater. The bottom photo is the remains of the explosive charge. This procedure will usually increase well production.

Blasting cap on the explosive cord. Below, some of the debris from inside the well casing following the explosion. After talking to this man, I found out that after 9-11, he had to increase his fees because of the ATF and new rules concerning explosives. Be prepared to pay through the nose for this treatment process. Consider this fee the price of admission for having adequate water to supply your customer's demands.

## Water Use or Demand

Water system demand comes from a number of sources including residential, commercial, industrial and public consumers as well as some unavoidable loss and waste. If fire protection is desired, that could also represent a rather significant (although not continuous) demand upon the system. The combination of storage reservoirs and distribution lines must be capable of meeting consumers' needs for quality, quantity and pressure at all times. The quantity of water used in any community varies from 50 to 500 gallons per person per day. A common design assumption is to use from 100 to 150 gallons per person per day for average domestic use. The maximum daily use is approximately 2 to 3 times the average daily use. Maximum daily use is usually encountered during the summer months and can vary widely depending on irrigation practices.

**Water Pressure**
For ordinary domestic use, water pressure should be between 25 and 45 psi. A minimum of 60 psi at a fire hydrant is usually adequate, since that allows for up to 20 psi pressure drop in fire hoses. In commercial and industrial districts, it may be common to have 75 psi or higher. 20 psi is considered the minimum required at any point in the water system, so that backflow and infiltration is prevented. Pressure is provided by the direct force of the water (such as water from a pump), or by the height of the water (such as a storage reservoir). 2.31 feet of water is equal to 1 psi, or 1 foot of water is equal to about a half a pound (.433 pounds to be exact).

**Storage and Distribution**
The cost of supplying water to the users of any water system includes the installation of storage and distribution facilities. Also, there are on-going maintenance costs associated with cleaning, repairing and replacing these facilities. The distribution system must also protect water quality between the source and the customer's tap. Proper construction is important in maintaining system integrity. Care must be taken that no foreign material is introduced into the system during pipe laying operations. Pipe ends should be covered at the end of the work day or during interruptions of construction.

All pipes, joints and fittings should be pressure tested and disinfected with a 5% chlorine solution such as household bleach before backfilling. It is also important that all materials in contact with potable water meet the requirements of the National Sanitation Foundation (**NSF**) or American Water Works Association (**AWWA**) or have equivalent third-party certification. This includes solders (must be lead-free), pipes, joining and sealing materials, and protective coatings.

## Water Storage Facilities
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 stand pipes, elevated tanks and reservoirs, hydropneumatic tanks and surge tanks.

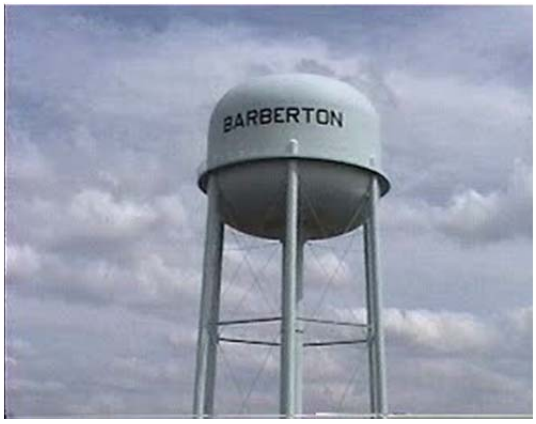
These tanks serve multiple purposes in the distribution system. Just the name alone can give you an idea of its purpose.

- **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, and oftentimes, 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 stand pipe 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.

## Storage Reservoirs

Storage reservoirs allow the system to meet the fluctuations in demand described earlier. It is recommended that the volume of storage be equal to from one to three days of the system's average daily use. It is also recommended that storage reservoirs be located at a high enough elevation to allow the water to flow by gravity to the distribution system.

This, coupled with restricted usage on the part of the consumers, should provide an uninterrupted water supply in the event of pump failure, loss of power or an acute contamination event or cross-connection. Also, if applicable, some storage for fire protection should be provided. Reservoirs are also used as detention basins to provide the required chlorine contact time necessary to ensure the adequacy of disinfection. As such, the contact time in a reservoir is greatly improved when the reservoir is constructed with a separate inlet and outlet pipe, preferably located on opposite sides of the reservoir and at different levels. Also, baffles inside the reservoir (walls, curtains, or spirals) increase the contact time by preventing the water from leaving the reservoir too quickly (known as "*short-circuiting*").

**Steel Reservoirs**
Steel reservoirs or tanks generally have lower construction and installation costs than concrete, but require more maintenance. To protect against corrosion, the exterior should be kept cleaned and painted. Interiors of steel reservoirs are commonly coated with an epoxy or enamel-type finish. Some coal-tar linings used in the past have apparently degraded over time and are implicated in the release of small amounts of solvents into the stored water.

Steel reservoirs are usually welded or bolted together and are manufactured in a variety of sizes. Small steel reservoirs can be manufactured off-site and then trucked and lifted into place. Steel tanks should be inspected once a year and repainted every 5-7 years. Steel tank should also have cathodic protection and be screened to keep birds and insects out. The maintenance program for reservoir tanks should call for annual draining for a complete inspection of the interior. Cleaning and disinfection prior to placing the reservoir or tank back in service is necessary.

**Disinfection by chlorine can be accomplished by one of three methods:**

1. Fill the tank or reservoir with a 25 mg/1chlorine solution and leave it for 24 hours.
2. Fill the reservoir with a 50 mg/1 chlorine solution and leave it for 3 hours.
3. Spray or brush on a 200 mg/1 chlorine solution and allow it to remain for 3 hours.

The chlorinated water shall be disposed of in a manner that will not have an adverse effect on the environment. Check with your state environmental, health or drinking water section.

Large steel water storage tank

## Disinfection of Water Storage Reservoirs

The distribution system is the piping that delivers water to service connections.

There are several types of piping material that can be used.

Each has its advantages and disadvantages.

The pipe material must have adequate strength to withstand external loads from backfill, traffic and earth movement, high burst strength to withstand high water pressure, smooth interior surfaces, corrosion resistant exteriors and tight joints.

A number of linings are also used to extend the life of the pipe and improve flow characteristics:

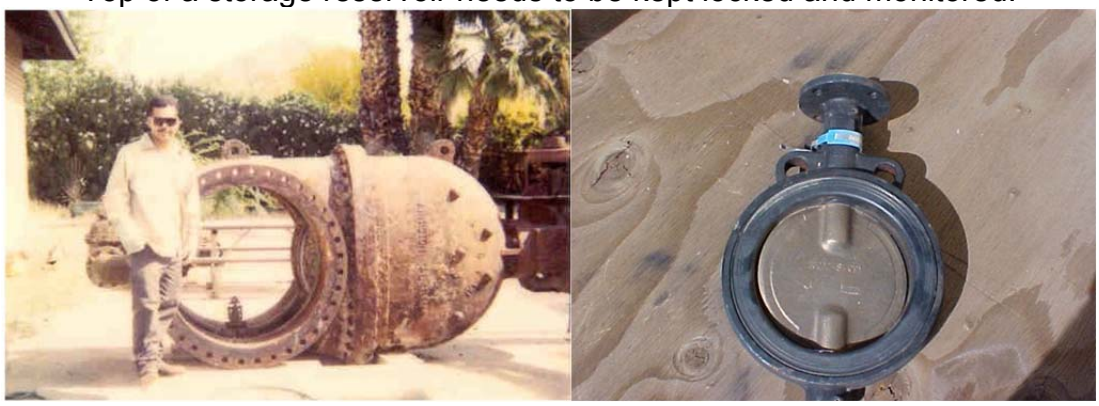
**Reservoir size (gals.) Gallons of 5% bleach to add to achieve a 25ppm chlorine dose**

| | |
|---|---|
| **1,000** | **.5** |
| **2,000** | **1** |
| **3,000** | **1.5** |
| **4,000** | **2** |
| **5,000** | **2.5** |
| **10,000** | **5** |
| **20,000** | **10** |
| **30,000** | **15** |
| **40,000** | **20** |
| **50,000** | **25** |

**Reservoir size (gals.) Amount (in pounds of dry weight) of 65% strength dry chlorine powder (HTH) to add to achieve a 25ppm dose.**

| | |
|---|---|
| **10,000** | **3.5** |
| **20,000** | **6.5** |
| **30,000** | **10** |
| **40,000** | **13** |
| **50,000** | **16** |
| **100,000** | **32** |
| **200,000** | **64** |
| **300,000** | **100** |
| **400,000** | **130** |
| **500,000** | **160** |

Top of a storage reservoir needs to be kept locked and monitored.



Large Gate Valve and a Butterfly Valve which works like an old fashioned carburetor.

Pouring a Calcium Hypochlorite solution down a well to disinfect the well.

150 pound chlorine gas cylinder.
Always tag the empty cylinder and store upright.

**Chlorine Review Statements**

- ✓ What are the requisite emergency procedures in case of a large, uncontrolled, Cl2 leak? Immediately notify the local emergency response team; immediately warn and evacuate people living or working in adjacent areas and

- ✓ What compounds are formed in water when Cl2 gas is introduced? Cl2 gas forms a mixture of hydrochloric and hypochlorous acids.

- ✓ What does '*breakpoint chlorination*' mean? Adding Cl2 to the water until the Cl2 demand is satisfied.

- ✓ What happens when hypochlorite is brought into contact with an organic material? The organic material decomposes, releasing heat very rapidly.

- ✓ What is the name of a device that has a transparent tube with a tapered bore containing a ball and is often used to measure the rate of a gas or liquid? Rotameter.

- ✓ What is the primary safety concern when using Cl2 gas as opposed to calcium hypochlorite or sodium hypochlorite? The potential for a gas leak.

- ✓ What is the purpose of an evaporator? To convert liquid Cl2 to gaseous Cl2 for use by gas chlorinators.

- ✓ What is the purpose of the bottom valve on a 1-ton Cl2 cylinder? To remove liquid Cl2.

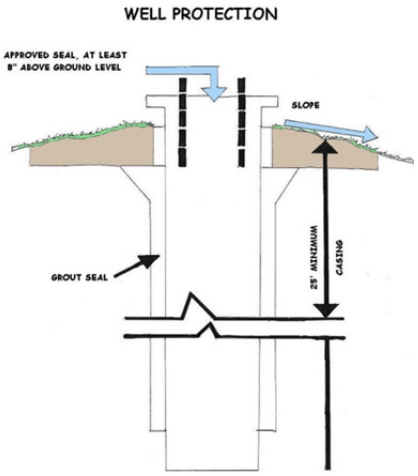
- ✓ What is the purpose of the ejector on a hypochlorinator? The ejector draws in additional water for dilution of the hypochlorinate solution.

What may happen if the temperature of a full Cl2 cylinder is increased by 50°F. (30° C.)? The cylinder may rupture.

# Hydropneumatic Tank Section

**Hydropneumatic Tanks Out of Service for Maintenance**
**Effects on the Water Supply**
Whenever a tank must be taken out of service for maintenance, the operator should insure that the water pressure is maintained by other back-up tanks in the system. If this is not possible, customers should be given as much advance notice as possible, maintenance should be conducted during periods of low water demand, and the maintenance should be conducted as quickly as possible to reduce the time without water service.

**Troubleshooting Hydropneumatic Tank Problems**
The purpose of a hydropneumatic tank is to provide air for the water system. It is the responsibility of the operator to perform basic troubleshooting of problems in hydropneumatic tank systems. The operator has to decide, based on his/her own training and capability when a problem requires assistance from another operator or an outside expert. Operators should not hesitate to seek assistance if they are uncomfortable with a particular problem or situation. Remember, the goal is to provide a safe and consistent supply of water and this cannot always be accomplished by one or two individuals who may have many other responsibilities. Corrective action should only be performed by individuals who are trained and skilled in that particular area.




Corrective actions by unskilled individuals could result in personal injury or serious damage to the water system equipment. The following troubleshooting table is provided to assist operators of small water systems to troubleshoot basic problem with hydropneumatic tanks. It must be recognized that problems occurring in hydropneumatic tanks could also be related to the well, water supply pump and controls, and the distribution system, therefore other troubleshooting tables included in this manual should be consulted in addition to the troubleshooting table for hydropneumatic tanks.

**Troubleshooting Table for Hydropneumatic Tanks**
**Problem**
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. Air is present in the water.
6. Oil is present in the water.
7. Dirt and or bacteria present in the water.
8. Excessively high distribution system pressure (greater than 70 psi).
9. Excessively low distribution system pressure (normal working pressure below 40 psi or occasional pressures below 20 psi during peak usage).
10. Corrosion present on outside of tank.
11. Tank is unstable and can be easily be moved, or tank is supported by the piping.

## Possible Hydropneumatic Tank Problem 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. Leaking foot valve or check valve.
3B. Defective pressure switch or automatic control system. High or Low pressure cutoff switches may need to be adjusted.
3C. Excessive water use or major leak in water distribution system.
3D. Water-logged hydropneumatic tank.
3E. Air-logged hydropneumatic tank.
4A. Problems with well screen or gravel
4B. If there is iron or manganese in the well water and it is not removed before the hydropneumatic tank, and the air in the hydropneumatic tank comes into direct contact with the water in the tank, then
the iron and manganese could be oxidizing and settling in the tank. Also, sediment could be present in the distribution system.
5A. If there is a check valve between the well pump and the hydropneumatic tank, and air is present on the well side of the check valve, then the pump may be breaking suction. In this case, the water level in well is near or below the pump intake.
5B. If there is a check valve between the well pump and the hydropneumatic tank, and air is present only on the hydropneumatic tank side of the check valve and in the distribution system, then air from hydropneumatic may be tank entering water.
6A. Oil leaking from air compressor.
7A. Refer to troubleshooting table on "*hypochlorinators*."
7B. Replace filter. Also review troubleshooting table on "*hypochlorinators*." Notify water system specialist.
8A. See Problem Item #2 in this troubleshooting table.
9A. Refer to troubleshooting guide section "*Pumps*." Notify supervisor.
10A. Clean area with a wire brush. Prime and paint the surface with. Do not chip rust from the tank unless it is drained and out of service. If chipping is required, contact a tank corrosion specialist. The tank may not be structurally sound and re-pressurizing could cause further damage or personal injury. Note: 50 psi exerts a pressure of 3.5 tons per square foot! Never paint the tank interior without first consulting the state regulatory authority.
11A. Provide suitable and permanent supports so the tank cannot be moved and the piping is not supporting the weight of the tank. This may require taking the system out of service while these repairs are made. Never try to move a tank that is pressurized. Notify your water system specialist.

## Possible Hydropneumatic Tank 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. Refer to trouble-shooting table on "*Pumps*."
3A. Contact well specialist.
3B. Contact well specialist or electrician.
3C. Locate and repair leak.
3D. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with water or if the water level exceeds 2/3 of the volume of the tank, then air will have to be introduced into the tank. Check tank and air system for leaks. The optimum air-to-water ratio in the hydropneumatic tank should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist.
3E. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with air or if the water level is less than 1/2 of the volume of the tank, then air will have to bled from the tank. The optimum air-to-water ratio should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist.
4A. Contact well contractor.
4B. Check air-to-water ratio from sight tube (if provided). If the tube is completely filled with air or if the water level is less than 1/2 of the volume of the tank, then air will have to bled from the tank. The optimum air-to-water ratio should be 2/3 water to 1/3 air. If the problem persists or if there is no sight tube, notify water system specialist. If there is a physical separation between the air and water in the tank, then the separator could have broken. Notify water system specialist.
5A. Partially throttle discharge valve. Notify supervisor or well service company.
5B. Improve removal of iron and manganese. If the hydropneumatic tank is equipped with a drain, open the drain valve and discharge the sediment to waste.
6A. Check the oil separator on the discharge side to the air compressor.
Notify water system specialist. Consider replacing the unit with a non-oil lubricated type unit.
7A. Inadequate disinfection.
7B. Intake filters on air compressor broken or dirty.
8A. Automatic pressure controls needs adjustment or cut-out sequence is not functioning.
9A. Automatic pressure controls needs adjustment or cut-in sequence is not functioning.
10A. Inadequate protective coating (paint).
11A. Tank supports are inadequate.

Note: If the water supply pump is running constantly, excessive pressures can develop in the hydropneumatic tank and distribution system. The tank should be equipped with a pressure relief valve that opens at approximately 100 psi. This may protect the tank from damage but it is possible that the distribution system could be damaged if pressures exceed normal working pressures. Check for leaks throughout the service area. Notify electrician experienced with industrial controls.

Effects of a broken water service.

Broken water main, much more larger and stronger leak, more damage, more customers without water.  More chance of water contamination.

## Common Water Quality Definitions

### Units of Measurement

**mg/l** = Milligrams per liter. One milligram per liter equals one packet of artificial sweetener sprinkled into 250 gallons of iced tea.
**µg/l** = Micrograms per liter. One microgram per liter is equal to one packet of artificial sweetener sprinkled into an Olympic-size swimming pool.
**NTU** = Nephelometric Turbidity Units. A measurement on the cloudiness of the water.
**pCi/l** = Picocuries per liter. A measure of radioactivity.

### Acronyms

**Maximum Contaminant Level (MCL)** - The highest level of a contaminant that is allowed in drinking water.
**Maximum Contaminant Level Goal (MCLG)** - The level of a contaminant in drinking water below which there is no known or expected risk to health.
**Treatment Technique (TT)** - A required process intended to reduce the level of a contaminant in drinking water.
**Action Level (AL)** - The concentration of a contaminant that, if exceeded, triggers treatment or other requirements which a water system must follow.

## Timeline of Existing Federal Water and State Drinking Water Quality Regulations

**National Interim Primary Drinking Water Regulations** (NIPDWR) Promulgated 1975-1981 Contained 7 contaminants Targeted: Trihalomethanes, Arsenic, and Radionuclides Established 22 drinking water standards.

**Phase 1 Standards** Promulgated 1987 Contained 8 contaminants Targeted: VOCs.

**Phase 2 Standards** Promulgated 1991 Contained 36 contaminants Targeted: VOCs, SOCs, and IOCs.

**Phase 5 Standards** Promulgated 1992 Contained 23 contaminants Targeted: VOCs, SOCs, and IOCs.

**Surface Water Treatment Rule** (SWTR) Promulgated 1989 Contained 5 contaminants Targeted: Microbiological and Turbidity.

**Stage 1 Disinfectant/Disinfection By-product** (D/DBP) Rule Promulgated 1998 Contained 14 contaminants Targeted: DBPs and precursors.

**Interim Enhanced Surface Water Treatment Rule** (IESWTR) Promulgated 1998 Contained 2 contaminants Targeted: Microbiological and Turbidity.

**Radionuclide Rule** Promulgated 2000 Contained 4 contaminants Targeted: Radionuclides.

**Arsenic Rule** Promulgated 2001 Contained 1 contaminant Targeted: Arsenic.

**Filter Backwash Recycling Rule** Promulgated 2001 Contained - Targeted: Microbiological and Turbidity.

# Water Quality Key Words

**2,4-D:** A chlorinated phenoxy compound, functions as a systemic herbicide and is used to control many types of broadleaf weeds. There are many forms or derivatives (esters, amines, salts) of 2,4-D and these vary in solubility and volatility. Unless otherwise specified, this document will refer to the acid form of 2,4-D. This compound is used in cultivated agriculture and in pasture and rangeland applications, forest management, home and garden situations and for the control of aquatic vegetation. 2,4-D was a major component (about 50%) of the product Agent Orange used extensively throughout Vietnam. However most of the problems associated with the use of Agent Orange were associated with a contaminant (dioxin) in the 2,4,5-T component of the defoliant. The association of 2,4-D with Agent Orange has prompted a vast amount of study on the herbicide.

**ANTIMONY:** A chemical element with the symbol Sb (Latin: stibium, meaning "mark") and atomic number 51. A metalloid, antimony has four allotropic forms. The stable form of antimony is a blue-white metalloid. Yellow and black antimony are unstable non-metals. Antimony is used in flame-proofing, paints, ceramics, enamels, a wide variety of alloys, electronics, and rubber.

**ASBESTOS:** A mineral fiber that has been used commonly in a variety of building construction materials for insulation and as a fire-retardant. EPA and CPSC have banned several asbestos products. Manufacturers have also voluntarily limited uses of asbestos. Today, asbestos is most commonly found in older homes, in pipe and furnace insulation materials, asbestos shingles, millboard, textured paints and other coating materials, and floor tiles.

**BARIUM:** A chemical element. It has the symbol Ba, and atomic number 56. Barium is a soft silvery metallic alkaline earth metal. It is never found in nature in its pure form due to its reactivity with air. Its oxide is historically known as baryta but it reacts with water and carbon dioxide and is not found as a mineral. The most common naturally occurring minerals are the very insoluble barium sulfate, $BaSO_4$ (barite), and barium carbonate, $BaCO_3$ (witherite). Benitoite is a rare gem containing barium.

**BERYLLIUM:** A chemical element with the symbol Be and atomic number 4. A bivalent element, beryllium is a steel grey, strong, light-weight yet brittle alkaline earth metal. It is primarily used as a hardening agent in alloys, most notably beryllium copper. Commercial use of beryllium metal presents technical challenges due to the toxicity (especially by inhalation) of beryllium-containing dusts.

**BROMATE:** An inorganic anion, bromate is tasteless and colorless, with a low volatility. As a moderately strong oxidant, bromate is reactive. $BrO_3^-$ is a bromine-based oxoanion. A bromate is a chemical compound that contains this ion. Examples of bromates include sodium bromate, ($NaBrO_3$), and potassium bromate, ($KBrO_3$).

**CADMIUM:** A chemical element with the symbol Cd and atomic number 48. A relatively abundant, soft, bluish-white, transition metal, cadmium is known to cause cancer and occurs with zinc ores. Cadmium is used largely in batteries and pigments, for example in plastic products.

**CHLORITE:** 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.

**CHROMIUM:** A chemical element which has the symbol Cr and atomic number 24. It is a steel-gray, lustrous, hard metal that takes a high polish and has a high melting point. It is also odorless, tasteless, and malleable.

**CONTACT TIME (CT):** To inactivate viruses and bacteria, the minimum disinfection contact time measured before the first customer should be six milligrams per minute per liter (6 mg-min/L).

This value is called “Chlorine Contact Time” or CT. To calculate CT, multiply the free chlorine residual concentration (C) times the contact time (T). To get the required CT value of 6, adjust the free chlorine residual concentration or the contact time.

**DISINFECTION BYPRODUCTS:** Disinfection byproducts are chemical, organic and inorganic substances that can form during a reaction of a disinfectant with naturally present organic matter in the water.

**DPD METHOD:** Presence of free chlorine in the distribution network is indication of correct disinfection. Chlorine in water is determined according to ISO 7393-2 by colorimetric HACH method on the basis of DPD (N, N-diethyl - p – phenylendiamine). The photometric detection uses the wave lengths of 490 – 555 nm. Hach elected, for most of his DPD colorimetric systems, the wave length of 530 nm.

**FORMAZIN TURBIDITY UNIT (FTU):** A unit used to measure the clarity of water. The ISO refers to the units as FNU (Formazin Nephelometric Units). The technique is the same as that for the NTU, but the calibration uses microspheres of the polymer formazin.

**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 ($CHCl_2CO_2H$).

**HIGH-TEST HYPOCHLORITE:** A composition composed mainly of calcium hypochlorite is commonly called high test hypochlorite. High-Test Hypochlorite contains not less than 60.0% of available chlorine.

**HYDROCHLORIC ACID:** It is the aqueous solution of hydrogen chloride gas (HCl). It is a strong acid, and the major component of gastric acid, and of wide industrial use. Hydrochloric acid must be handled with appropriate safety precautions because it is a highly corrosive liquid.

**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.

**IRON BACTERIA:** In the management of water-supply wells, iron bacteria are bacteria that derive the energy they need to live and multiply by oxidizing dissolved ferrous iron (or the less frequently available manganese and aluminum). The resulting ferric oxide is insoluble, and appears as brown gelatinous slime that will stain plumbing fixtures, and clothing or utensils washed with the water carrying it, and may contribute to internal corrosion of the pipes and fixtures the water flows through. They are known to grow and proliferate in waters containing as low as 0.1mg/l of iron. However, at least 0.3 ppm of dissolved oxygen is needed to carry out oxidation. The proliferation of iron bacteria, in some way, increases the chance of sulfur bacteria infestation.

**LETHAL CONCENTRATION 50:** Also referred to as LC50, a concentration of a pollutant or effluent at which 50 percent of the test organisms die; a common measure of acute toxicity.

**MANGANESE (IV) OXIDE:** The chemical compound MnO2, commonly called manganese dioxide. This blackish or brown solid occurs naturally as the mineral pyrolusite, which is the main ore of manganese. It is also present in manganese nodules. The principal use for MnO2 is for dry-cell batteries, such as the alkaline battery and the zinc-carbon battery. In 1976 this application accounted for 500,000 tons of pyrolusite. MnO2 is also used for production of MnO4–. It is used extensively as an oxidizing agent in organic synthesis, for example, for the oxidation of allylic alcohols.

**MAXIMUM CONTAMINANT LEVEL (MCL):** The maximum concentration of a chemical that is allowed in public drinking water systems.

**MAXIMUM CONTAMINANT LEVEL GOAL (MCLG):** The maximum level at which a contaminant can exist in drinking water without having an adverse effect on human health.

**NEPHELOMETRIC TURBIDITY UNIT (NTU):** The unit used to describe turbidity. Nephelometric refers to the way the instrument, a nephelometer, measures how much light is scattered by suspended particles in the water. The greater the scattering, the higher the turbidity. Therefore, low NTU values indicate high water clarity, while high NTU values indicate low water clarity.

**PERMISSIBLE EXPOSURE LIMIT (PEL or OSHA PEL):** A legal limit in the United States for exposure of an employee to a substance or physical agent. For substances it is usually expressed in parts per million (ppm), or sometimes in milligrams per cubic meter ($mg/m^3$). Units of measure for physical agents such as noise are specific to the agent. Permissible Exposure Limits are established by the Occupational Safety and Health Administration (OSHA).

**POWDERED ACTIVATED CARDON TREATMENT (PACT):** A wastewater technology in which powdered activated carbon is added to an anaerobic or aerobic treatment system. The carbon in the biological treatment process acts as a "buffer" against the effects of toxic organics in the wastewater.

**PPM:** Abbreviation for parts per million.

**QUICKLIME:** A calcium oxide material produced by calcining limestone to liberate carbon dioxide, also called “calcined lime” or “pebble lime”, commonly used for pH adjustment. Chemical formula is CaO.

**RECOMMENDED EXPOSURE LIMIT (REL):** An occupational exposure limit that has been recommended by the U.S. National Institute for Occupational Safety and Health to OSHA for adoption as a Permissible Exposure Limit. The REL is a level that NIOSH believes would be protective of worker safety and health over a working lifetime if used in combination with engineering and work practice controls, exposure and medical monitoring, posting and labeling of hazards, worker training and personal protective equipment. No REL has ever been adopted by OSHA, but they have been used as guides by some industry and advocacy organizations.

**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.

**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.

**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.

**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.

Top photograph, HPC plate. Bottom, Bac-T or Colilert samples, the yellow indicates coliform bacteria, if this sample fluoresces under a black light that means that fecal or e. coli is present.

**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.

# Water Sampling Terms, and Definitions

***Microbes***

**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.

**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.

**Turbidity** has no health effects. However, turbidity can interfere with disinfection and provide a medium for microbial growth. Turbidity may indicate the presence of disease causing organisms. These organisms include bacteria, viruses, and parasites that can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.

***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 the 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, cramps).

***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 the EPA standard 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 the EPA standard 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 standard 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.

***Inorganic Contaminants***

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

**Arsenic.** Some people who drink water containing arsenic in excess of the EPA standard 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 |

**Point-of-Entry P.O.E**. will usually be a designated sampling point on a water treatment or distribution system.

# Waterborne Pathogens and Disease Section

Bacteria, viruses, and protozoan 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.

**How Diseases are Transmitted**

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.

Cryptosporidium→

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 the 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. The general public and some of the medical community usually refer to diarrhea symptoms as stomach flu.

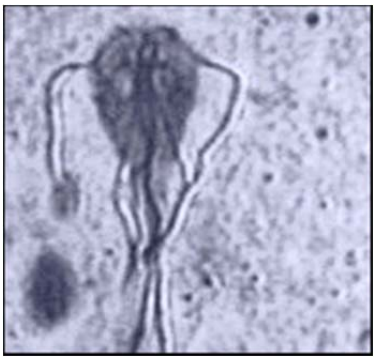
Technically, influenza is an upper respiratory illness and rarely has diarrhea associated with it; therefore, stomach flu is a misleading description for foodborne or waterborne illnesses, yet is accepted by the general public. So the next time you get the stomach flu, you may want to think twice about what you've digested within the past few days.

**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 and 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. Illness (disease) will occur.

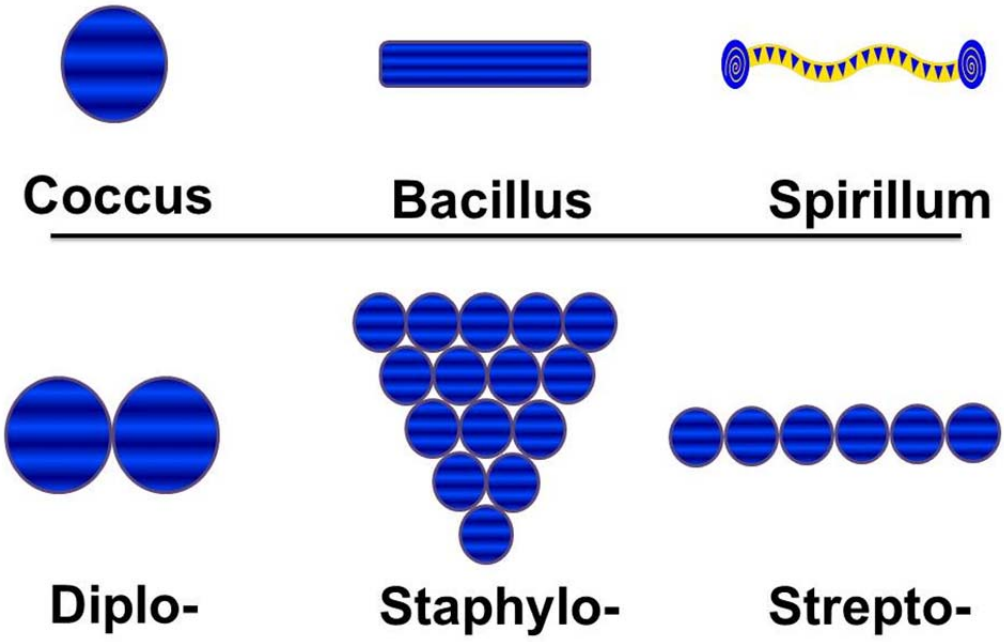
This chain lists the events that must occur for the transmission of disease via drinking water. By breaking the chain at any point, the transmission of disease will be prevented.



**Bacterial Diseases**

Giardia→

Campylobacteriosis is the most common diarrhea illness caused by bacteria. Symptoms include abdominal pain, malaise, fever, nausea and vomiting, and they usually 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 unpasteurized milk, as well as un-chlorinated water.




Types of Bacteria

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, and 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-Caused 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 Caused 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 is extremely resistant to conventional disinfectants such as chlorine. Effective filtration treatment is therefore critical to removing these organisms from water sources.

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.

**Giardia lamblia**
*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.

**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.

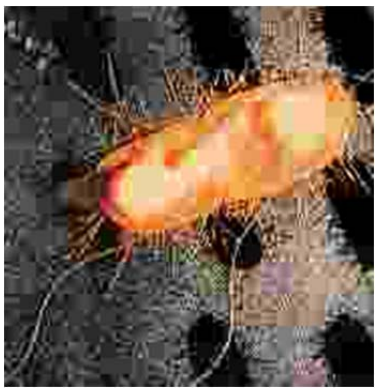
## Waterborne Diseases

| 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/**

# 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.

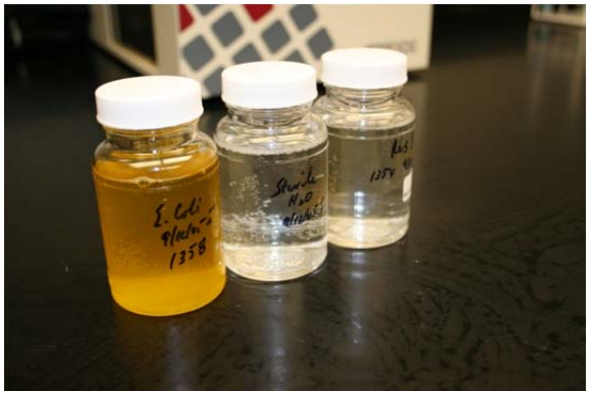
Indicator bacteria are usually harmless, occur in high densities in their natural environment and are easily cultured in relatively simple bacteriological media. Indicators in common use today for routine monitoring of drinking water include total coliforms, fecal coliforms, and *Escherichia coli (E. 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 bleach or alcohol solution or flaming the end of the tap with disposable butane lighter.

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.

**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 preformed? When a public water system exceeds an action level for lead of copper.

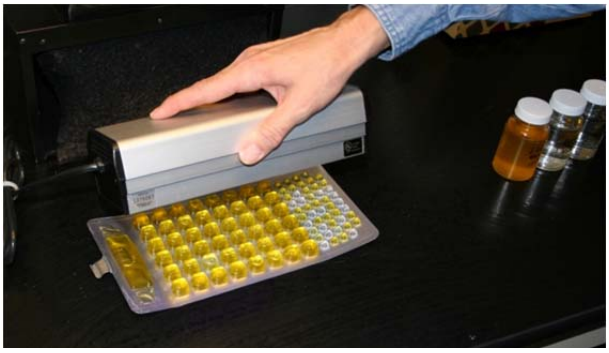
**Noncommunity and nontransient noncommunity public water systems will sample at the same frequency as a like sized community public water system if:**
1. It has more than 1,000 daily population and has ground water as a source, or
2. It serves 25 or more daily population and utilizes surface water as 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.

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

**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 |

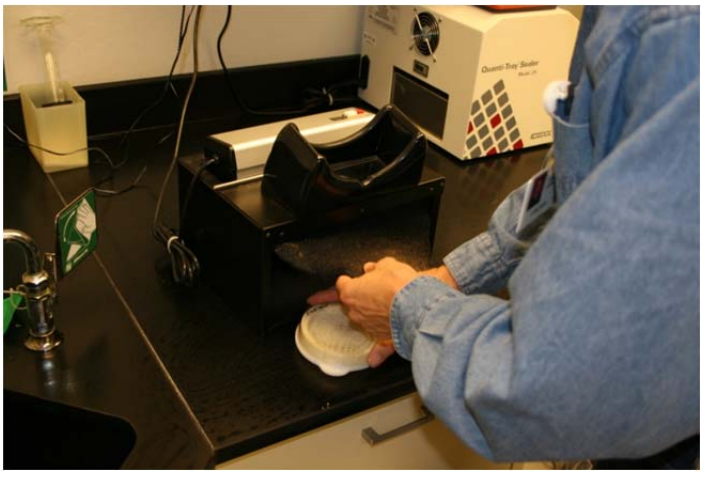


**Using a black light to see fecal bacteria.**

**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 is 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.

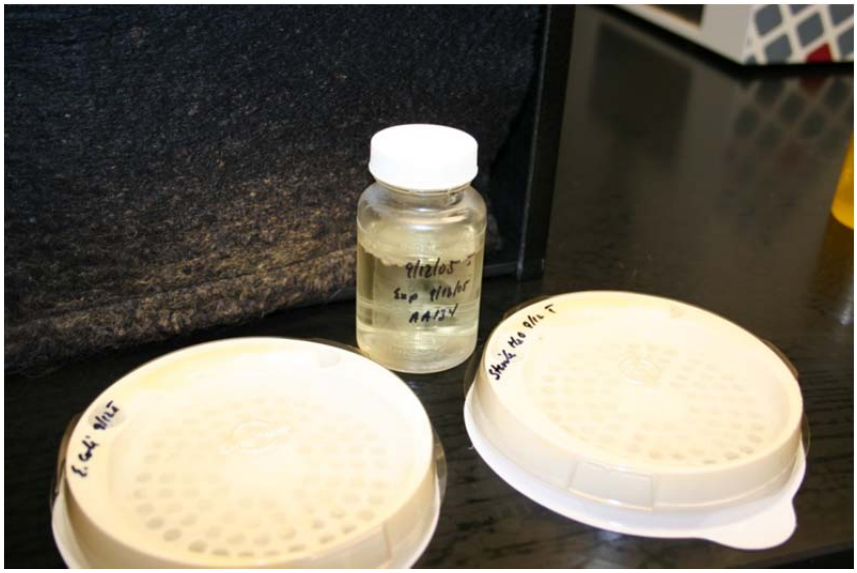
**Some examples of typical corrective measures to coliform problems are:**
1. Shock chlorination of a ground water well. The recommended dose of 5% household bleach is 2 cups per 100 gallons of water in the well. This should be done anytime the bell is opened for repair (pump replacement, etc.). If you 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 back flow prevention devices.
4. Upgrade the wellhead area to meet current construction standards as set 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 HPC**
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 fewer tendencies 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 easily can be 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 Necessary for Testing:**

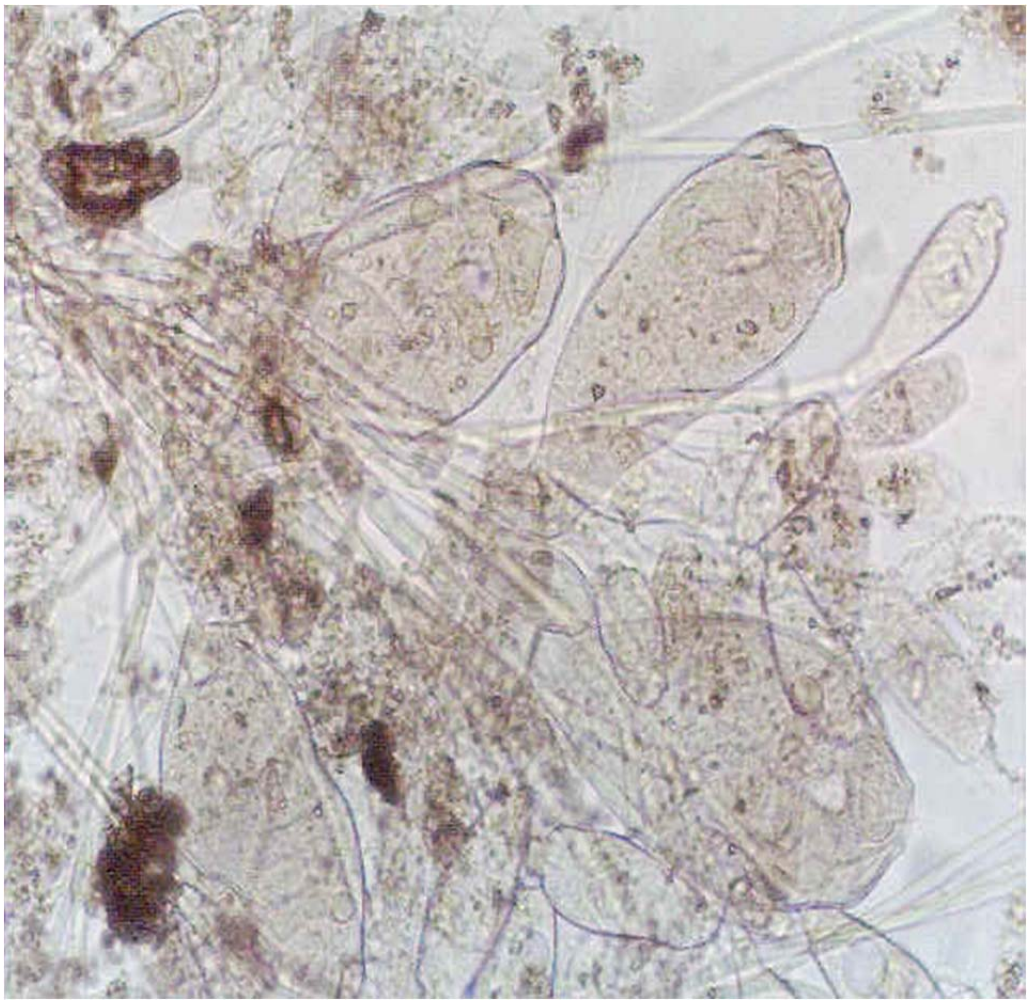
i ) Apparatus
- Glass rod
- Erlenmeyer flask
- Graduated Cylinder
- Pipet
- Petri dish
- Incubator

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

**Procedure***
1. Boil mixture of nutrient agar and nutrient broth for 15 minutes, and 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.



Ciliates, a wastewater bug, it shouldn't be in drinking water, but can be found if a well is close to a septic tank or marsh.

# 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:**
**100 x 15 Petri Dishes**
**Turntable**
**Glass Rods:** Bend fire polished glass rod 45 degrees about 40 mm from one end. Sterilize before using.
**Pipet:** 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 degrees 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. Pipet 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 degrees 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 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 happens:***

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.

**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 siting 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 siting 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 siting plan, sample sites should be selected to represent the varying conditions that exist in the distribution system. The sample siting plan should be updated as changes are made in the water system, especially the distribution system.

**Sampling Procedures** The sample siting 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 siting 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.

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 Volital Organics (625) | Chloride | | Cyanide | Florida | Surfactants (MBAS) | Tot. Coliform MPN | Fecal Coliform MPN-HPC | Organo-Phosphorus Pest. (8141) | Sulfate | EC Conductivity | Number/Containers |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
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**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:

Company

**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.

## 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.

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.

# Chemical Monitoring

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.

## 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).

Modern water quality or sampling truck set-up. Various tools, rope, hammers are nice to have but not always necessary. I like that this sampler wears a reflective vest, I think he is safety conscience, I like the gloves too.

# Examples of Water Sampling Letters and Forms

January 13, 2015

Wyatt Curtiss
1718 West Van Buren Street
Sunflower, AZ 85007

Dear Mr. Curtiss:

The City of Sunflower initially responded to your water quality concerns on May 19, 2015. We found insufficient chlorine in the drinking water at your business. We proceeded to flush and redirect the water in your area.

We resampled your area on two additional dates:

| | May 28, 2011 | | July 25, 2011 | |
|---|---|---|---|---|
| Address | Chlorine (mg/L) | CFU | Chlorine (mg/L) | CFU |
| 310 N. 17th Professor | O.3 | 780 | 0.8 | <1 |
| 1708 W. Van Buren St. | 0.2 | 305 | 0.6 | 8 |

Currently our results indicate good conditions in your area. According to our testing method, a CFU (Colony Forming Units) count of bacteria below 500 is considered adequately disinfected (passing). Other evidence of good water quality is the absence of Total Coliform and the *Escherichia coli* bacteria. This is indicated by the "-" (negative) results in the "Total Coliform" and the "E. Coli" columns of the Bacteriological Analysis Form.

Quality control is documented on the bottom of the Bacteriological Analysis Form. The results are normal and indicate that the incubator was kept at the correct temperature and that we were looking for the correct organisms.

All tests indicate that the drinking water being provided is safe. Should you have any questions regarding drinking water quality in the City of Sunflower, please contact me at 474-8888. Our office hours are 8:00 a.m. to 5:00 p.m., Monday through Friday.

Sincerely,

Bill Fields
Water Quality Inspector

<DATE>

<NAME>
<ADDRESS>

Dear <NAME>:

Thank you for collecting drinking water samples from your home for the City of Sunflower's Lead and Copper monitoring program. You will be receiving the test results soon -- if you haven't received them already.

Our tests show there is essentially no lead or copper in water coming to you from our water treatment plants. But we also need to know if our drinking water leaches lead or copper from your household plumbing. The only way we can learn this information is to analyze samples from inside your home.

Thanks again for your help. With the information we gain we can do an even better job of making sure your tap water meets all federal and state health and safety regulations.

Sincerely,

Chris Mitchell
Mayor

June 11, 2019

Mr. Doc Curtiss
1008 East Northern Avenue
Sunflower, Arizona 85020

Dear Mr. Curtiss:

The City of Sunflower responded to your water quality concerns on 11/27/19. We collected a bacteriological sample and checked the chlorine level at your home. The results are recorded on our worksheet, the Bacteriological Analysis Form, and are attached to this letter.

Our results indicate excellent conditions with 10 Colony Forming Units (CFU) per site. According to our testing method, a CFU count below 500 is considered adequately disinfected (passing). Other evidence of good water quality is the absence of Total Coliform and the Escherichia Coli bacteria. This is indicated by the "-" (negative) results in the Total Coliform and the E. Coli columns of the Bacteriological Analysis Form.

Quality control is documented on the bottom of the Bacteriological Analysis Form. The results are normal and indicate that the incubator was kept at the correct temperature and that we were looking for the correct organisms.

The chlorine level was checked at the same sampling site. The chlorine level was adequate with a reading of 0.7 mg/L.

All tests indicate that the drinking water being provided is safe. Should you have any questions, please contact me at 232-9508. Our office hours are 8:00 a.m. to 5:00 p.m., Monday through Friday.

Sincerely,

Bill Fields
Water Quality Inspector

## Facts About Water Taste and Odor *Customer Letter Example*

Musty or earthy odors are something common to water systems that use surface water (rivers, streams and lakes) as a source of their drinking water. These odors are natural and are usually the result of algae growth. The growth is most common when air and water temperatures begin to drop in the fall as a result of changes in the weather. A certain temperature range makes algae grow more quickly in the surface water. The odor may occur intermittently through January.

Some people find the odor objectionable and/or a nuisance, but it represents no health hazard. The odor affects only the aesthetic quality of the water.

The Water Services Department treats water at treatment plants to ensure it meets all health and safety standards. We add chlorine to the water to protect against harmful organisms. The department regularly tests the drinking water for about 150 different compounds.

If you experience a musty odor in the water you drink, try the following:

- First, fill a water bottle and leave it uncapped on the counter for 30 to 60 minutes.
- Then, refrigerate the water for a few hours.
- If there still is some odor, try running the tap for 15 to 30 seconds before filling the water jug.
- Finally, inexpensive carbon filters can be added at the faucet to help eliminate the odors. However, remember to follow directions concerning maintenance such as cleaning or replacing the filter.

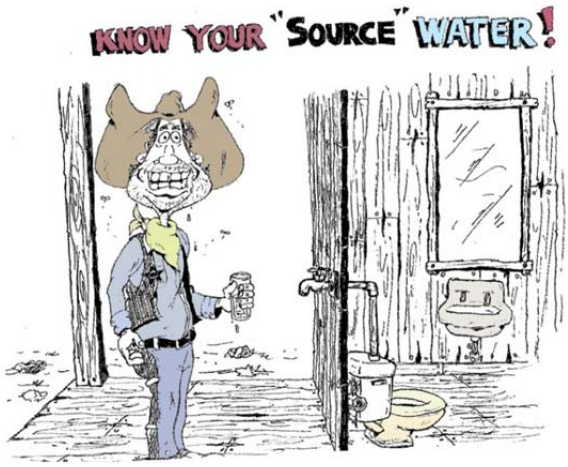
During seasonal changes, our water often contains 10-15 parts per trillion of the natural compound that creates the musty odor. Some people can detect the odor when there is as little as five parts per trillion in the water. For purposes of comparison, five parts per trillion is comparable to five seconds in 32,000 years.

Remember, the odor is seasonal and is not a health hazard. It usually occurs in the fall and disappears sometime during the winter.

# 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.

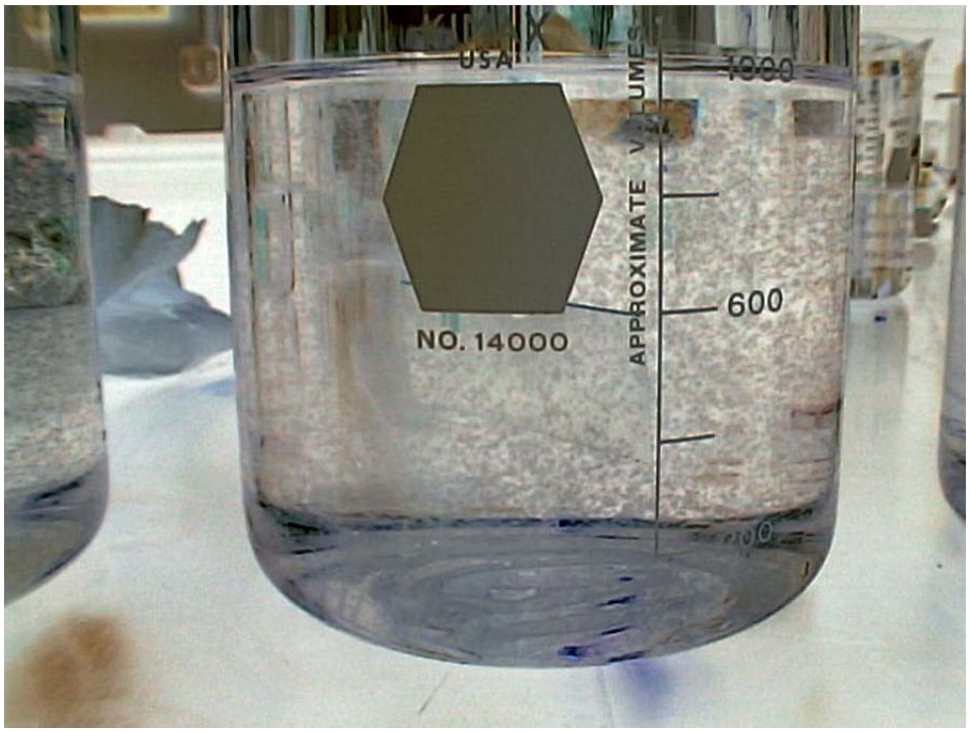



**Possible Cause**

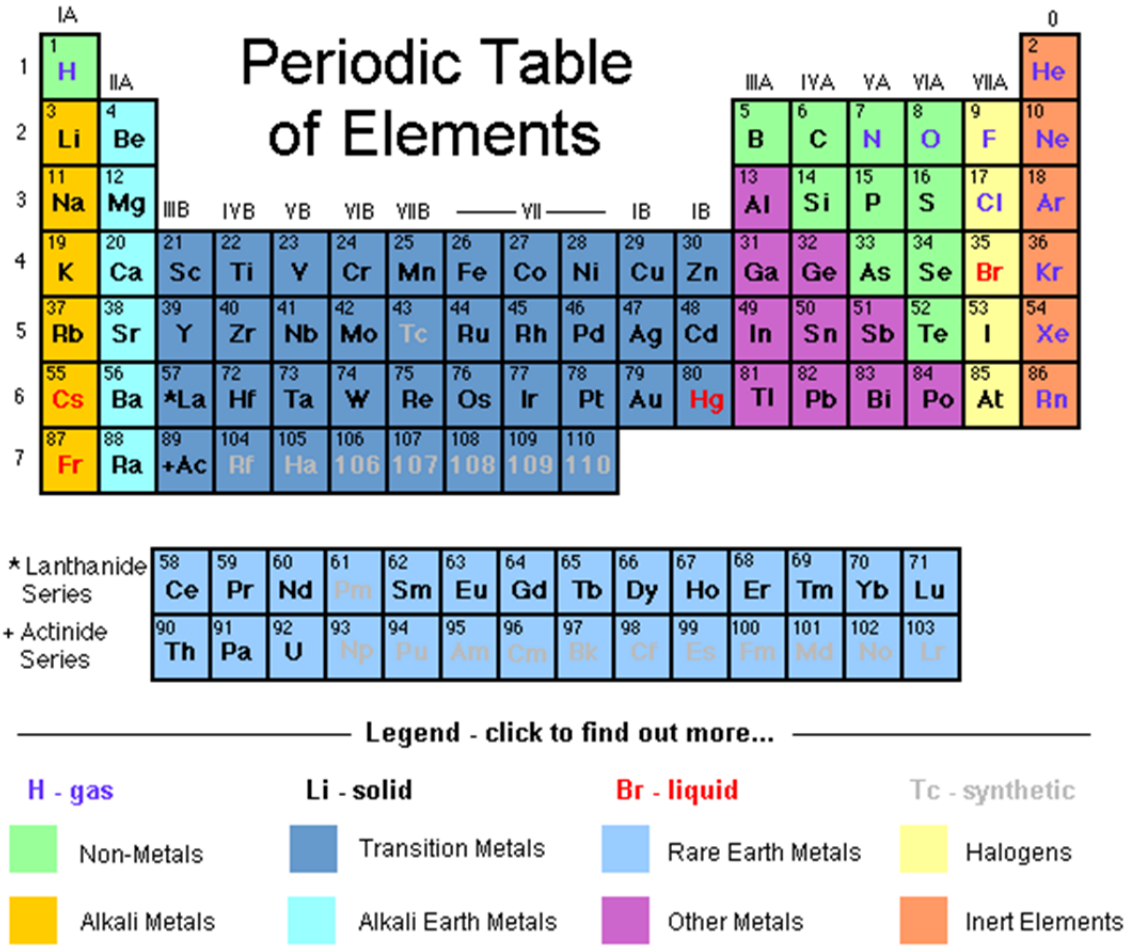
1A. Improper sampling technique.
1B. Contamination entering distribution system.
1C. Inadequate chlorine residual at the sampling site.
1D. Growth of biofilm in the distribution system.
2A. High total chlorine residual and low free residual.
3A. Inadequate chlorine dose at treatment plant.
3B. Problems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




The jar test is an attempt to duplicate water treatment plant conditions.




**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.

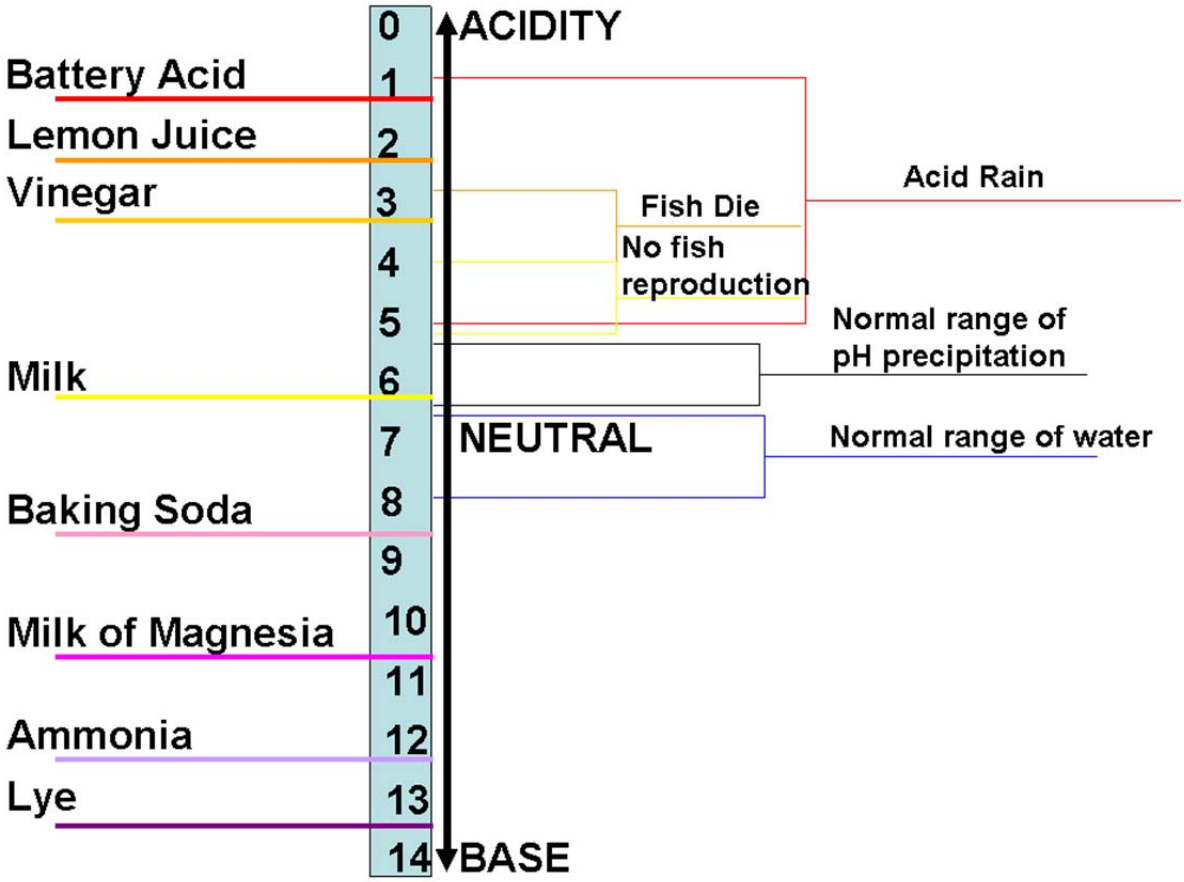
**What are the eight groups of the Periodic Table?**

- ✓ **Group I: Alkali Metals - Li, Na, K, Rb, Cs, Fr**
  known as alkali 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

**How do the properties of metals and nonmetals differ?**

**Properties of Metals**
*Solids at room temperature, Conduct heat very well*
*Have electrical conductivities that increase with decreasing temperature*
*Have a high flexibility and a shiny metallic luster*
*Are malleable-can be beaten out into sheets or foils*
*Are ductile-can be pulled into thin wires without breaking*
*Emit electrons when they are exposed to radiation of sufficiently high energy or when They are heated (known as photoelectric effect and thermionic effect)*
**Properties of Nonmetals**
*May be gases, liquids, or solids at room temperature, poor conductors of heat*
*Are insulators-very poor conductors of electricity*
*Do not have a high reflectivity or a shiny metallic appearance*
*In solid form generally brittle and fracture easily under stress*
*Do not exhibit photoelectric or thermionic effects*

## 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.

***Here is a party that will never stop…***

Never keep food or drinks in your sample refrigerator. I know all of you have done this in the past and I know you've seen someone work without gloves, but you need to be strong and remind personnel that you had enough of tasting all the nastiness. If you are new to this industry, don't fret, you will get a free taste very soon, one way or another. My advice, ask for the hepatitis injections and prepare for a case of the runs that will last for about 1-2 days, after this, you should be good to go. All of us have suffered through this ordeal.

**What are the symptoms of viral gastroenteritis?**
The main symptoms of viral gastroenteritis are watery diarrhea and vomiting. The affected person may also have headache, fever, and abdominal cramps ("stomach ache"). In general, the symptoms begin 1 to 2 days following infection with a virus that causes gastroenteritis and may last for 1 to 10 days, depending on which virus causes the illness.

## Chlorine Section

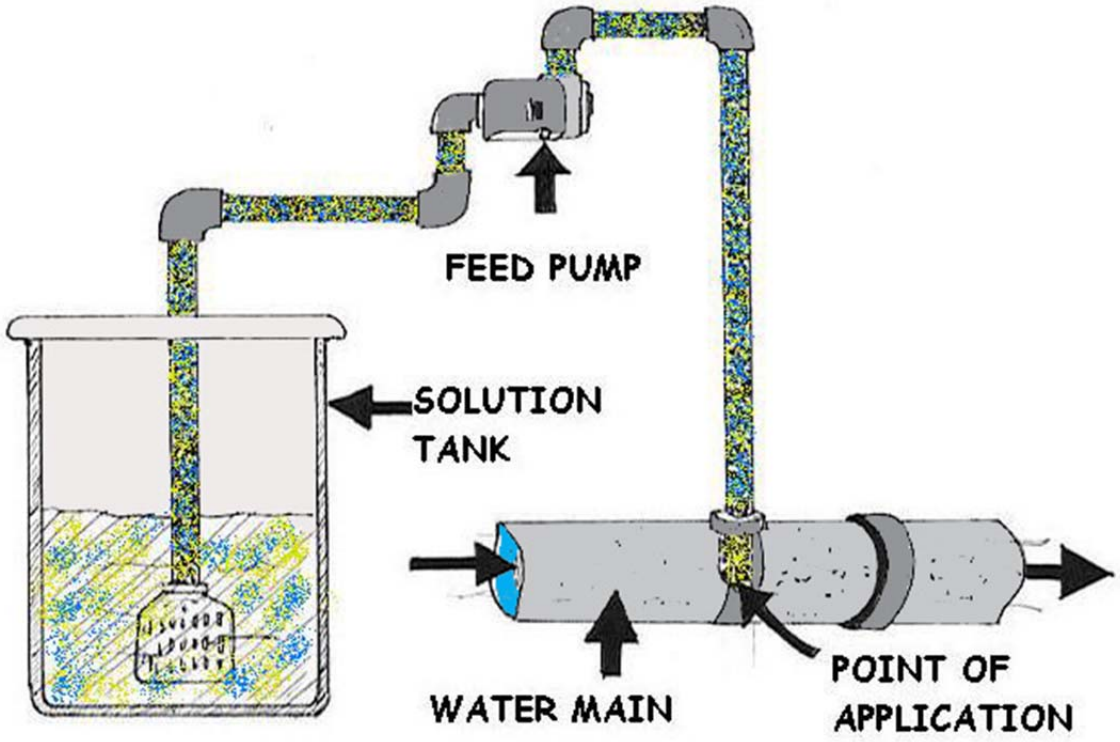
1-ton chlorine containers, rear side of container.

Professor Melissa Durbin in front of a Chlorine rotometer.

Top photograph, chlorine container gaskets.  Bottom, we often take our students on a walking tours of a large chlorine facilities.

## 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 burns the skin. Just a few breaths of it are fatal. $Cl_2$ 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 concentration of chlorine gas, duration of exposure, water content of the tissues exposed, and 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.

Chlorine gas piping.

## Using DPD Method for Chlorine Residuals

**N, N – diethyl-p-phenylenediame, want to impress someone, memorize that.**

Small portable chlorine measuring kit. The redder the mixture, the hotter or stronger the chlorine is 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.

## 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.

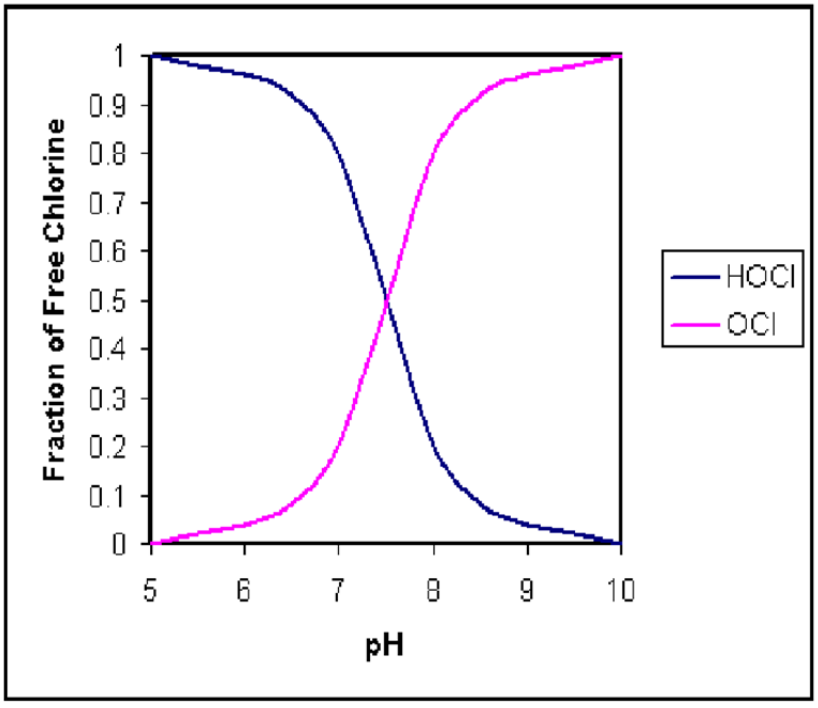
The balancing of equations is simple. You need to learn the valency of the common ions (see tables). The rest is pure mathematics; you are balancing valency charges, positives versus negatives. You have to have the **same number** of **negatives**, or **positives**, each side of the equation, and the **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 $3Mg(OH)_2 + 2H_3PO_4 \rightarrow$ ?



Hard to tell, but these are one-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?

## 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, and they are not capable of disinfection. It is free chlorine which 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 = Concentration (mg/L) x Time (minutes)**

The effective reduction in pathogens can be calculated by reference to standard tables of required CTs.

500-pound chlorine container and 150 pound chlorine gas cylinders. The 1/2 ton is on a scale. Cylinders stand upright and containers on their sides.

**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 are some important chlorine cylinder parts. Upper left, yoke type connector, upper right cylinder wrenches and fusible plugs.

## 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 2.5 times heavier than air and 1.2 times heavier than water.

## Risks and Benefits of Chlorine

Current evidence indicates 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 infectious 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 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.

Chlorine Piping

Water softening may be needed when your source water is too hard for successful chlorination using HTH.

## Chlorinator Parts

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**

Various Chlorine measurement devices or Rotometers.

Safety Information: There is a fusible plug on every chlorine tank. 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. As a minimum, a platform scale shall be provided. Scales shall be of corrosion-resistant material.

**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 be 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 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.

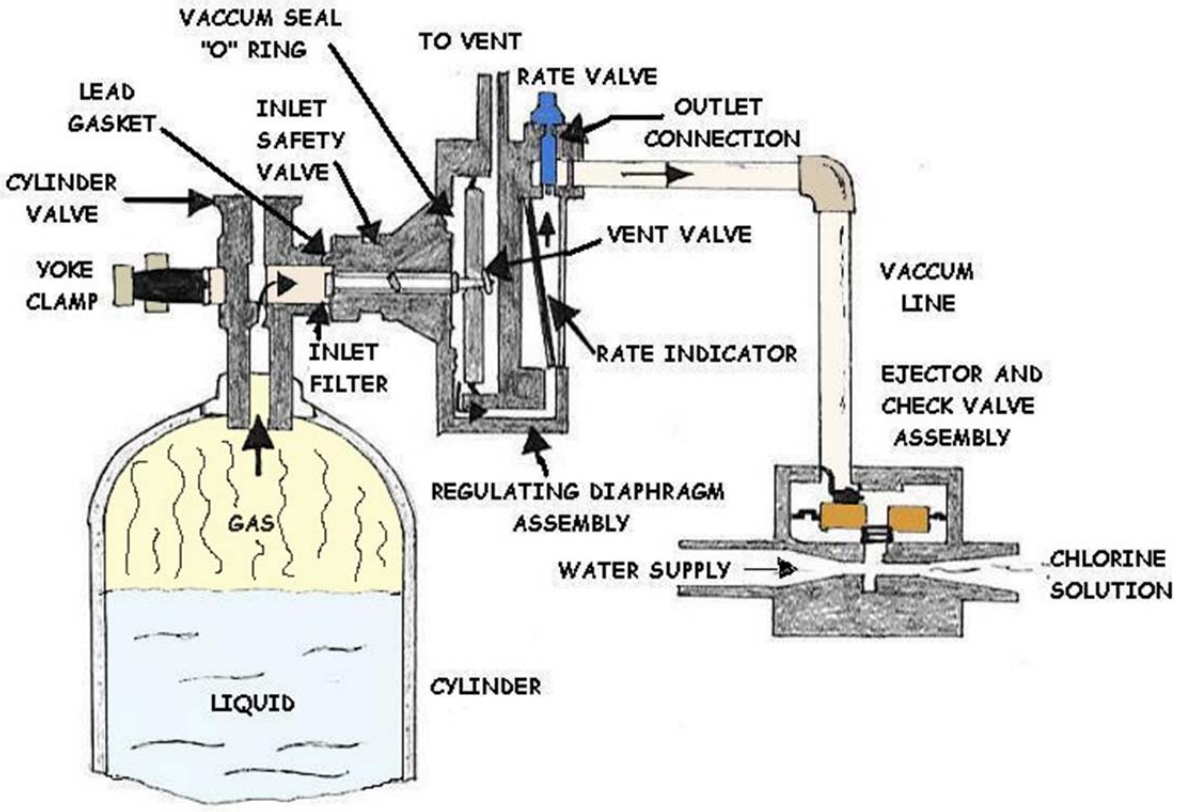
# Troubleshooting Hypochlorination Problems

**Problem**
1. Chemical feed pump won't run.
2. Low chlorine residual at POE.
2. Low chlorine residual at POE.
3. Chemical feed pump won't prime.
4. Loss of prime

**Possible Cause**
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 Solution**
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.



## Disinfection Policy Procedure Example

A. Disinfection may be accomplished with calcium or sodium hypochlorites or gas chlorine or other disinfecting agents approved by the Department. Proposals for the use of disinfecting agents other than those specifically listed above must be approved by the Department prior to preparation of final plans and specifications. The Department will grant approval when all available information establishes that the chemical to be used as a disinfecting agent meets the following conditions: the residual levels created by the use of the chemical will not jeopardize the health of the user of the water, testing procedures for residual elements are recognized in "*Standard Methods for the Examination of Water and Wastewater*" (1978 Edition-American Public Health Association) (see Section 930.15) and the chemical will destroy bacteria in the water supply.

B. **Chlorination Equipment.** The Chlorinator shall be designed to provide a free chlorine residual of at least two milligrams per liter in the water after contact time of at least 30 minutes at flow rates as indicated in Exhibit A. The equipment shall be of such design that it will operate accurately over the desired feeding range. Where flow is uniform, actuation of a constant volume feeder by the pump circuit is required. Where flow is variable, automatic flow proportioning is required.

C. **Contact Time and Point of Application**. A minimum free chlorine residual of at least 0.1 milligram per liter shall be maintained at distant points in the water distribution system. Chlorine shall be applied after the filter and prior to the filtered water storage tank.

D. **Testing Equipment.** Chlorine residual test equipment capable of measuring free chlorine residual shall be provided and shall be capable of measuring residuals to the nearest 0.1 mg/1 in the range below 0.5 mg/1, to the nearest 0.3 mg/1 between 0.5 and 1.0 mg/1, and to the nearest 0.5 mg/1 between 1.0 mg/1 and 2.0 mg/1.

E. **Hypochlorinator.** Positive displacement pumps shall be provided to inject hypochlorite solution. The pump shall be of variable flow type and shall be of sufficient capacity to feed the required amount of disinfectant. If calcium hypochlorite is used, the concentration of calcium hypochlorite in the solution shall not exceed 5 percent. The solution container shall have a minimum capacity equal to the volume of solution required per day. The hypochlorinator shall be electrically interconnected with the raw water feed pump so that both will start and stop together.

The Water Department should maintain an emergency hypochlorinator in reserve status at the operation center to be used during non-routine chlorination occurrences. Additionally, an adequate supply of Sodium Hypochlorite is maintained at all times. All reservoirs are routinely chlorinated to produce a free chlorine residual. Emergency chlorination of any of the Water Department's reservoirs can occur through access ports in each of the reservoir structures.

## 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 stoichiometric amount needed, should be limited to inhibit growth of nitrifying bacteria.

**Chlorine Dioxide**
Chlorine dioxide may be used for either taste or 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 (contact time) values 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 | Order Number | 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |
| 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. |

## 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 |

## Chlorine Exposure Limits

**This information is 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 and they are known 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 $Cl_2$ 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.

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. Bad news.

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.

Ozone generator and Oxygen storage tank.

Various water sample bottles and chain-of-custody form.

## 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.

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 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.
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.

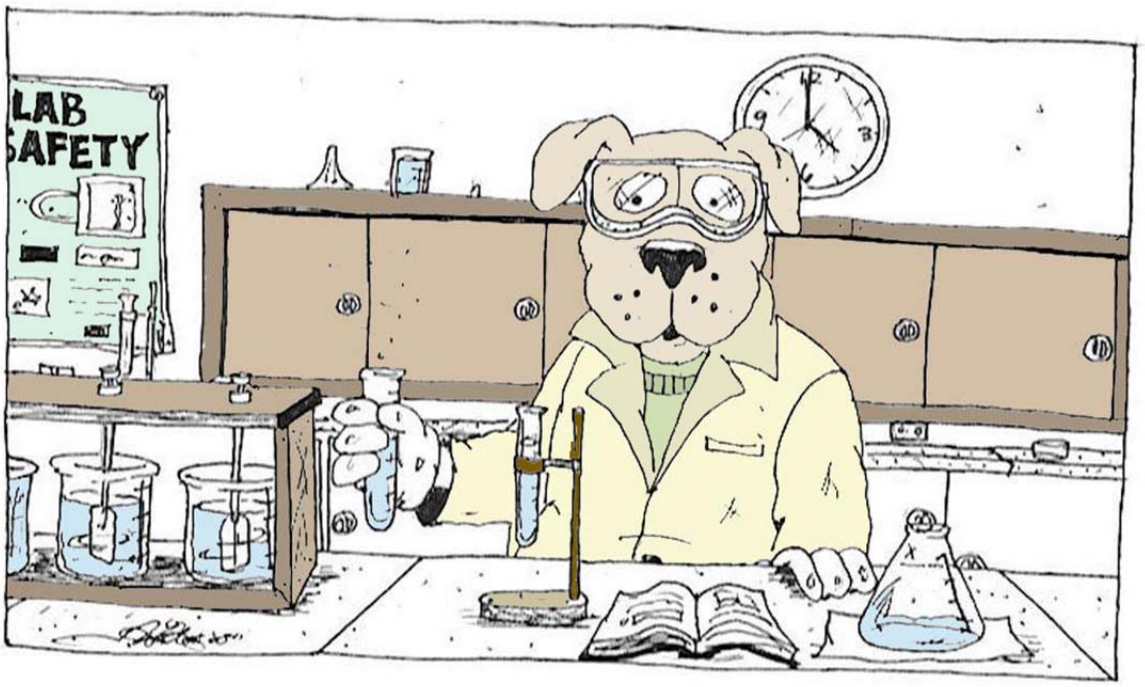
6. Chemical respirators, rubber gloves, boots, chemical safety goggles and acid proof aprons shall be worn where acids are handled.

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.

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 or replacement is complete. Records shall be maintained and submitted during the period that the equipment is not in operation.




**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.

# 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.

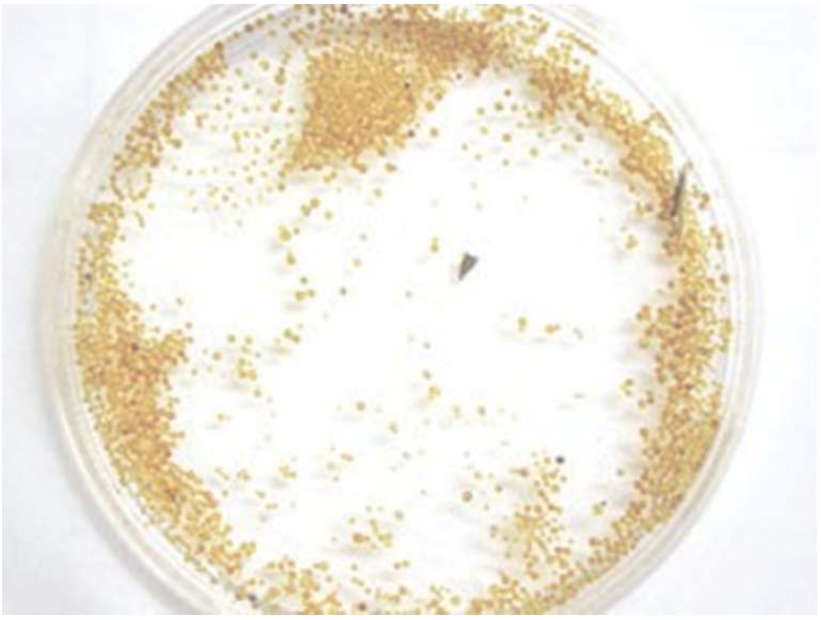
**Infrared Spectroscopy**
When particulates cannot be completely identified by the above means, use IR to identify organic and inorganic materials. Inorganic compounds include calcium carbonate, calcium sulfate, barium sulfate, lead carbonate, metal oxides, silicates, or phosphates. Visually, and with 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 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*

## 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 is an electrical system used for the prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. 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. E.M.F. is a crazy term is used to express the electrical pressure available to cause a flow of current when an electric circuit is closed.

**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 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 that 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 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 times 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 considerations.
6. Possibility of over protection 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.

## 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 (CaOH2 or calcium hydroxide), caustic soda (NaOH or sodium hydroxide), soda ash (Na2CO3 or sodium carbonate), and sodium bicarbonate (NaHCO3, 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 boilers of steam heating systems.

## 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 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.

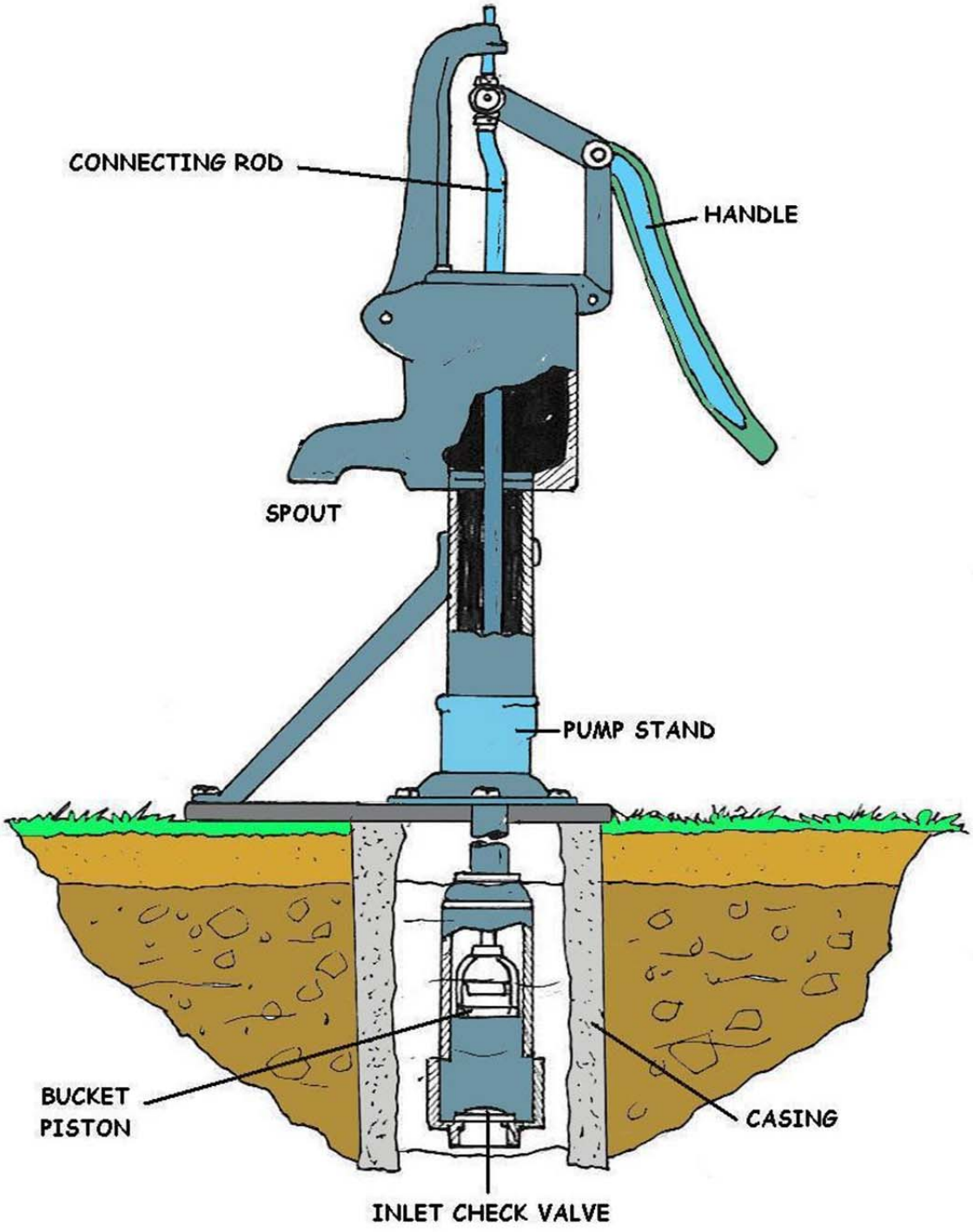
Bacterial growth on the carbon is another potential problem. Excessive bacterial growth may cause clogging and higher bacterial counts in the treated water. The disinfection process must be carefully monitored in order to avoid this problem.

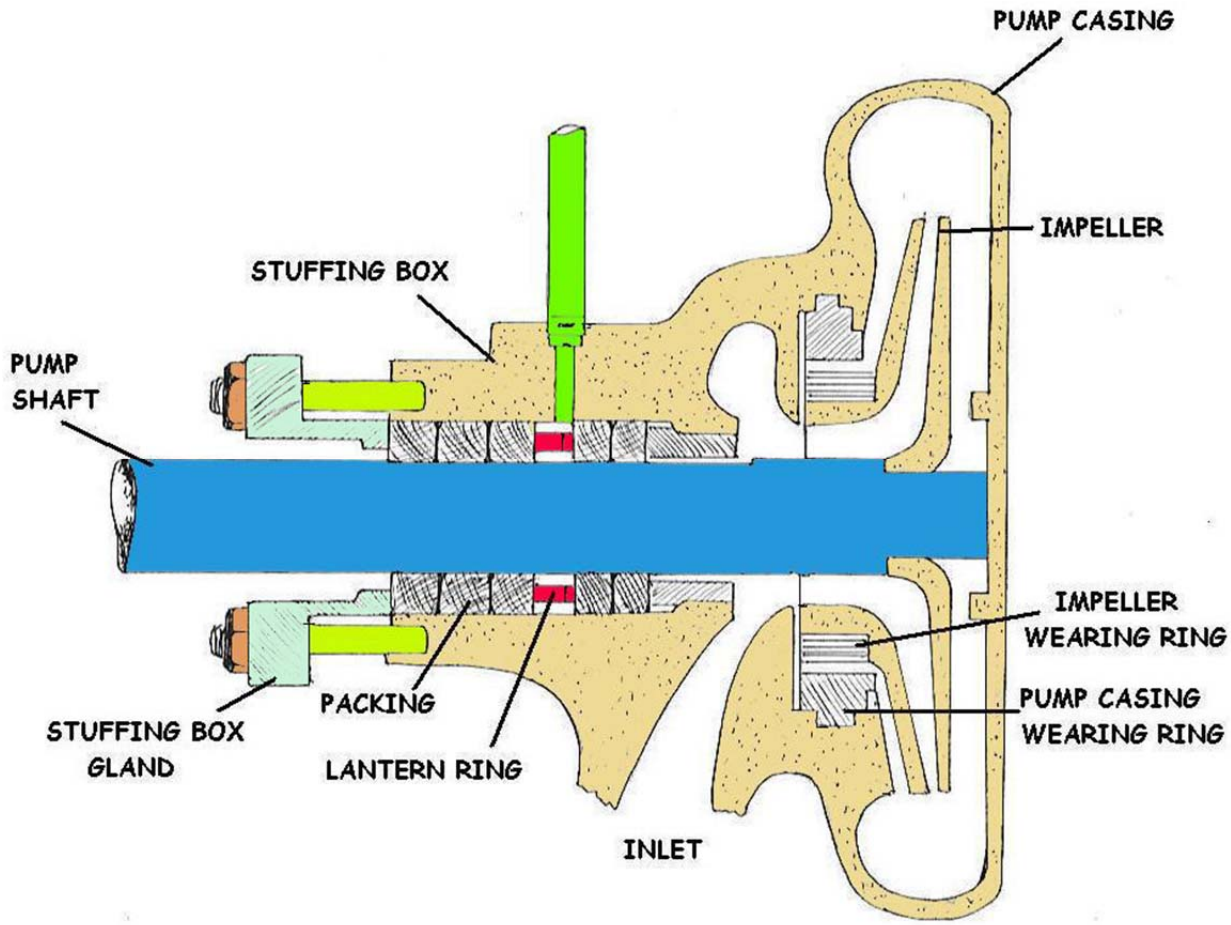
Powdered activated carbon consists of finely ground particles and exhibits the same adsorptive properties as the granular form. PAC is normally applied to the water in a slurry and then filtered out. The addition of PAC can improve the organic removal effectiveness of conventional treatment processes and also remove tastes and odors.

Advantages of PAC are that it can be used on a short-term or emergency basis with conventional treatment, creates no headloss, does not encourage microbial growth, and has relatively small capital costs.

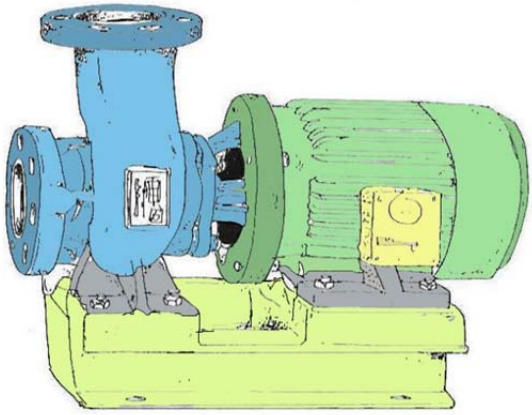
The main disadvantage is that some contaminants require large doses of PAC for removal. It is also somewhat ineffective in removing natural organic matter due to the competition from other contaminants for surface adsorption and the limited contact time between the water and the carbon.

# 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.

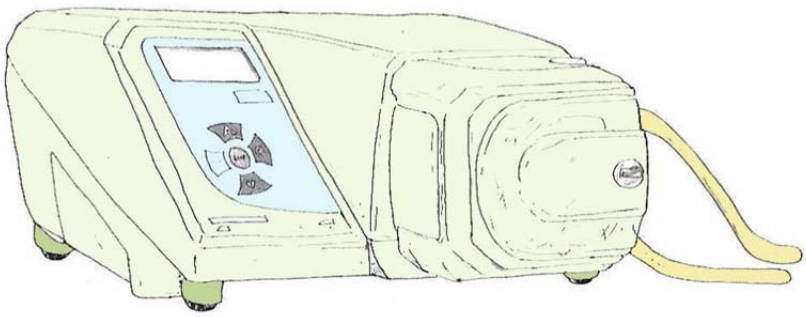
**Pressure**
The application of continuous force by one body upon another that it is touching; compression. Force per unit area, usually expressed in pounds per square inch (Pascal or bar).

**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).

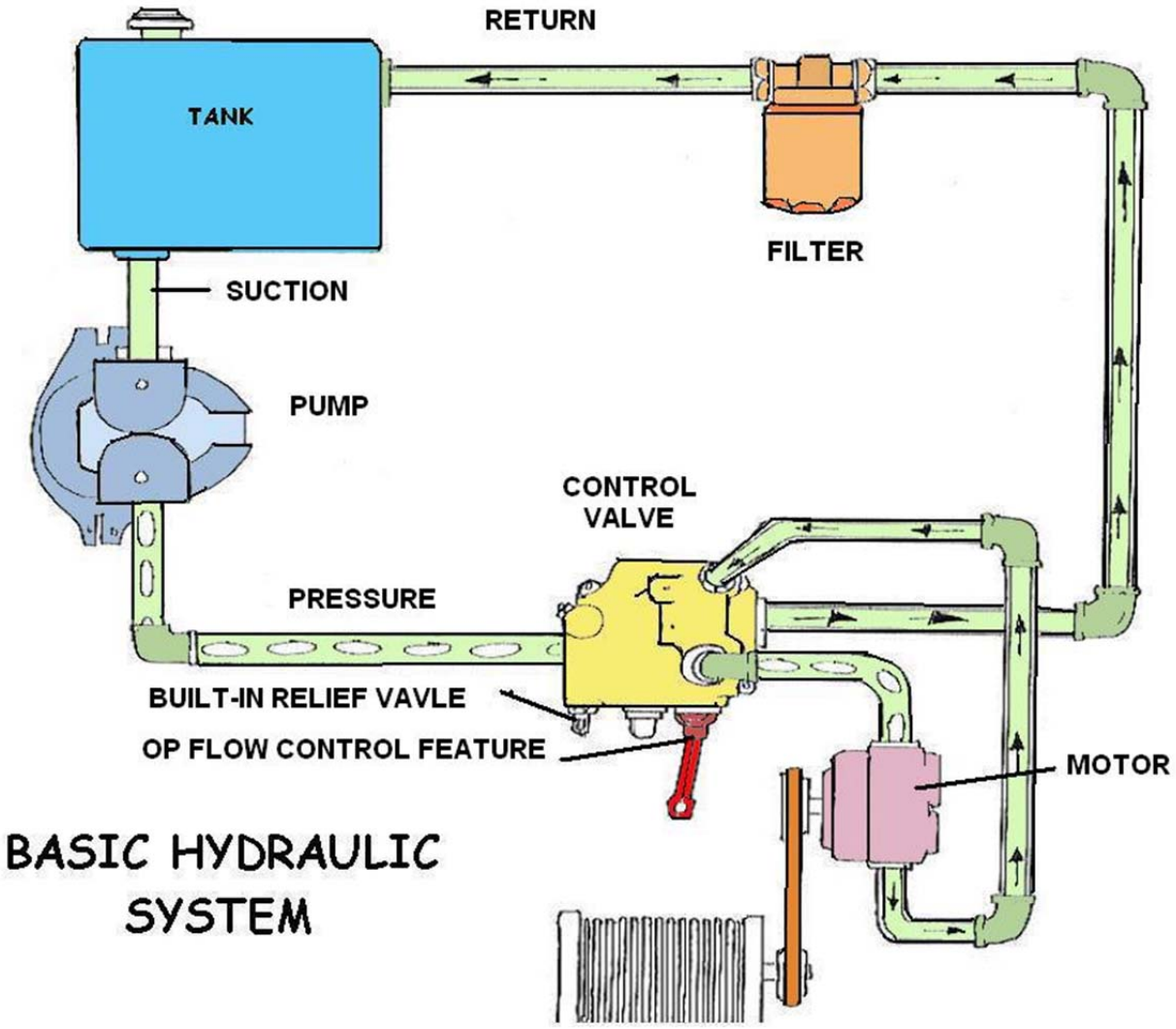
**Pressure, Atmospheric**
Pressure exported by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

**Pressure, Gauge**
Pressure differential above or below ambient atmospheric pressure.

**Pressure, Static**
The pressure in a fluid at rest.



PERISTALTIC PUMP


RETURN
TANK
FILTER
SUCTION
PUMP
CONTROL
VALVE
PRESSURE
BUILT-IN RELIEF VAVLE
OP FLOW CONTROL FEATURE
MOTOR
BASIC HYDRAULIC
SYSTEM

## 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.

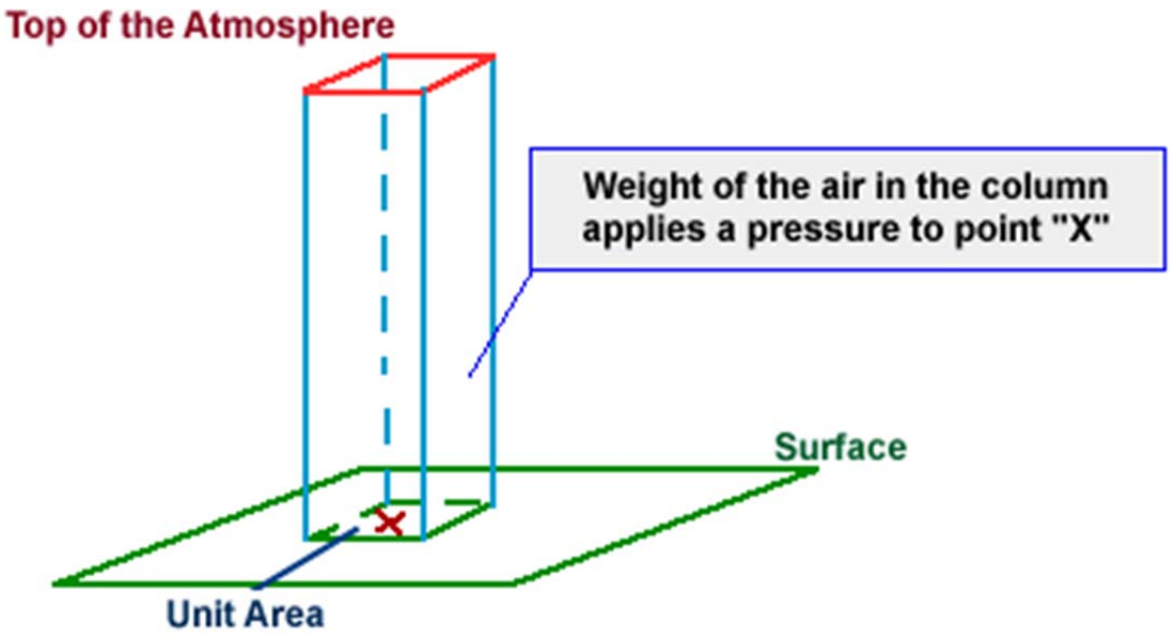
If a column of air 1-inch square extending all the way to the "*top*" of the atmosphere could be weighed, this column of air would weigh approximately 14.7 pounds at sea level. Thus, atmospheric pressure at sea level is approximately 14.7 psi.

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.

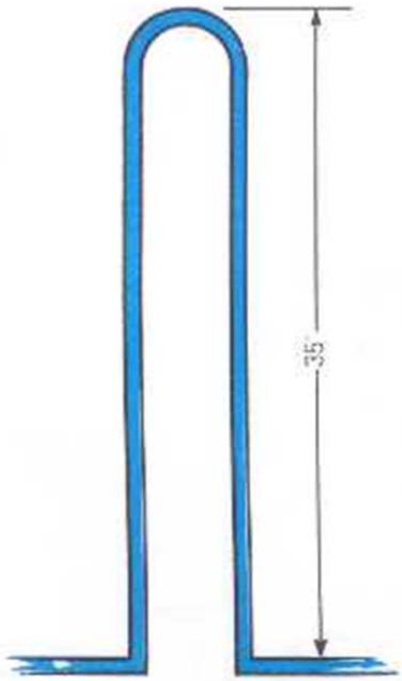
Another device used to measure atmospheric pressure is the aneroid barometer. The aneroid barometer uses the change in shape of an evacuated metal cell to measure variations in atmospheric pressure. The thin metal of the aneroid cell moves in or out with the variation of pressure on its external surface. 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.



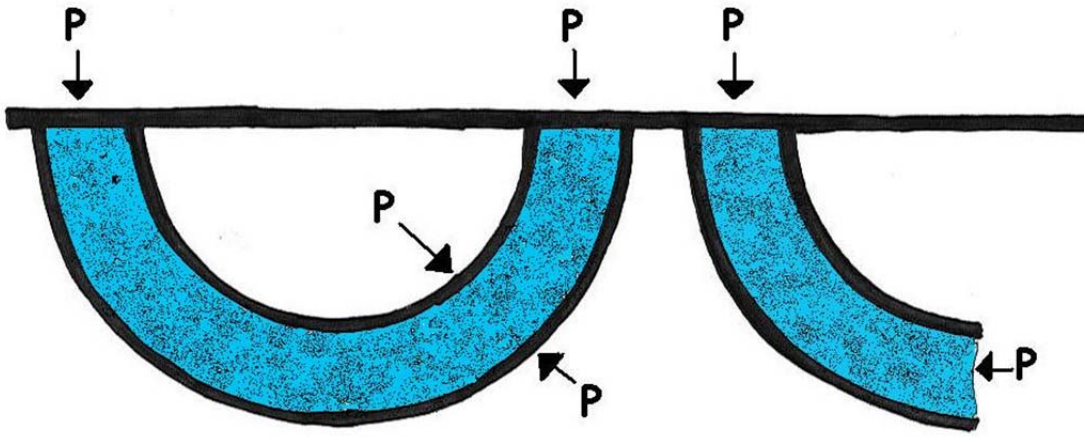

Its operation, in the protection against backsiphonage, is based upon the principle that a water column, at sea level pressure, will not rise above 33.9 feet. In general, barometric loops are locally fabricated, and are 35 feet high.

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.

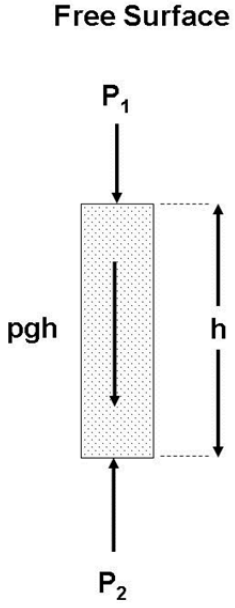
Therefore, in this case the pressure will be the same throughout the fluid, and the same in any direction at a point (Pascal's Principle). Pressure is expressed in units of force per unit area such as dyne/cm$^2$, N/cm$^2$ (pascal), pounds/in$^2$ (psi) or pounds/ft$^2$ (psf). The axiom that if a certain 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$^2$, $\rho$ is the density, the mass per unit volume, expressed in g/cm$^3$, kg/m$^3$, or slug/ft$^3$, and $\gamma$ 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.

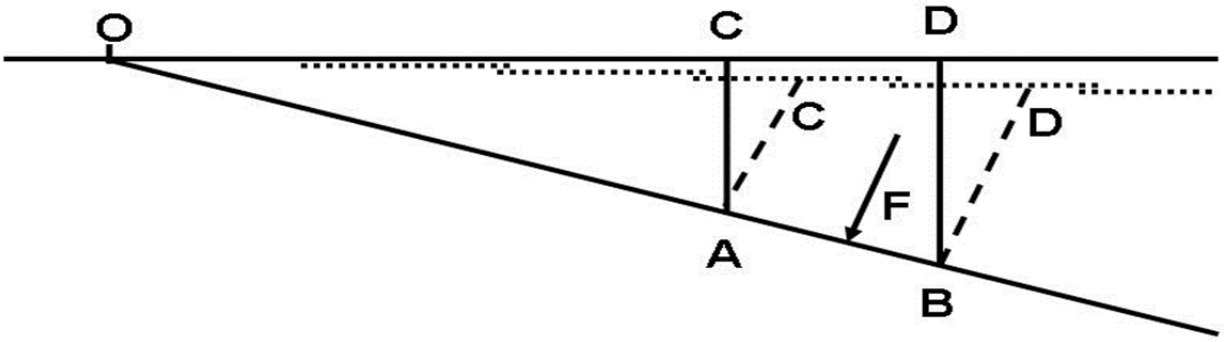
The density of water is about 1 g/cm$^3$, or its specific weight is 62.4 pcf. We may ask what depth of water gives the normal sea-level atmospheric pressure of 14.7 psi, or 2117 psf.

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.



Increase of Pressure with Depth

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.



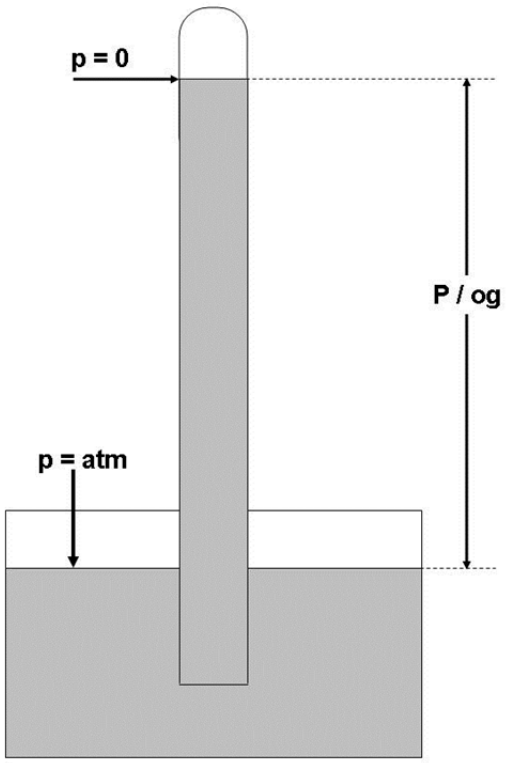
Thrust on a Plane

## 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

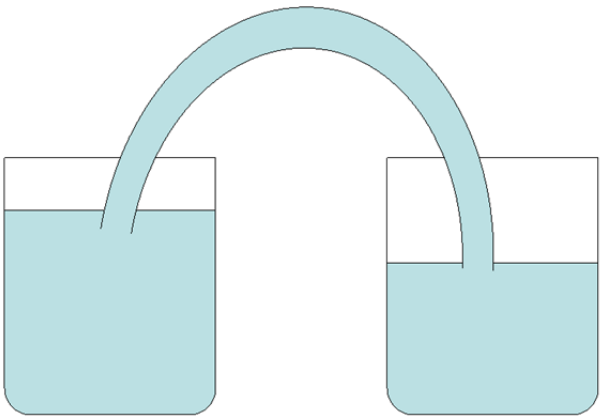
## Atmospheric Pressure and its Effects

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.

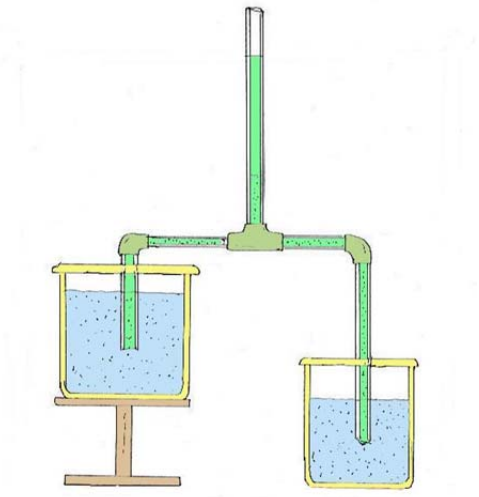
## Water Pressure

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

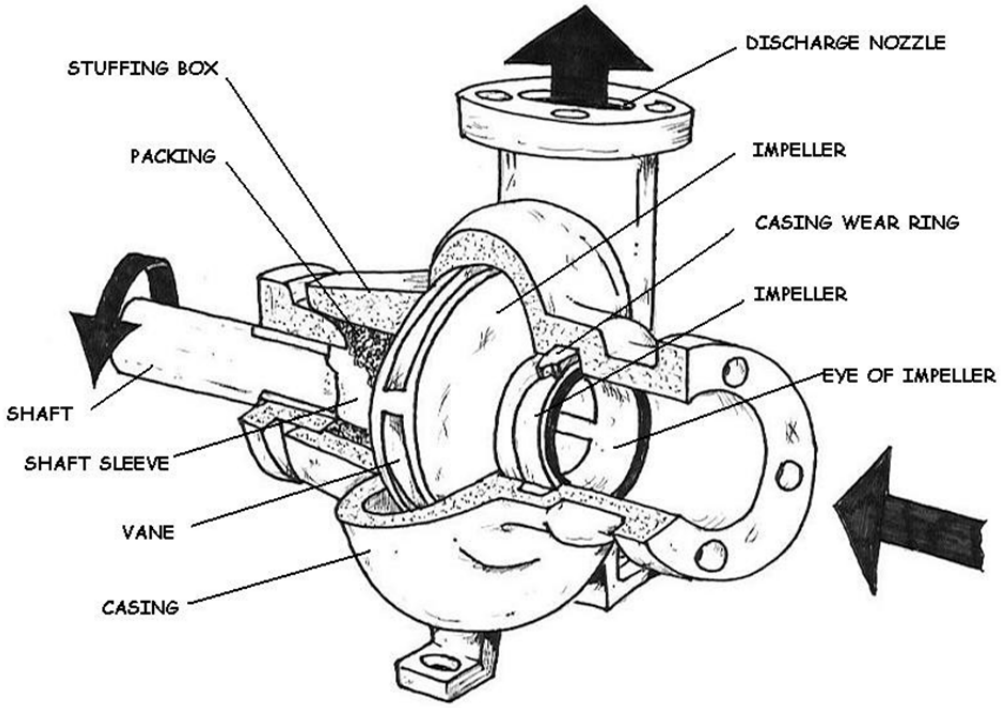
Pressure is the force that pushes water through pipes. Water pressure determines the flow of water from the tap. If pressure is not sufficient then the flow can reduce to a trickle and it will take a long time to fill a kettle or a cistern.

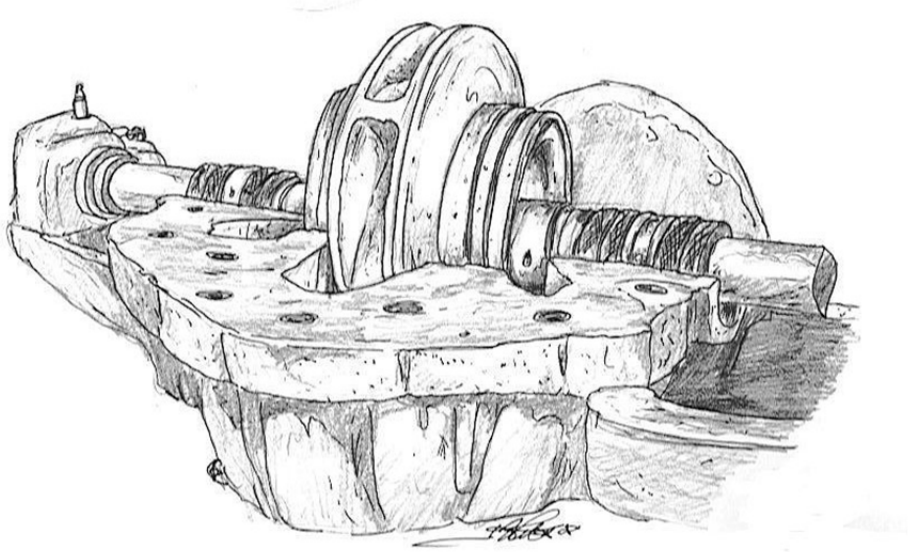
The terms ***force*** and ***pressure*** are used extensively in the study of fluid power. It is essential that we distinguish between the terms.

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:



CENTRIFUGAL PUMP

## Development of Hydraulics

Although the modern development of hydraulics is comparatively recent, the ancients were familiar with many hydraulic principles and their applications. The Egyptians and the ancient people of Persia, India, and China conveyed water along channels for irrigation and domestic purposes, using dams and sluice gates to control the flow. The ancient Cretans had an elaborate plumbing system. Archimedes studied the laws of floating and submerged bodies. The Romans constructed aqueducts to carry water to their cities.

After the breakup of the ancient world, there were few new developments for many centuries. Then, over a comparatively short period, beginning near the end of the seventeenth century, Italian physicist, Evangelista Torricelle, French physicist, Edme Mariotte, and later, Daniel Bernoulli conducted experiments to study the elements of force in the discharge of water through small openings in the sides of tanks and through short pipes. During the same period, Blaise Pascal, a French scientist, discovered the fundamental law for the science of hydraulics. Pascal's law states that increase in pressure on the surface of a confined fluid is transmitted undiminished throughout the confining vessel or system.

For Pascal's law to be made effective for practical applications, it was necessary to have a piston that "fit exactly." It was not until the latter part of the eighteenth century that methods were found to make these snugly fitted parts required in hydraulic systems.

This was accomplished by the invention of machines that were used to cut and shape the necessary closely fitted parts and, particularly, by the development of gaskets and packings. Since that time, components such as valves, pumps, actuating cylinders, and motors have been developed and refined to make hydraulics one of the leading methods of transmitting power.

Liquids are almost incompressible. For example, if a pressure of 100 pounds per square inch (**psi**) is applied to a given volume of water that is at atmospheric pressure, the volume will decrease by only 0.03 percent. It would take a force of approximately 32 tons to reduce its volume by 10 percent; however, when this force is removed, the water immediately returns to its original volume. Other liquids behave in about the same manner as water.

Another characteristic of a liquid is the tendency to keep its free surface level. If the surface is not level, liquids will flow in the direction which will tend to *make* the surface level.

## Evangelista Torricelli

Evangelista Torricelli (1608-1647), Galileo's student and secretary and a member of the Florentine Academy of Experiments, invented the mercury barometer in 1643, and brought the weight of the atmosphere to light. The mercury column was held up by the pressure of the atmosphere, not by horror vacui as Aristotle had supposed. Torricelli's early death was a blow to science, but his ideas were furthered by Blaise Pascal (1623-1662).

Pascal had a barometer carried up the 1465 m high Puy de Dôme, an extinct volcano in the Auvergne just west of his home of Clermont-Ferrand in 1648 by Périer, his brother-in-law. Pascal's experimentum crucis is one of the triumphs of early modern science. The Puy de Dôme is not the highest peak in the Massif Central--the Puy de Sancy, at 1866 m is, but it was the closest. Clermont is now the center of the French pneumatics industry.

## Burgomeister of Magdeburg

The remarkable Otto von Guericke (1602-1686), Burgomeister of Magdeburg, Saxony, took up the cause, making the first vacuum pump, which he used in vivid demonstrations of the pressure of the atmosphere to the Imperial Diet at Regensburg in 1654. Famously, he evacuated a sphere consisting of two well-fitting hemispheres about a foot in diameter, and showed that 16 horses, 8 on each side, could not pull them apart. An original vacuum pump and hemispheres from 1663 are shown at the right (photo edited from the Deutsches Museum; see on right). He also showed that air had weight, and how much force it did require to separate evacuated hemispheres. Then, in England, Robert Hooke (1635-1703) made a vacuum pump for Robert Boyle (1627-1691). Christian Huygens (1629-1695) became interested in a visit to London in 1661 and had a vacuum pump built for him. By this time, Torricelli's doctrine had triumphed over the Church's support for horror vacui. This was one of the first victories for rational physics over the illusions of experience, and is well worth consideration.

Pascal demonstrated that the siphon worked by atmospheric pressure, not by horror vacui. The two beakers of mercury are connected by a three-way tube as shown, with the upper branch open to the atmosphere. As the large container is filled with water, pressure on the free surfaces of the mercury in the beakers pushes mercury into the tubes. When the state shown is reached, the beakers are connected by a mercury column, and the siphon starts, emptying the upper beaker and filling the lower. The mercury has been open to the atmosphere all this time, so if there were any horror vacui, it could have flowed in at will to soothe itself.

## Torr

The mm of mercury is sometimes called a torr after Torricelli, and Pascal also has been honored by a unit of pressure, a newton per square meter or 10 dyne/cm2. A cubic centimeter of air weighs 1.293 mg under standard conditions, and a cubic meter 1.293 kg, so air is by no means even approximately weightless, though it seems so. The weight of a sphere of air as small as 10 cm in diameter is 0.68 g, easily measurable with a chemical balance. The pressure of the atmosphere is also considerable, like being 34 ft under water, but we do not notice it. A bar is 106 dyne/cm2, very close to a standard atmosphere, which is 1.01325 bar. In meteorology, the millibar, mb, is used. 1 mb = 1.333 mmHg = 100 Pa = 1000 dyne/cm2.

A kilogram-force per square centimeter is 981,000 dyne/cm2, also close to one atmosphere. In Europe, it has been considered approximately 1 atm, as in tire pressures and other engineering applications. As we have seen, in English units the atmosphere is about 14.7 psi, and this figure can be used to find other approximate equivalents. For example, 1 psi = 51.7 mmHg. In Britain, tons per square inch has been used for large pressures. The ton in this case is 2240 lb, not the American short ton. 1 tsi = 2240 psi, 1 tsf = 15.5 psi (about an atmosphere!).The fluid in question here is air, which is by no means incompressible. As we rise in the atmosphere and the pressure decreases, the air also expands.

To see what happens in this case, we can make use of the ideal gas equation of state, $p = \rho RT/M$, and assume that the temperature T is constant. Then the change of pressure in a change of altitude dh is $dp = -\rho g\, dh = -(pM/RT)\, g\, dh$, or $dp/p = -(Mg/RT)\, dh$.

This is a little harder to integrate than before, but the result is ln p = -Mgh/RT + C, or ln (p/p0) = -Mgh/RT, or finally p = p0exp (-Mgh/RT).

In an isothermal atmosphere, the pressure decreases exponentially. The quantity H = RT/Mg is called the "height of the homogeneous atmosphere" or the scale height, and is about 8 km at T = 273K.

This quantity gives the rough scale of the decrease of pressure with height. Of course, the real atmosphere is by no means isothermal close to the ground, but cools with height nearly linearly at about 6.5°C/km up to an altitude of about 11 km at middle latitudes, called the tropopause.

Above this is a region of nearly constant temperature, the stratosphere, and then at some higher level the atmosphere warms again to near its value at the surface. Of course, there are variations from the average values. When the temperature profile with height is known, we can find the pressure by numerical integration quite easily.

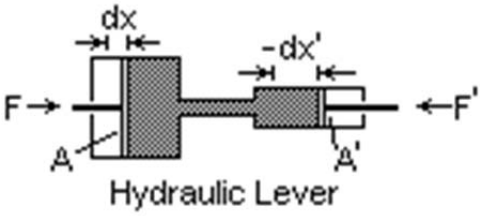
## Meteorology

The atmospheric pressure is of great importance in meteorology, since it determines the winds, which generally move at right angles to the direction of the most rapid change of pressure, that is, along the isobars, which are contours of constant pressure. Certain typical weather patterns are associated with relatively high and relatively low pressures, and how they vary with time. The barometric pressure may be given in popular weather forecasts, though few people know what to do with it. If you live at a high altitude, your local weather reporter may report the pressure to be, say, 29.2 inches, but if you have a real barometer, you may well find that it is closer to 25 inches. At an elevation of 1500 m (near Denver, or the top of the Puy de Dôme), the atmospheric pressure is about 635 mm, and water boils at 95 °C.

In fact, altitude is quite a problem in meteorology, since pressures must be measured at a common level to be meaningful. The barometric pressures quoted in the news are reduced to sea level by standard formulas that amount to assuming that there is a column of air from your feet to sea level with a certain temperature distribution, and adding the weight of this column to the actual barometric pressure. This is only an arbitrary 'fix' and leads to some strange conclusions, such as the permanent winter highs above high plateaus that are really imaginary.

## The Hydraulic Lever

A cylinder and piston is a chamber of variable volume, a mechanism for transforming pressure to force.



Hydraulic Lever

If A is the area of the cylinder, and p the pressure of the fluid in it, then F = pA is the force on the piston. If the piston moves outwards a distance dx, then the change in volume is dV = A dx.

The work done by the fluid in this displacement is dW = F dx = pA dx = p dV. If the movement is slow enough that inertia and viscosity forces are negligible, then hydrostatics will still be valid. A process for which this is true is called quasi-static. Now consider two cylinders, possibly of different areas A and A', connected with each other and filled with fluid. For simplicity, suppose that there are no gravitational forces.

Then the pressure is the same, p, in both cylinders. If the fluid is incompressible, then dV + dV' = 0, so that dW = p dV + p dV' = F dx + F' dx' = 0. This says the work done on one piston is equal to the work done by the other piston: the conservation of energy. The ratio of the forces on the pistons is F' / F = A' / A, the same as the ratio of the areas, and the ratios of the displacements dx' / dx = F / F' = A / A' is in the inverse ratio of the areas. This mechanism is the hydrostatic analogue of the lever, and is the basis of hydraulic activation.

## Bramah Hydraulic Press

The most famous application of this principle is the Bramah hydraulic press, invented by Joseph Bramah (1748-1814), who also invented many other useful machines, including a lock and a toilet. Now, it was not very remarkable to see the possibility of a hydraulic press; what was remarkable was to find a way to seal the large cylinder properly.

This was the crucial problem that Bramah solved by his leather seal that was held against the cylinder and the piston by the hydraulic pressure itself. In the presence of gravity, p' = p + ρgh, where h is the difference in elevation of the two cylinders. Now, p' dV' = -dV (p + ρgh) =-p dV - (ρ dV) gh, or the net work done in the process is p' dV' + p dV = -dM gh, where dM is the mass of fluid displaced from the lower cylinder to the upper cylinder. Again, energy is conserved if we take into account the potential energy of the fluid. Pumps are seen to fall within the province of hydrostatics if their operation is quasi-static, which means that dynamic or inertia forces are negligible.

## Pumps

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.

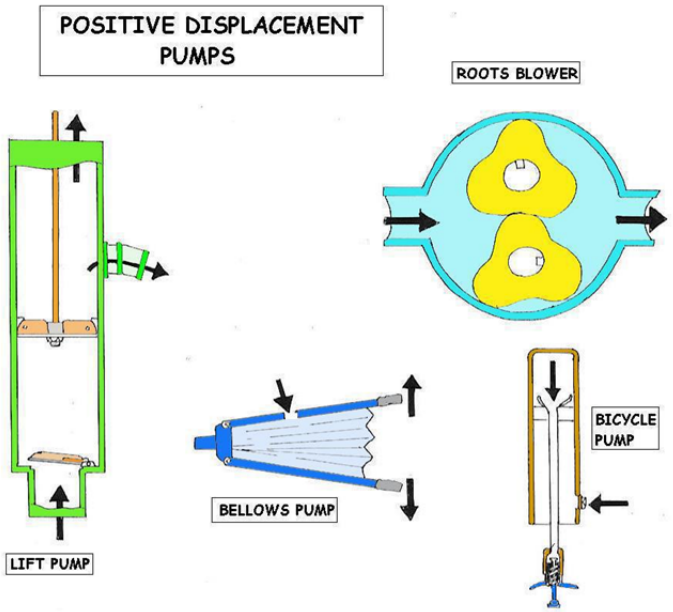
The simplest pump is the syringe, filled by withdrawing the piston and emptied by pressing it back in, as its port is immersed in the fluid or removed from it. More complicated pumps have valves allowing them to work repetitively. These are usually check valves that open to allow

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 a 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.

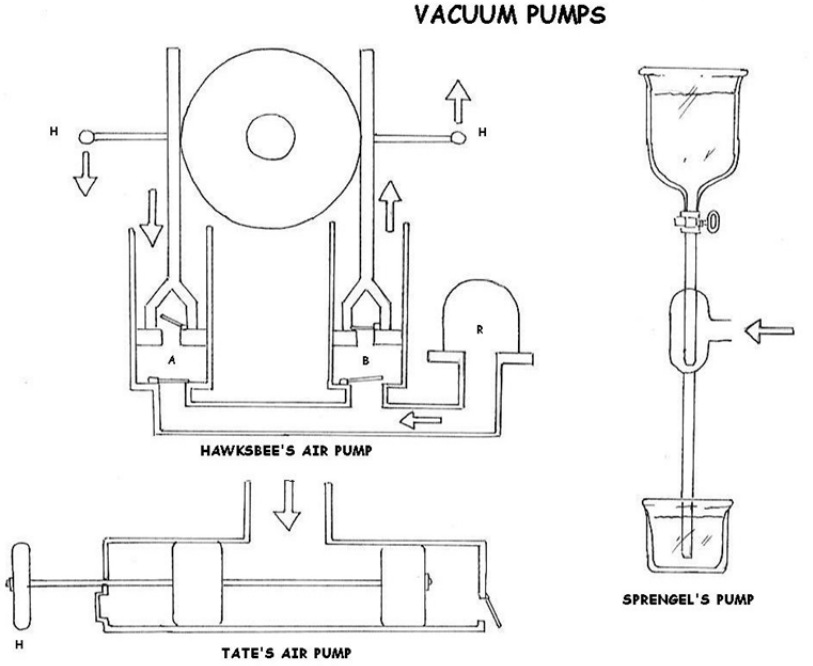
The three pumps on the right are typically used for air, but would be equally applicable to liquids. The Roots blower has no valves, their place taken by the sliding contact between the rotors and the housing. The Roots blower can either exhaust a receiver or provide air under moderate pressure, in large 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. Pumps were applied to the dewatering of mines, a very necessary process as mines became deeper. Newcomen's atmospheric engine was invented to supply the power for pumping.



## Dudley Castle Engine

The first engine may have been erected in Cornwall in 1710, but the Dudley Castle engine of 1712 is much better known and thoroughly documented. The first pumps used in Cornwall were called bucket pumps, which we recognize as lift pumps, with the pistons somewhat miscalled buckets. They pumped on the up-stroke, when a clack in the bottom of the pipe opened and allowed water to enter beneath the piston. At the same time, the piston lifted the column of water above it, which could be of any length. The piston could only "suck" water 33 ft, or 28 ft more practically, of course, but this occurred at the bottom of the shaft, so this was only a limit on the piston stroke. On the down stroke, a clack in the bucket opened, allowing it to sink through the water to the bottom, where it would be ready to make another lift. More satisfactory were the plunger pumps, also placed at the bottom of the shaft. A plunger displaced volume in a chamber, forcing the water in it through a check valve up the shaft, when it descended. When it rose, water entered the pump chamber through a clack, as in the bucket pump.

Only the top of the plunger had to be packed; it was not necessary that it fit the cylinder accurately. In this case, the engine at the surface lifted the heavy pump rods on the up-stroke. When the atmospheric engine piston returned, the heavy timber pump rods did the actual pumping, borne down by their weight. A special application for pumps is to produce a vacuum by exhausting a container, called the receiver.




## Hawksbee's Dual Cylinder Pump

Hawksbee's dual cylinder pump, designed in the 18th century, is the final form of the air pump invented by Guericke by 1654. A good pump could probably reach about 5-10 mmHg, the limit set by the valves. The cooperation of the cylinders made the pump much easier to work when the pressure was low. In the diagram, piston A is descending, helped by the partial vacuum remaining below it, while piston B is rising, filling with the low-pressure air from the receiver.

## Bell-jar Receiver

The bell-jar receiver, invented by Huygens, is shown; previously, a cumbersome globe was the usual receiver. Tate's air pump is a 19th century pump that would be used for simple vacuum demonstrations and for utility purposes in the lab. It has no valves on the low-pressure side, just exhaust valves V, V', so it could probably reach about 1 mmHg. It is operated by pushing and pulling the handle H. At the present day, motor-driven rotary-seal pumps sealed by running in oil are used for the same purpose. At the right is Sprengel's pump, with the valves replaced by drops of mercury. Small amounts of gas are trapped at the top of the fall tube as the mercury drops, and moves slowly down the fall tube as mercury is steadily added, coming out at the bottom carrying the air with it. The length of the fall tube must be greater than the barometric height, of course.

Theoretically, a vacuum of about 1 μm can be obtained with a Sprengel pump, but it is very slow and can only evacuate small volumes. Later, Langmuir's mercury diffusion pump, which was much faster, replaced Sprengel pumps, and led to oil diffusion pumps that can reach very high vacua. The column of water or hydrostatic engine is the inverse of the force pump, used to turn a large head (pressure) of water into rotary motion. It looks like a steam engine, with valves operated by valve gear, but of course is not a heat engine and can be of high efficiency.

However, it is not of as high efficiency as a turbine, and is much more complicated, but has the advantage that it can be operated at variable speeds, as for lifting. A few very impressive column of water engines were made in the 19th century, but they were never popular and remained rare. Richard Trevithick, famous for high pressure steam engines, also built hydrostatic engines in Cornwall. The photograph at the right shows a column-of-water engine built by Georg von Reichenbach, and placed in service in 1917. This engine was exhibited in the Deutsches Museum in München as late as 1977.

It was used to pump brine for the Bavarian state salt industry. A search of the museum website did not reveal any evidence of it, but a good drawing of another brine pump with four cylinders and driven by a water wheel, also built by von Reichenbach, was found.

## Solehebemaschine

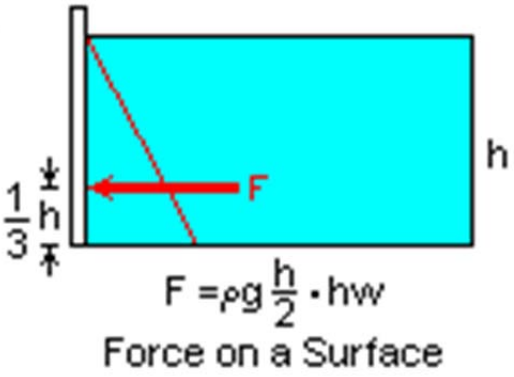
This machine, a Solehebemaschine ("brine-lifting machine"), entered service in 1821. It had two pressure-operated poppet valves for each cylinder. These engines are brass to resist corrosion by the salt water. Water pressure engines must be designed taking into account the incompressibility of water, so both valves must not close at the same time, and abrupt changes of rate of flow must not be made. Air chambers can be used to eliminate shocks. Georg von Reichenbach (1771-1826) is much better known as an optical designer than as a mechanical engineer. He was associated with Joseph Fraunhofer, and they died within days of each other in 1826. He was of an aristocratic family, and was Salinenrat, or manager of the state salt works, in southeastern Bavaria, which was centered on the town of Reichenhall, now Bad Reichenhall, near Salzburg.

The name derives from "rich in salt." This famous salt region had salt springs flowing nearly saturated brine, at 24% to 26% (saturated is 27%) salt, that from ancient times had been evaporated over wood fires. A brine pipeline to Traunstein was constructed in 1617-1619, since wood fuel for evaporating the brine was exhausted in Reichenhall. The pipeline was further extended to Rosenheim, where there was turf as well as wood, in 1818-10.

Von Reichenbach is said to have built this pipeline, for which he designed a water-wheel-driven, four-barrel pump. Maximilian I, King of Bavaria, commissioned von Reichenbach to bring brine from Berchtesgaden, elevation 530 m, to Reichenhall, elevation 470 m, over a summit 943 m high. Fresh water was also allowed to flow down to the salt beds, and the brine was then pumped to the surface. This was a much easier way to mine salt than underground mining. The salt industry of Bad Reichenhall still operates, but it is now Japanese-owned.

## Forces on Submerged Surfaces

Suppose we want to know the force exerted on a vertical surface of any shape with water on one side, assuming gravity to act, and the pressure on the surface of the water zero. We have already solved this problem by a geometrical argument, but now we apply calculus, which is easier but not as illuminating.



Force on a Surface

The force on a small area dA a distance x below the surface of the water is dF = p dA = ρgx dA, and the moment of this force about a point on the surface is dM = px dA = ρgx2 dA.

By integration, we can find the total force F, and the depth at which it acts, c = M / F. If the surface is not symmetrical, the position of the total force in the transverse direction can be obtained from the integral of dM' = ρgxy dA, the moment about some vertical line in the plane of the surface. If there happens to be a pressure on the free surface of the water, then the forces due to this pressure can be evaluated separately and added to this result. We must add a force equal to the area of the surface times the additional pressure, and a moment equal to the product of this force and the distance to the centroid of the surface.

The simplest case is a rectangular gate of width w, and height h, whose top is a distance H below the surface of the water.

In this case, the integrations are very easy, and F = ρgw [(h + H) 2 - h2]/2 = ρgH (H + 2h)/2 = ρg (h + H/2) Hw.

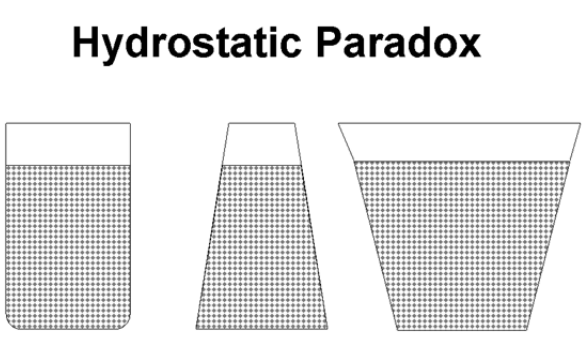
The total force on the gate is equal to its area times the pressure at its centre. M = ρgw [(h + H) 3 - h3]/3 = ρg (H2/3 + Hh + h2) Hw, so that c = (H2/3 + Hh + h2)/ (h + H/2).

In the simple case of h = 0, c = 2H/3, or two-thirds of the way from the top to the bottom of the gate. If we take the atmospheric pressure to act not only on the surface of the water, but also the dry side of the gate, there is no change to this result. This is the reason atmospheric pressure often seems to have been neglected in solving sub h problems.

Consider a curious rectangular tank, with one side vertical but the opposite side inclined inwards or outwards. The horizontal forces exerted by the water on the two sides must be equal and opposite, or the tank would scoot off. If the side is inclined outward, then there must be a downward vertical force equal to the weight of the water above it, and passing through the centroid of this water. If the side is inclined inward, there must be an upward vertical force equal to the weight of the 'missing' water above it. In both cases, the result is demanded by ordinary statics.

## Hydrostatic Paradox

What we have here has been called the 'hydrostatic paradox.' It was conceived by the celebrated Flemish engineer Simon Stevin (1548-1620) of Brugge, the first modern scientist to investigate the statics of fluids and solids. Consider three tanks with bottoms of equal sizes and equal heights, filled with water. The pressures at the bottoms are equal, so the vertical force on the bottom of each tank is the same. But suppose that one tank has vertical sides, one has sides inclined inward, and third sides inclined outwards. The tanks do not contain the same weight of water, yet the forces on their bottoms are equal! I am sure that you can spot the resolution of this paradox.




Sometimes the forces are required on curved surfaces. The vertical and horizontal components can be found by considering the equilibrium of volumes with a plane surface equal to the projected area of the curved surface in that direction. The general result is usually a force plus a couple, since the horizontal and vertical forces are not necessarily in the same plane. Simple surfaces, such as cylinders, spheres and cones, may often be easy to solve. In general, however, it is necessary to sum the forces and moments numerically on each element of area, and only in simple cases can this be done analytically.

If a volume of fluid is accelerated uniformly, the acceleration can be added to the acceleration of gravity. A free surface now becomes perpendicular to the total acceleration, and the pressure is proportional to the distance from this surface. The same can be done for a rotating fluid, where the centrifugal acceleration is the important quantity. The earth's atmosphere is an example. When air moves relative to the rotating system, the Coriolis force must also be taken into account. However, these are dynamic effects and are not strictly a part of hydrostatics.

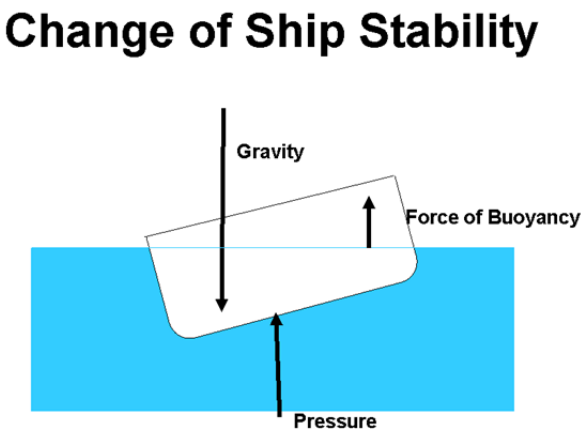
## Buoyancy

Archimedes, so the legend runs, was asked to determine if the goldsmith who made a golden crown for Hieron, Tyrant of Syracuse, had substituted cheaper metals for gold. The story is told by Vitruvius. A substitution could not be detected by simply weighing the crown, since it was craftily made to the same weight as the gold supplied for its construction. Archimedes realized that finding the density of the crown, that is, the weight per unit volume, would give the answer.

The weight was known, of course, and Archimedes cunningly measured its volume by the amount of water that ran off when it was immersed in a vessel filled to the brim. By comparing the results for the crown, and for pure gold, it was found that the crown displaced more water than an equal weight of gold, and had, therefore, been adulterated. This story, typical of the charming way science was made more interesting in classical times, may or may not actually have taken place, but whether it did or not, Archimedes taught that a body immersed in a fluid lost apparent weight equal to the weight of the fluid displaced, called Archimedes' Principle. Specific gravity, the ratio of the density of a substance to the density of water, can be determined by weighing the body in air, and then in water. The specific gravity is the weight in air divided by the loss in weight when immersed. This avoids the difficult determination of the exact volume of the sample.

## How Buoyancy Works

To see how buoyancy works, consider a submerged brick, of height h, width w and length l. The difference in pressure on top and bottom of the brick is ρgh, so the difference in total force on top and bottom of the brick is simply (ρgh) (wl) = ρgV, where V is the volume of the brick.




The forces on the sides have no vertical components, so they do not matter. The net upward force is the weight of a volume V of the fluid of density ρ. Anybody can be considered made up of brick shapes, as small as desired, so the result applies in general. This is just the integral calculus in action, or the application of Professor Thomson's analogy.

Consider a man in a rowboat on a lake, with a large rock in the boat. He throws the rock into the water. What is the effect on the water level of the lake? Suppose you make a drink of ice water with ice cubes floating in it. What happens to the water level in the glass when the ice has melted?

The force exerted by the water on the bottom of a boat acts through the centre of gravity B of the displaced volume, while the force exerted by gravity on the boat acts through its own centre of gravity A. This looks bad for the boat, since the boat's c.g. will naturally be higher than the c.g. of the displaced water, so the boat will tend to capsize. Well, a board floats, and can tell us why. Should the board start to rotate to one side, the displaced volume immediately moves to that side, and the buoyant force tends to correct the rotation. A floating body will be stable provided the line of action of the buoyant force passes through a point M above the c.g. of the body, called the metacenter, so that there is a restoring couple when the boat heels. A ship with an improperly designed hull will not float. It is not as easy to make boats as it might appear.

## Montgolfier Brothers' Hot Air Balloon

Archimedes' Principle can also be applied to balloons. The Montgolfier brothers' hot air balloon with a paper envelope ascended first in 1783 (the brothers got Pilâtre de Rozier and Chevalier d'Arlandes to go up in it). Such "fire balloons" were then replaced with hydrogen-filled balloons, and then with balloons filled with coal gas, which was easier to obtain and did not diffuse through the envelope quite as rapidly. Methane would be a good filler, with a density 0.55 that of air. Slack balloons, like most large ones, can be contrasted with taut balloons with an elastic envelope, such as weather balloons. Slack balloons will not be filled full on the ground, and will plump up at altitude. Balloons are naturally stable, since the center of buoyancy is above the center of gravity in all practical balloons. Submarines are yet another application of buoyancy, with their own characteristic problems. Small neoprene or natural rubber balloons have been used for meteorological observations, with hydrogen filling. A 10g ceiling balloon was about 17" in diameter when inflated to have a free lift of 40g. It ascended 480ft the first minute, 670ft in a minute and a half, and 360ft per minute afterwards, to find cloud ceilings by timing, up to 2500ft, when it subtended about 2' of arc, easily seen in binoculars.

Large sounding balloons were used to lift a radiosonde and a parachute for its recovery. An AN/AMT-2 radiosonde of the 1950's weighed 1500g, the paper parachute 100g, and the balloon 350g. The balloon was inflated to give 800g free lift, so it would rise 700-800 ft/min to an altitude of about 50,000 ft (15 km) before it burst. This balloon was about 6 ft in diameter when inflated at the surface, 3 ft in diameter before inflation. The information was returned by radio telemetry, so the balloon did not have to be followed optically. Of intermediate size was the pilot balloon, which was followed with a theodolite to determine wind directions and speeds. At night, a pilot balloon could carry a light for ceiling determinations.

## Weather Balloons

The greatest problem with using hydrogen for lift is that it diffuses rapidly through many substances. Weather balloons had to be launched promptly after filling, or the desired free lift would not be obtained. Helium is a little better in this respect, but it also diffuses rapidly. The lift obtained with helium is almost the same as with hydrogen (density 4 compared to 2, where air is 28.97). However, helium is exceedingly rare, and only its unusual occurrence in natural gas from Kansas makes it available. Great care must be taken when filling balloons with hydrogen to avoid sparks and the accumulation of hydrogen in air, since hydrogen is exceedingly flammable and explosive over a wide range of concentrations. Helium has the great advantage that it is not inflammable.

The hydrogen for filling weather balloons came from compressed gas in cylinders, from the reaction of granulated aluminum with sodium hydroxide and water, or from the reaction of calcium hydroxide with water. The chemical reactions are $2Al + 2NaOH + 2H2O \rightarrow 2NaAlO2 + 3H2$, or $CaH2 + 2H2O \rightarrow Ca (OH) 2 + 2H2$. In the first, silicon or zinc could be used instead of aluminum, and in the second, any similar metal hydride. Both are rather expensive sources of hydrogen, but very convenient when only small amounts are required. Most hydrogen is made from the catalytic decomposition of hydrocarbons, or the reaction of hot coke with steam.

Electrolysis of water is an expensive source, since more energy is used than is recovered with the hydrogen. Any enthusiasm for a "hydrogen economy" should be tempered by the fact that there are no hydrogen wells, and all the hydrogen must be made with an input of energy usually greater than that available from the hydrogen, and often with the appearance of carbon.

Although about 60,000 Btu/lb is available from hydrogen, compared to 20,000 Btu/lb from gasoline, hydrogen compressed to 1000 psi requires 140 times as much volume for the same weight as gasoline. For the energy content of a 13-gallon gasoline tank, a 600-gallon hydrogen tank would be required. The critical temperature of hydrogen is 32K, so liquid storage is out of the question for general use.

## Measurement of Specific Gravity

The specific gravity of a material is the ratio of the mass (or weight) of a certain sample of it to the mass (or weight) of an equal volume of water, the conventional reference material. In the metric system, the density of water is 1 g/cc, which makes the specific gravity numerically equal to the density. Strictly speaking, density has the dimensions g/cc, while specific gravity is a dimensionless ratio. However, in casual speech the two are often confounded. In English units, however, density, perhaps in lb/cu.ft or pcf, is numerically different from the specific gravity, since the weight of water is 62.5 lb/cu.ft.

## Variations

Things are complicated by the variation of the density of water with temperature, and also by the confusion that gave us the distinction between cc and ml. The milliliter is the volume of 1.0 g of water at 4°C, by definition. The actual volume of 1.0 g of water at 4°C is 0.999973 cm3 by measurement. Since most densities are not known, or needed, to more than three significant figures, it is clear that this difference is of no practical importance, and the ml can be taken equal to the cc. The density of water at 0°C is 0.99987 g/ml, at 20° 0.99823, and at 100°C 0.95838. The temperature dependence of the density may have to be taken into consideration in accurate work. Mercury, while we are at it, has a density 13.5955 at 0°C, and 13.5461 at 20°C.

The basic idea in finding specific gravity is to weigh a sample in air, and then immersed in water. Then the specific gravity is W/ (W - W'), if W is the weight in air, and W' the weight immersed. The denominator is just the buoyant force, the weight of a volume of water equal to the volume of the sample. This can be carried out with an ordinary balance, but special balances, such as the Jolly balance, have been created specifically for this application. Adding an extra weight to the sample allows measurement of specific gravities less than 1.

## Pycnometer

A pycnometer is a flask with a close-fitting ground glass stopper with a fine hole through it, so a given volume can be accurately obtained. The name comes from the Greek word meaning "density." If the flask is weighed empty, full of water, and full of a liquid whose specific gravity is desired, the specific gravity of the liquid can easily be calculated. A sample in the form of a powder, to which the usual method of weighing cannot be used, can be put into the pycnometer. The weight of the powder and the weight of the displaced water can be determined, and from them the specific gravity of the powder.

The specific gravity of a liquid can be found with a collection of small weighted, hollow spheres that will just float in certain specific gravities. The closest spheres that will just float and just sink put limits on the specific gravity of the liquid. This method was once used in Scotland to determine the amount of alcohol in distilled liquors. Since the density of a liquid decreases as the temperature increases, the spheres that float are an indication of the temperature of the liquid. Galileo's thermometer worked this way.

## Hydrometer

A better instrument is the hydrometer, which consists of a weighted float and a calibrated stem that protrudes from the liquid when the float is entirely immersed. A higher specific gravity will result in a greater length of the stem above the surface, while a lower specific gravity will cause the hydrometer to float lower.

The small cross-sectional area of the stem makes the instrument very sensitive. Of course, it must be calibrated against standards. In most cases, the graduations ("degrees") are arbitrary and reference is made to a table to determine the specific gravities. Hydrometers are used to determine the specific gravity of lead-acid battery electrolyte, and the concentration of antifreeze compounds in engine coolants, as well as the alcohol content of whiskey.

## Pascal's Law

The foundation of modern hydraulics was established when Pascal discovered that pressure in a fluid acts equally in all directions. This pressure acts at right angles to the containing surfaces. If some type of pressure gauge, with an exposed face, is placed beneath the surface of a liquid at a specific depth and pointed in different directions, the pressure will read the same. Thus, we can say that pressure in a liquid is independent of direction.

Pressure due to the weight of a liquid, at any level, depends on the depth of the fluid from the surface. If the exposed face of the pressure gauges are moved closer to the surface of the liquid, the indicated pressure will be less. When the depth is doubled, the indicated pressure is doubled. Thus the pressure in a liquid is directly proportional to the depth. Consider a container with vertical sides that is 1 foot long and 1 foot wide. Let it be filled with water 1 foot deep, providing 1 cubic foot of water. 1 cubic foot of water weighs 62.4 pounds. Using this information and equation, **P = F/A**, we can calculate the pressure on the bottom of the container.

Since there are 144 square inches in 1 square foot, this can be stated as follows: the weight of a column of water 1 foot high, having a cross-sectional area of 1 square inch, is 0.433 pound. If the depth of the column is tripled, the weight of the column will be 3 x 0.433, or 1.299 pounds, and the pressure at the bottom will be 1.299 $lb/in^2$ (psi), since pressure equals the force divided by the area.

Thus, the pressure at any depth in a liquid is equal to the weight of the column of liquid at that depth divided by the cross-sectional area of the column at that depth. The volume of a liquid that produces the pressure is referred to as the fluid head of the liquid. The pressure of a liquid due to its fluid head is also dependent on the density of the liquid.

## Gravity

Gravity is one of the four forces of nature. The strength of the gravitational force between two objects depends on their masses. The more massive the objects are, the stronger the gravitational attraction.

When you pour water out of a container, the earth's gravity pulls the water towards the ground. The same thing happens when you put two buckets of water, with a tube between them, at two different heights. You must work to start the flow of water from one bucket to the other, but then gravity takes over and the process will continue on its own.

Gravity, applied forces, and atmospheric pressure are static factors that apply equally to fluids at rest or in motion, while inertia and friction are dynamic factors that apply only to fluids in motion. The mathematical sum of gravity, applied force, and atmospheric pressure is the static pressure obtained at any one point in a fluid at any given time.

## Static Pressure

Static pressure exists in addition to any dynamic factors that may also be present at the same time. Pascal's law states that a pressure set up in a fluid acts equally in all directions and at right angles to the containing surfaces. This covers the situation only for fluids at rest or practically at rest. It is true only for the factors making up static head.

Obviously, when velocity becomes a factor it must have a direction, and as previously explained, the force related to the velocity must also have a direction, so that Pascal's law alone does not apply to the dynamic factors of fluid power.

The dynamic factors of inertia and friction are related to the static factors. Velocity head and friction head are obtained at the expense of static head. However, a portion of the velocity head can always be reconverted to static head. Force, which can be produced by pressure or head when dealing with fluids, is necessary to start a body moving if it is at rest, and is present in some form when the motion of the body is arrested; therefore, whenever a fluid is given velocity, some part of its original static head is used to impart this velocity, which then exists as velocity head.

## Volume and Velocity of Flow

The volume of a liquid passing a point in a given time is known as its *volume of flow* or flow rate. The volume of flow is usually expressed in gallons per minute (gpm) and is associated with relative pressures of the liquid, such as 5 gpm at 40 psi. The *velocity of flow* or velocity of the fluid is defined as the average speed at which the fluid moves past a given point. It is usually expressed in feet per second (fps) or feet per minute (fpm). Velocity of flow is an important consideration in sizing the hydraulic lines.

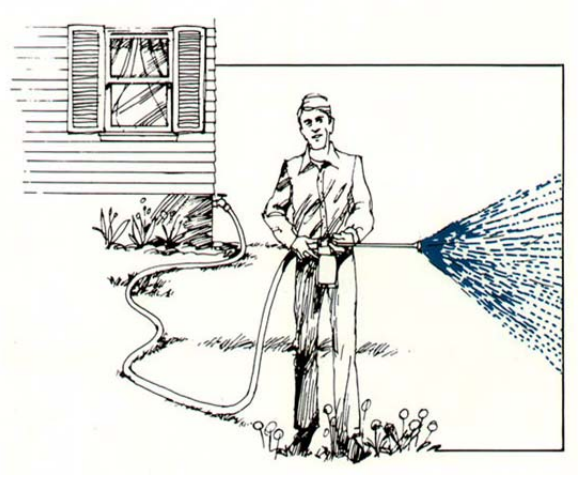
Volume and velocity of flow are often considered together. With other conditions unaltered—that is, with volume of input unchanged—the velocity of flow increases as the cross section or size of the pipe decreases, and the velocity of flow decreases as the cross section increases. For example, the velocity of flow is slow at wide parts of a stream and rapid at narrow parts, yet the volume of water passing each part of the stream is the same.

## Bernoulli's Principle

Bernoulli's principle thus says that a rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and conversely, if an increase (decrease) in, the speed of the fluid results in a decrease (increase) in the pressure.

This is at the heart of a number of everyday phenomena. As a very trivial example, Bernoulli's principle is responsible for the fact that a shower curtain gets "***sucked inwards***" when the water is first turned on. What happens is that the increased water/air velocity inside the curtain (relative to the still air on the other side) causes a pressure drop.

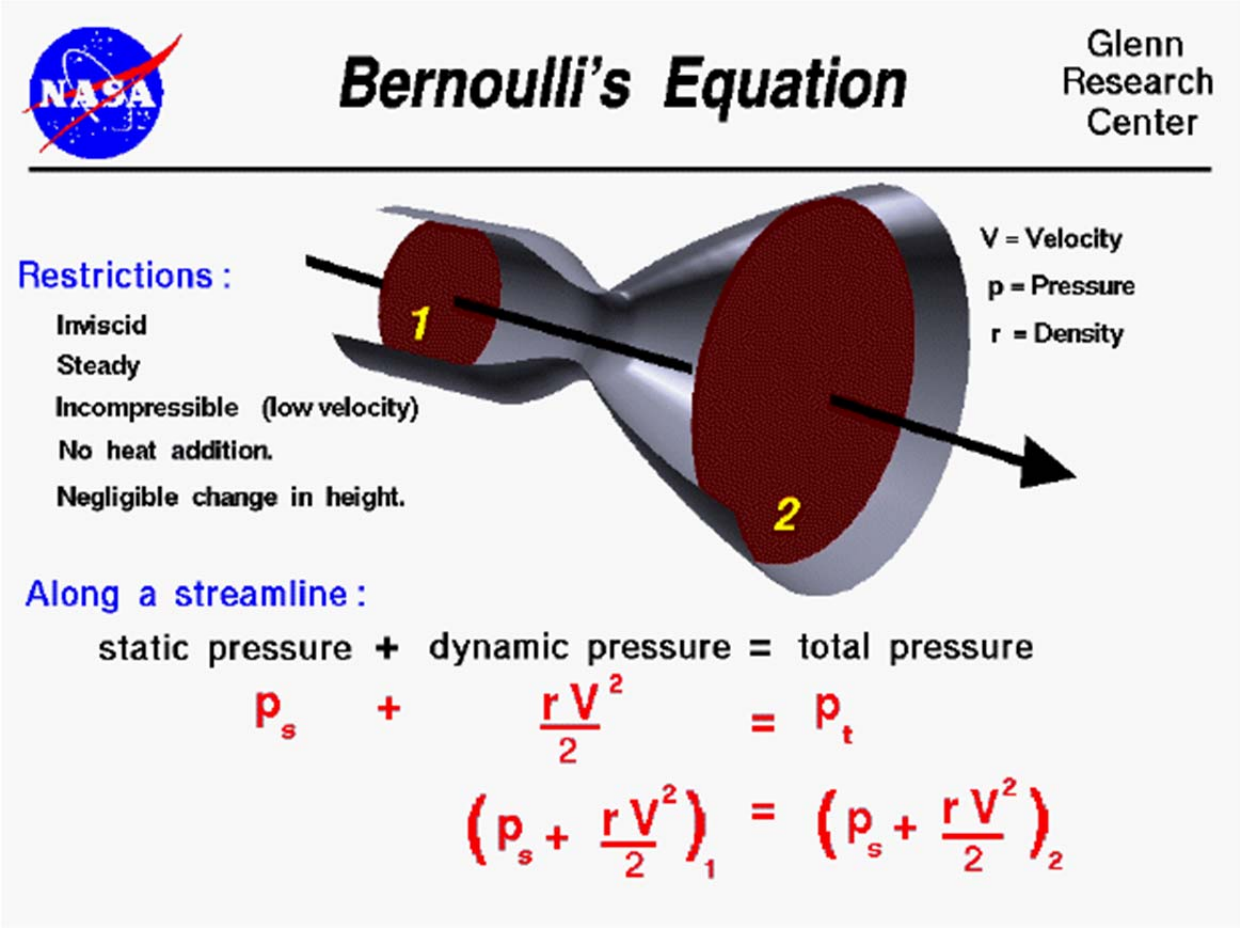
The pressure difference between the outside and inside causes a net force on the shower curtain which sucks it inward. A more useful example is provided by the functioning of a perfume bottle: squeezing the bulb over the fluid creates a low pressure area due to the higher speed of the air, which subsequently draws the fluid up. This is illustrated in the following figure.



***Action of a spray atomizer***

Bernoulli's principle also tells us why windows tend to explode, rather than implode in hurricanes: the very high speed of the air just outside the window causes the pressure just outside to be much less than the pressure inside, where the air is still. The difference in force pushes the windows outward, and hence they explode. If you know that a hurricane is coming it is therefore better to open as many windows as possible, to equalize the pressure inside and out.

Another example of Bernoulli's principle at work is in the lift of aircraft wings and the motion of "***curve balls"*** in baseball. In both cases the design is such as to create a speed differential of the flowing air past the object on the top and the bottom - for aircraft wings this comes from the movement of the flaps, and for the baseball it is the presence of ridges. Such a speed differential leads to a pressure difference between the top and bottom of the object, resulting in a net force being exerted, either upwards or downwards.



## General Pumping Fundamentals

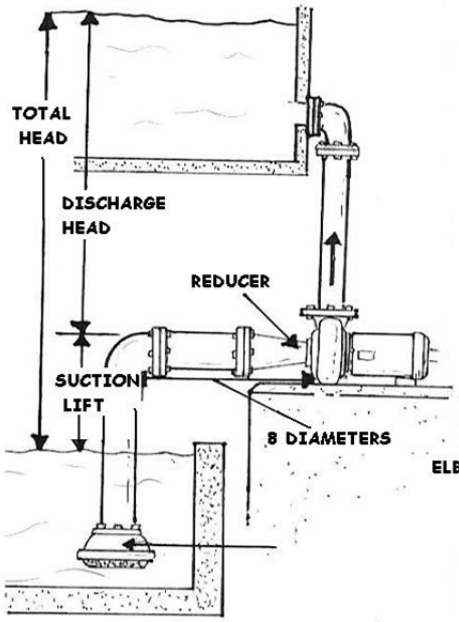



ILLUSTRATION 1

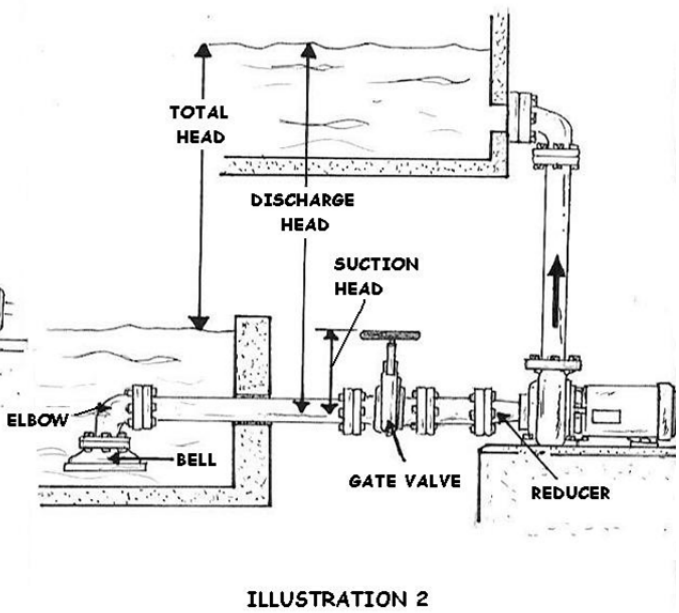



ILLUSTRATION 2

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.

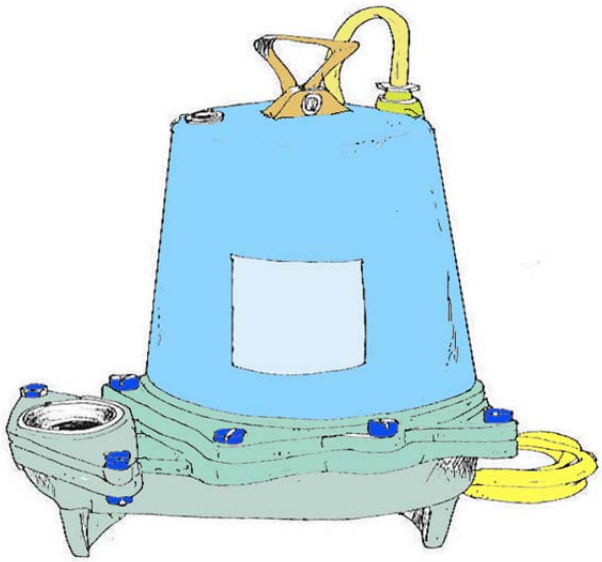
Notice in illustration "2" that the liquid is above the level of the pump. Sometimes this is referred to as *'flooded suction'* or *'suction head'* situations.

**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 Operation Section

## Pump Objectives. In this section we will examine…

- ★ What is a pump?
- ★ Identify different types of pumps and related parts.
- ★ Identify the main purpose of a motor starter.
- ★ Describe the main use of AC and DC motors.
- ★ Describe the operations of level sensor controls.
- ★ Identify and describe the most commonly used pumps.
- ★ Identify the suction and discharge valving.
- ★ Distinguish between discharge head, total head, suction head, and suction lift.
- ★ Describe information to be obtained from pump performance graphs.
- ★ Identify types of couplings, bearings, seals and other pump components.
- ★ Describe the importance of the alignment of couplings.
- ★ Indicate when packing seals need to be replaced.
- ★ Describe cavitation.
- ★ Describe water hammer.
- ★ State the basic principles of positive displacement pumps.



ELECTRICAL SUBMERSIBLE PUMP

Vertical Turbine well with a mineral oil cooled seal.  Mechanical seal bottom.

## 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.

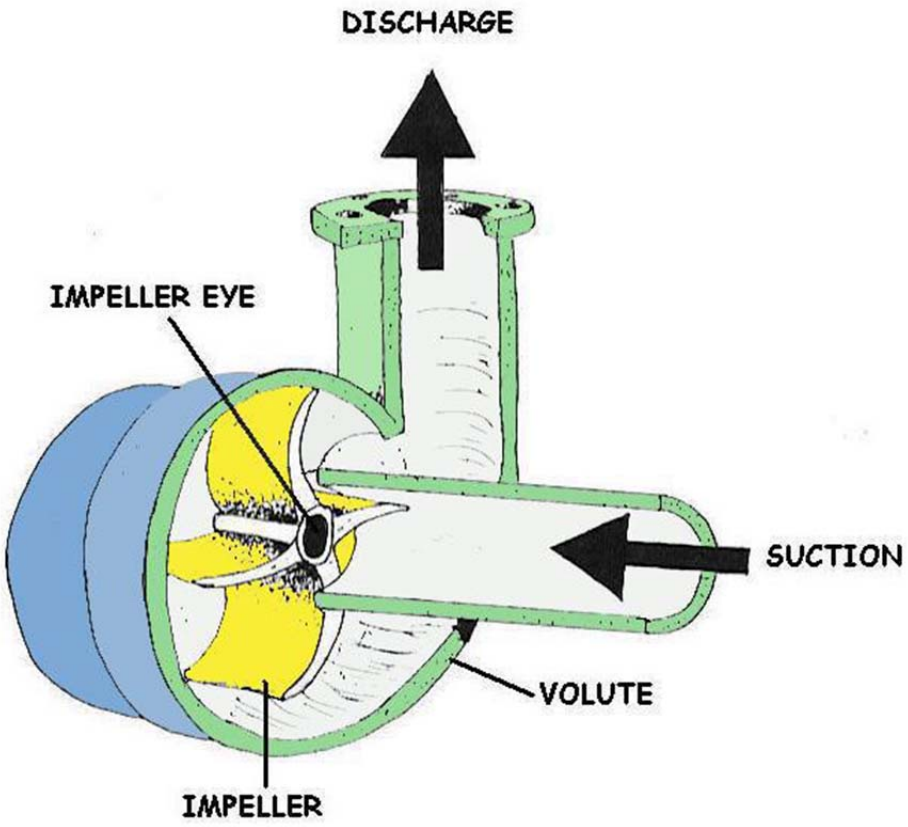
**Vertical pumps**: Pumps in which the center line of the shaft runs vertically.

**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.

## Understanding Pumps

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.

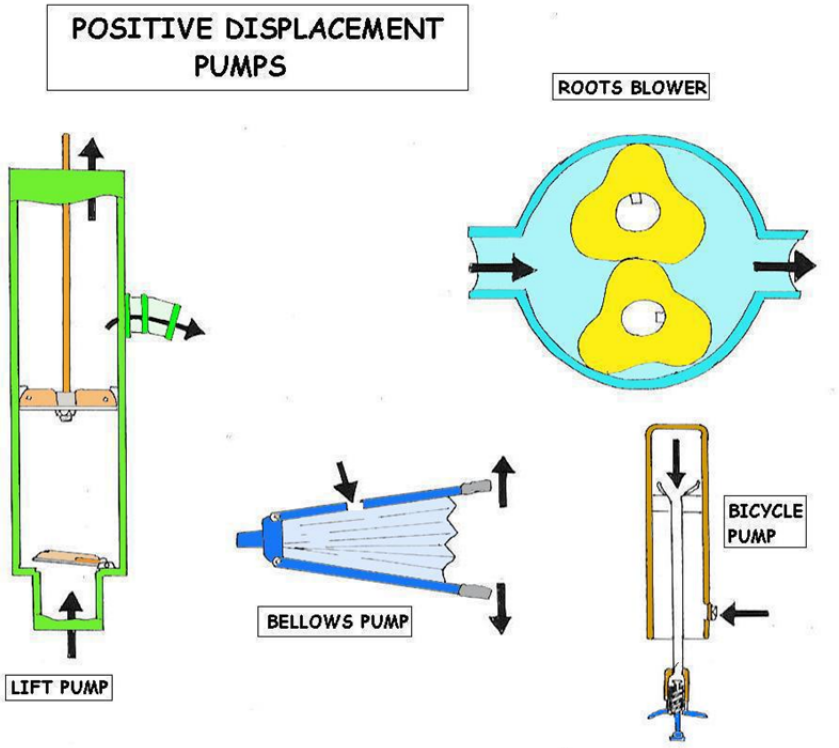
The lift pump has a supply valve and a valve in the piston that allows the liquid to pass around it when the volume of the cylinder is reduced. The delivery in this case is from the upper part of the cylinder, which the piston does not enter.

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.

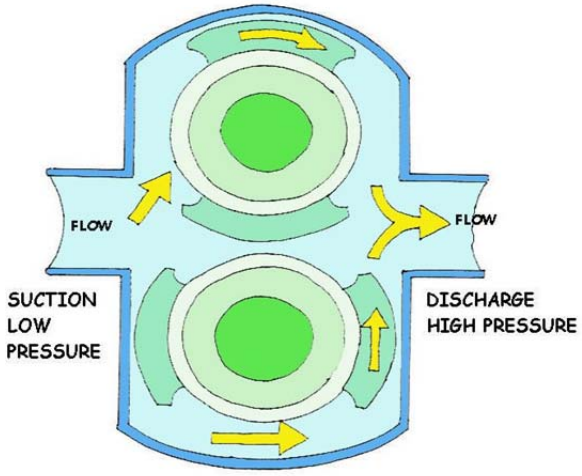
## Positive Displacement Pumps

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.

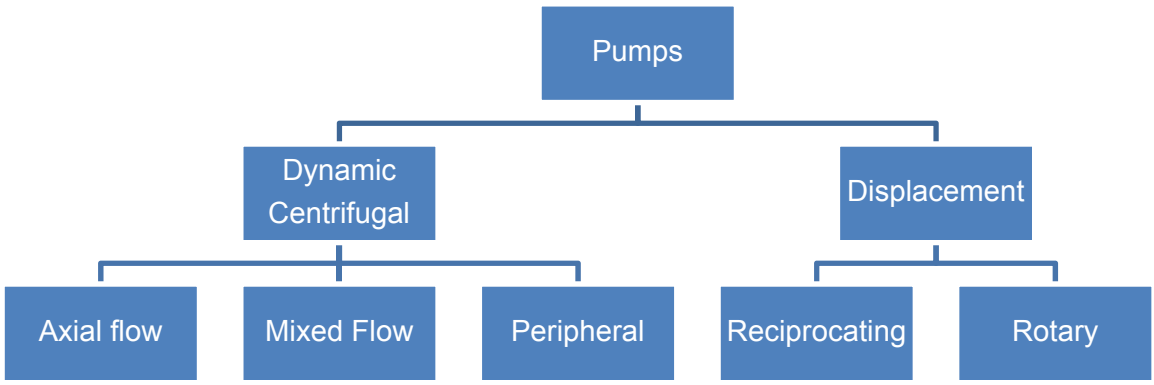
**There are three main types of diaphragm pumps available:**

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.



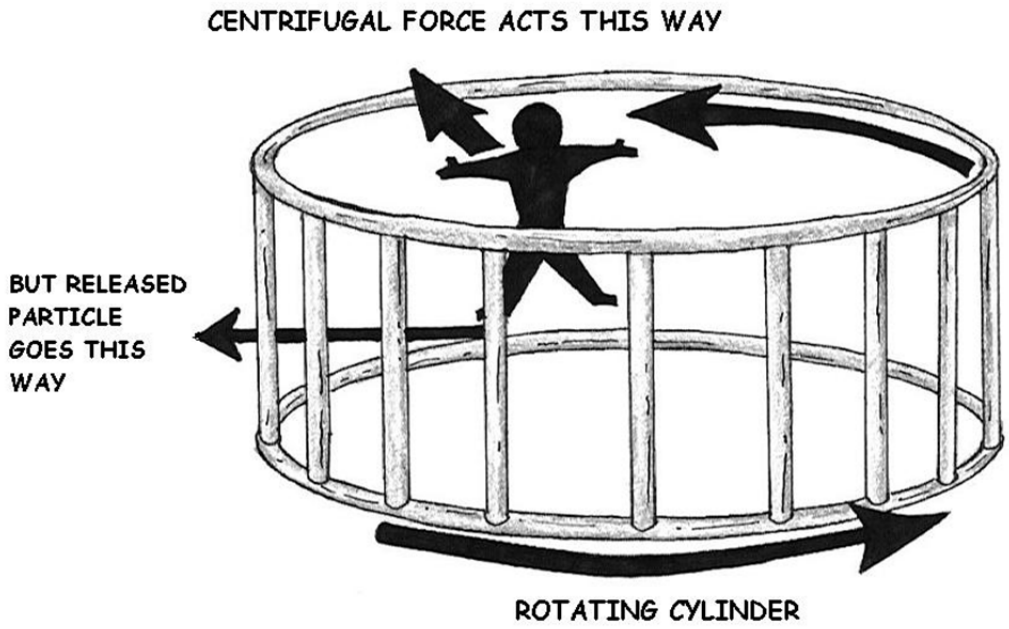
Split-case centrifugal pump.

BFP – 12 inch diameter multi-bowl vertical turbine well pump.

## Basic Water Pump

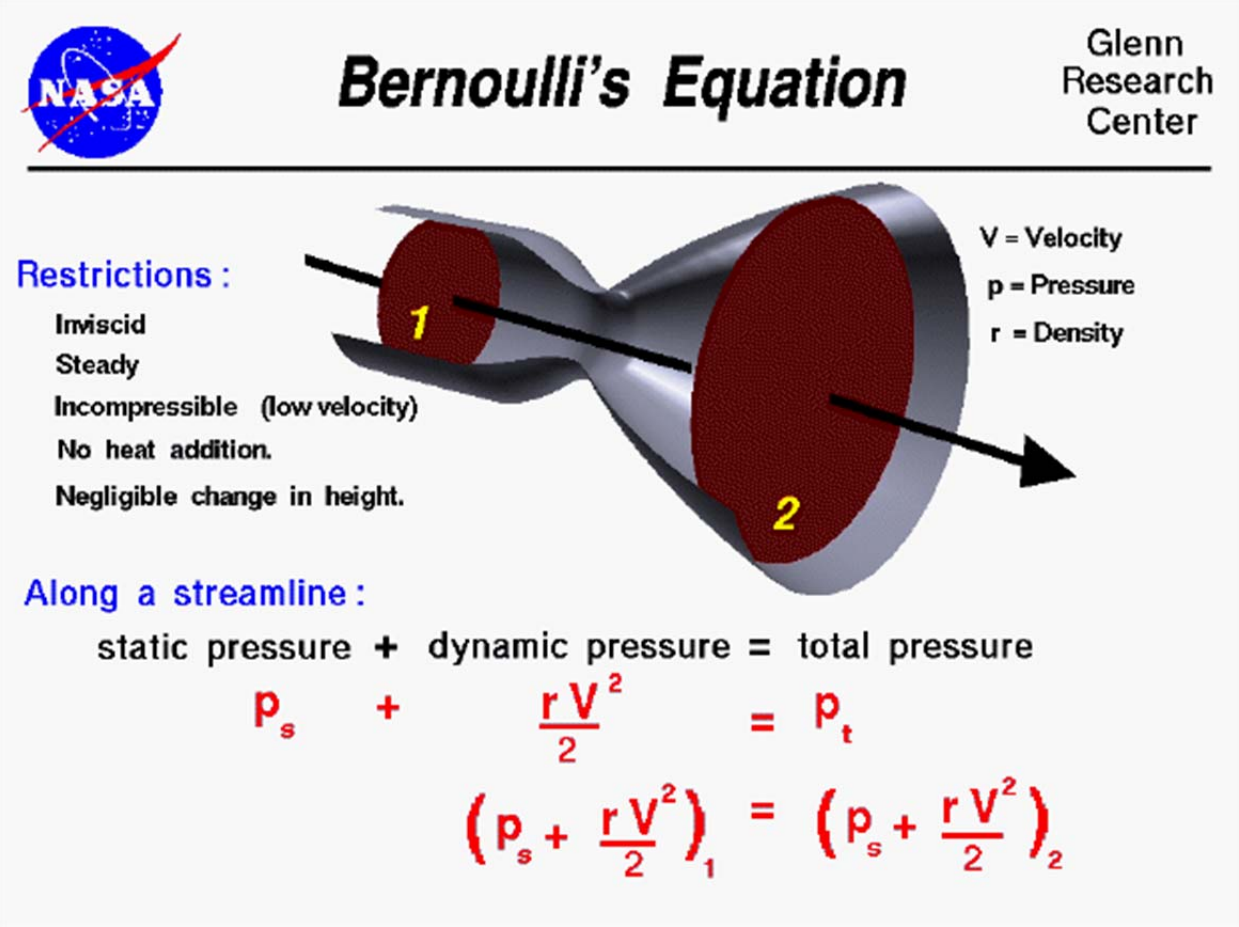
The water pump commonly found in our systems is centrifugal pumps. These pumps work by spinning water around in a circle inside a cylindrical pump housing. The pump makes the water spin by pushing it with an impeller. The blades of this impeller project outward from an axle like the arms of a turnstile 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:***

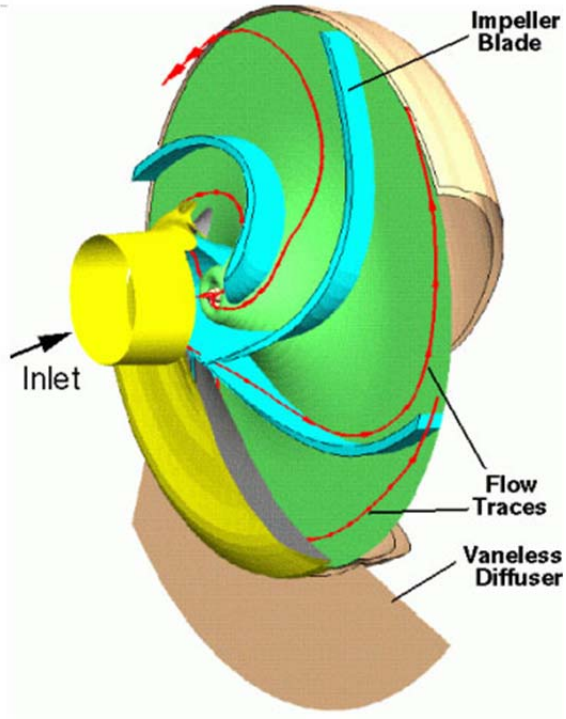



First, you can view the water between the impeller blades as an object traveling in a circle. Objects do not naturally travel in a circle--they need an inward force to cause them to accelerate inward as they spin. Without such an inward force, an object will travel in a straight line and will not complete 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.

Insertion of motor spline into the pump keyway.

Cut away of a small submersible pump.

## 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.

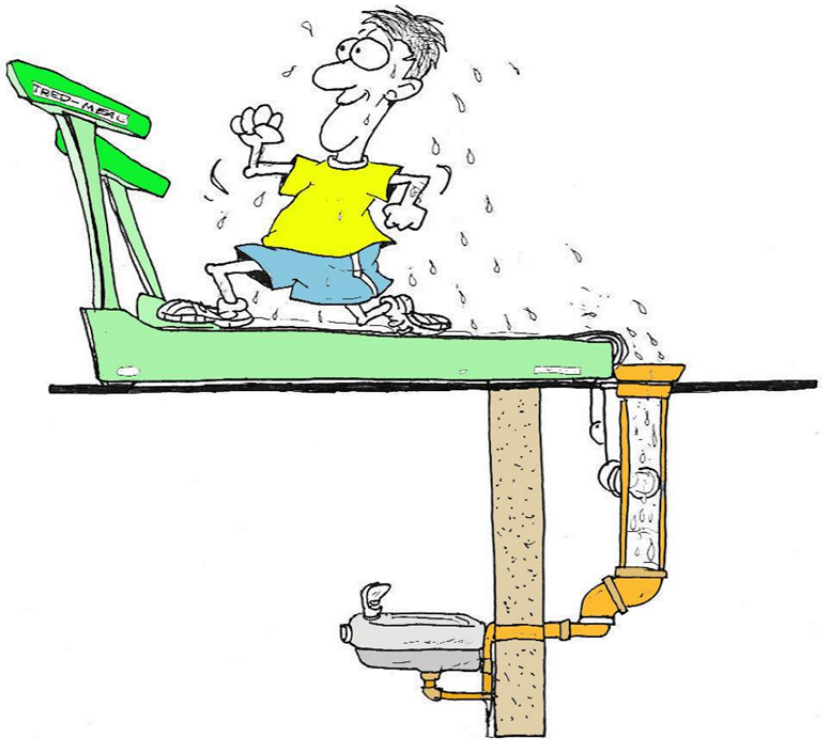
**S.G.:** Specific gravity. The weight of liquid in comparison to water at approx. 20 degrees C (SG = 1).

**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.

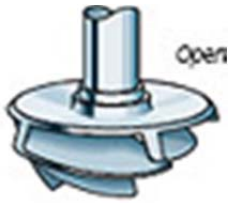
**Vapor Pressure:** If the vapor pressure of a liquid is greater than the surrounding air pressure, the liquid will boil.

**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 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.

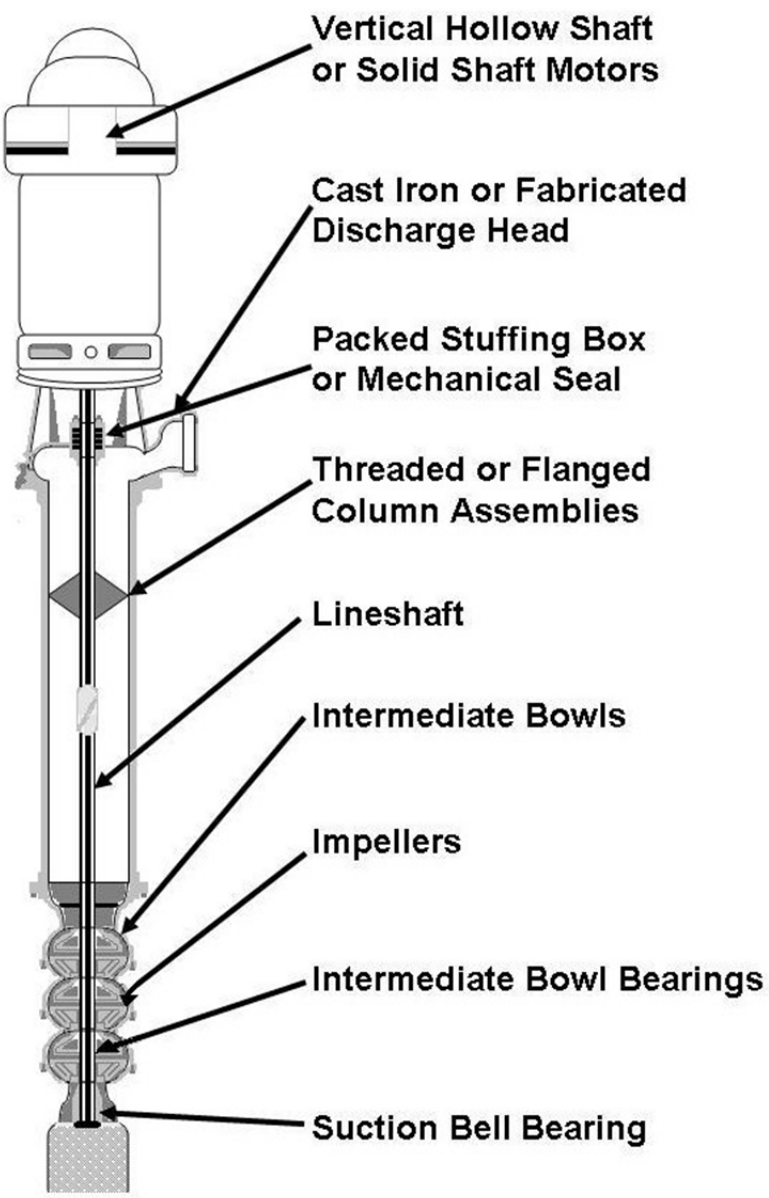
The head assembly must be mounted on a good foundation at least 12 inches above the ground surface. A foundation of concrete provides a permanent and trouble-free installation. The foundation must be large enough to allow the head assembly to be securely fastened. The foundation should have at least 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

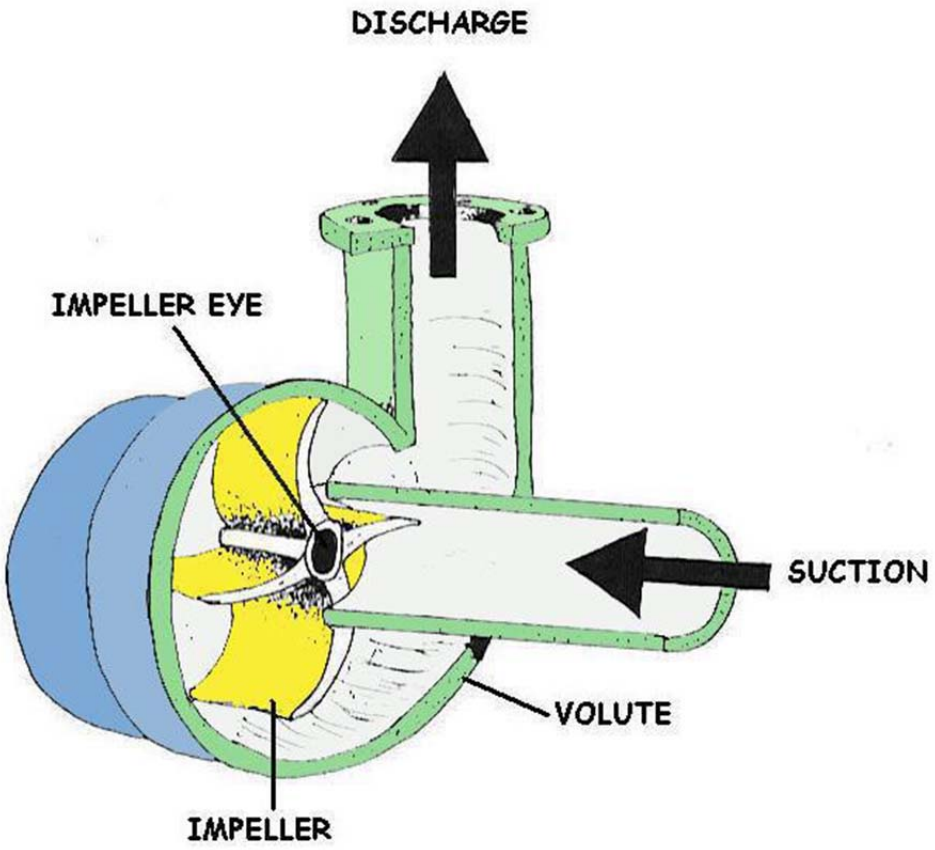
## Centrifugal Pump

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.

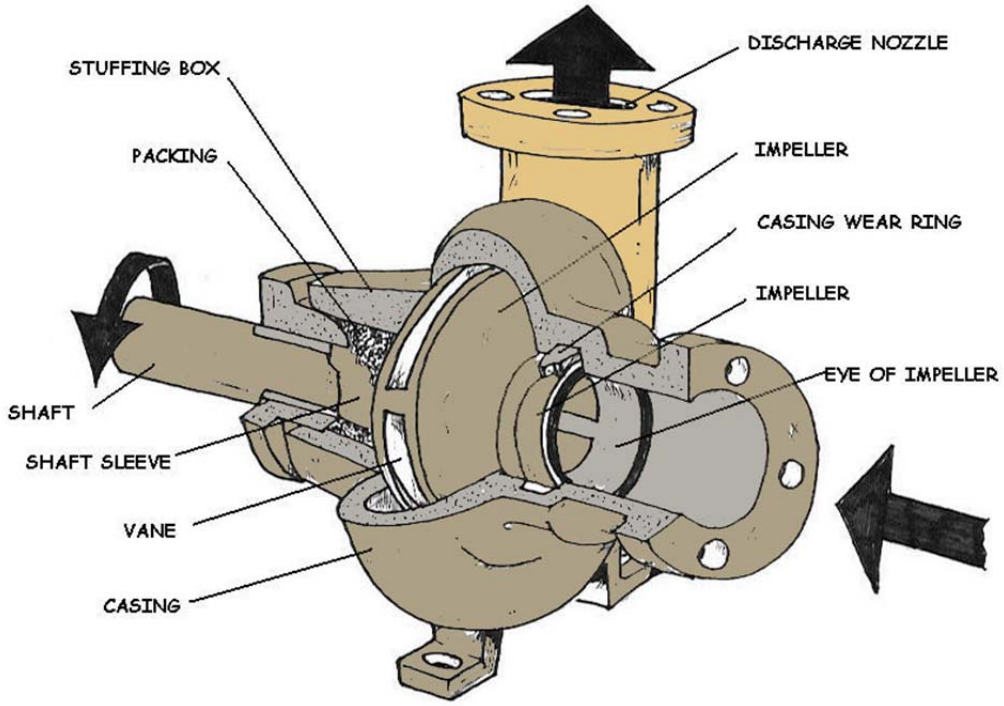
Recirculation lines are installed on some centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off or the flow of fluid is stopped for extended periods.

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).

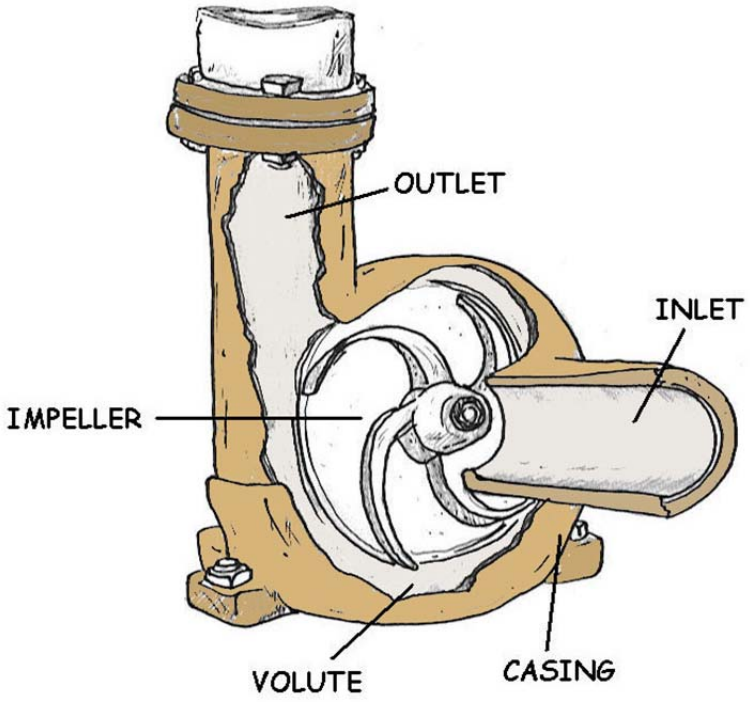
Water flinger rings are fitted on the shaft between the packing gland and the pump bearing housing. These flingers prevent water in the stuffing box from flowing along the shaft and entering the bearing housing.

**Look at the components of the centrifugal pump.**

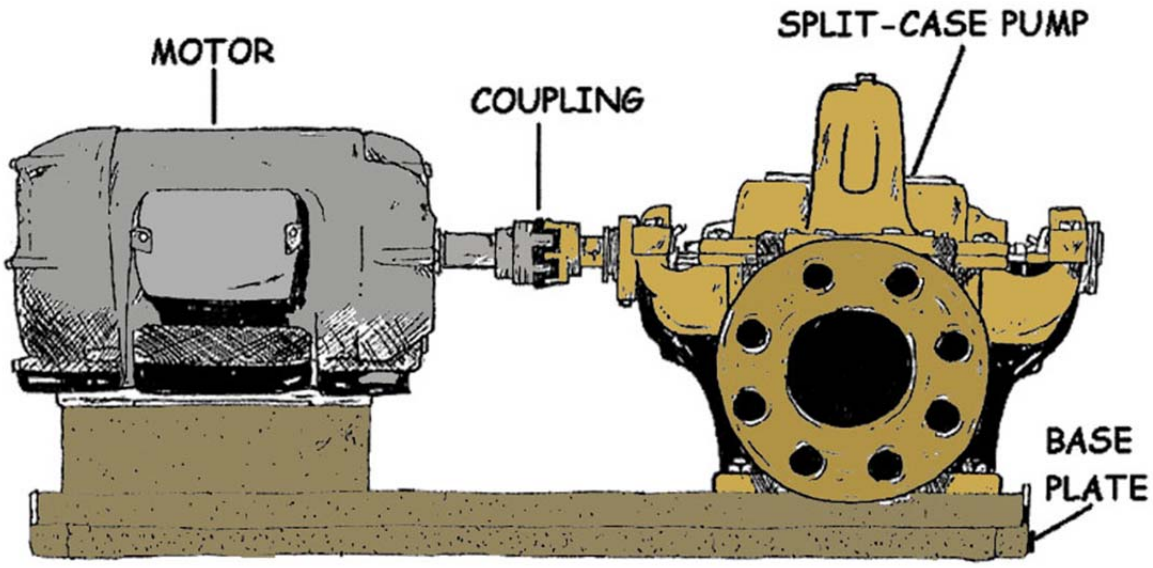



**Centrifugal Pump**

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 degrees 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

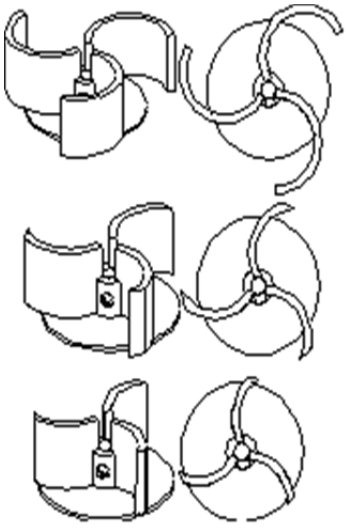
There are many variations of centrifugal pumps. The most common type is an end suction pump. Another type of pump used is the split case. There are many variations of split case, such as; two-stage, single suction, and double suction. Most of these pumps are horizontal.

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.

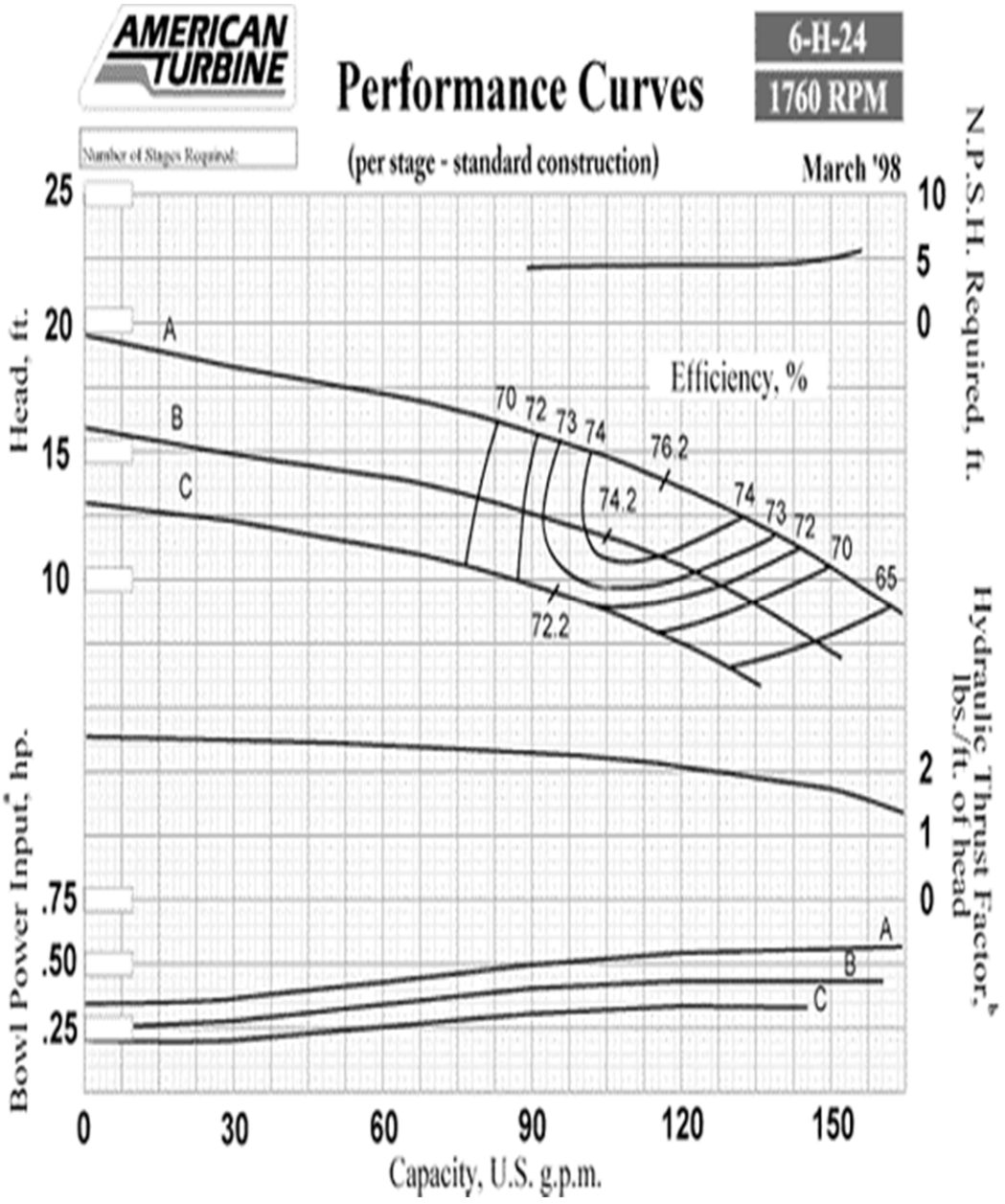
**Axial flow** impellers look like a propeller and create a flow that is parallel to the shaft.

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.

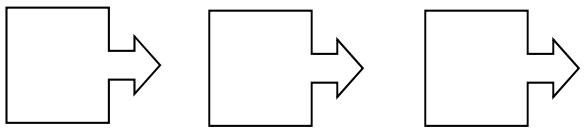
**Total Dynamic Head (TDH)** is the total height that a fluid is to be pumped, taking into account friction losses in the pipe.

**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

$$\text{Specific yield, gpm/ft} = \frac{\text{Well yield, gpm}}{\text{Drawdown, ft}}$$

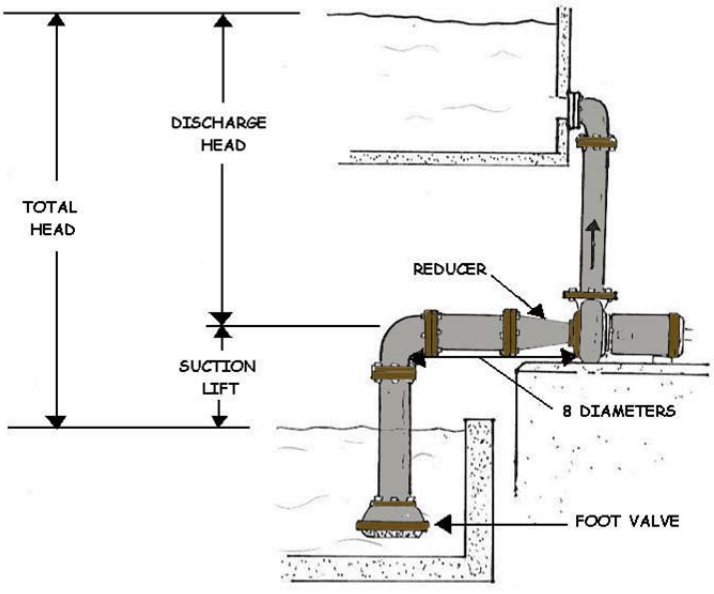
4. Deep well turbine pump calculations.

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.

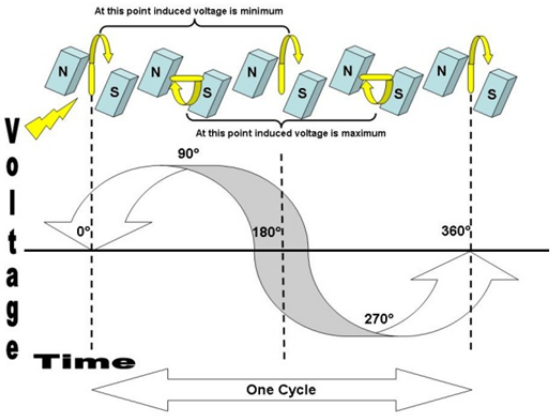
**There are two general categories of electric motors:**

- 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 start-up 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:**

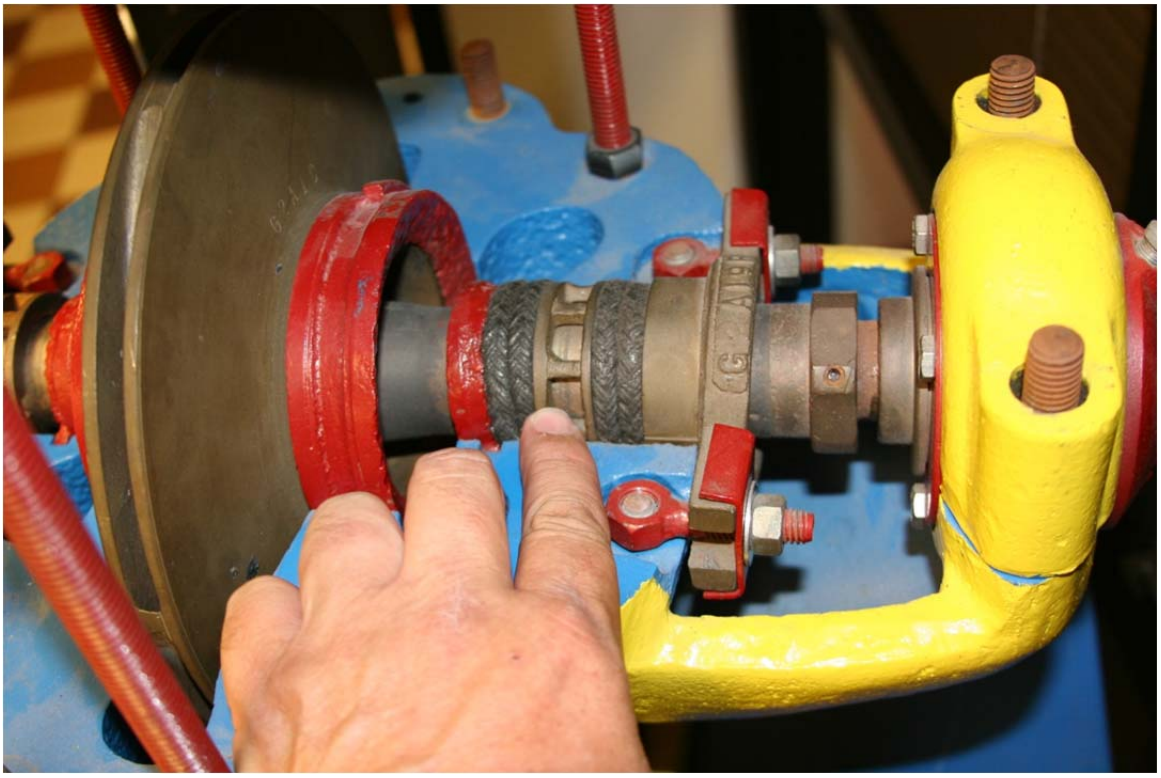
1. Remove the protective plugs and caps from the grease inlet and relief holes.
2. Pump grease in until fresh starts coming from the relief hole.

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.

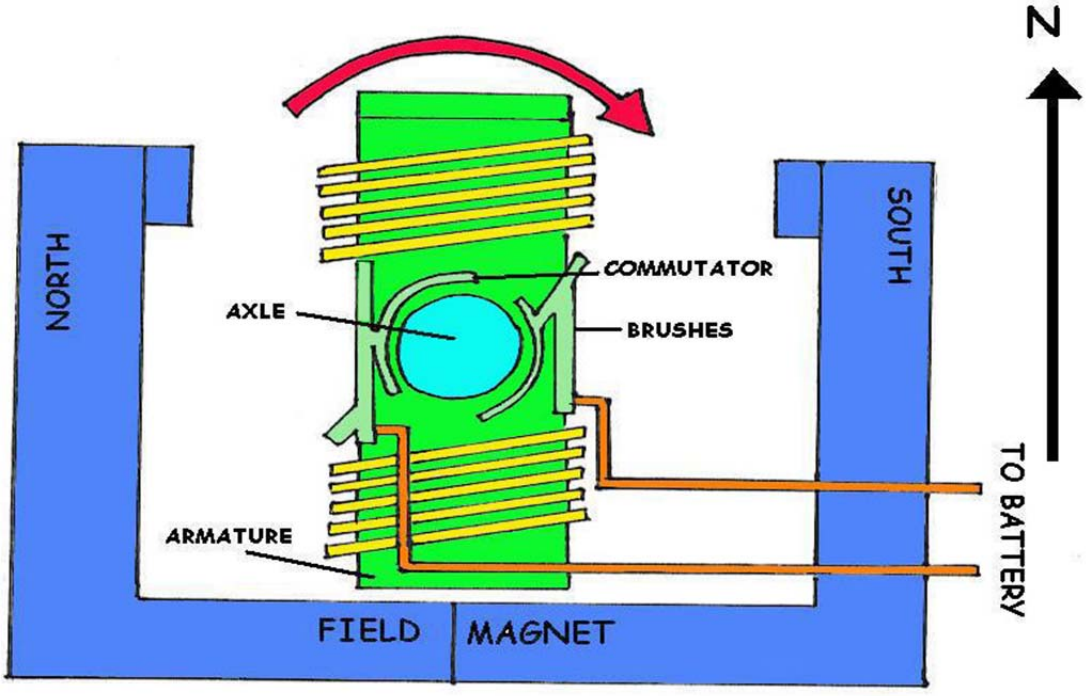
**To change the oil in an oil lubricated motor, this is the usual approach:**

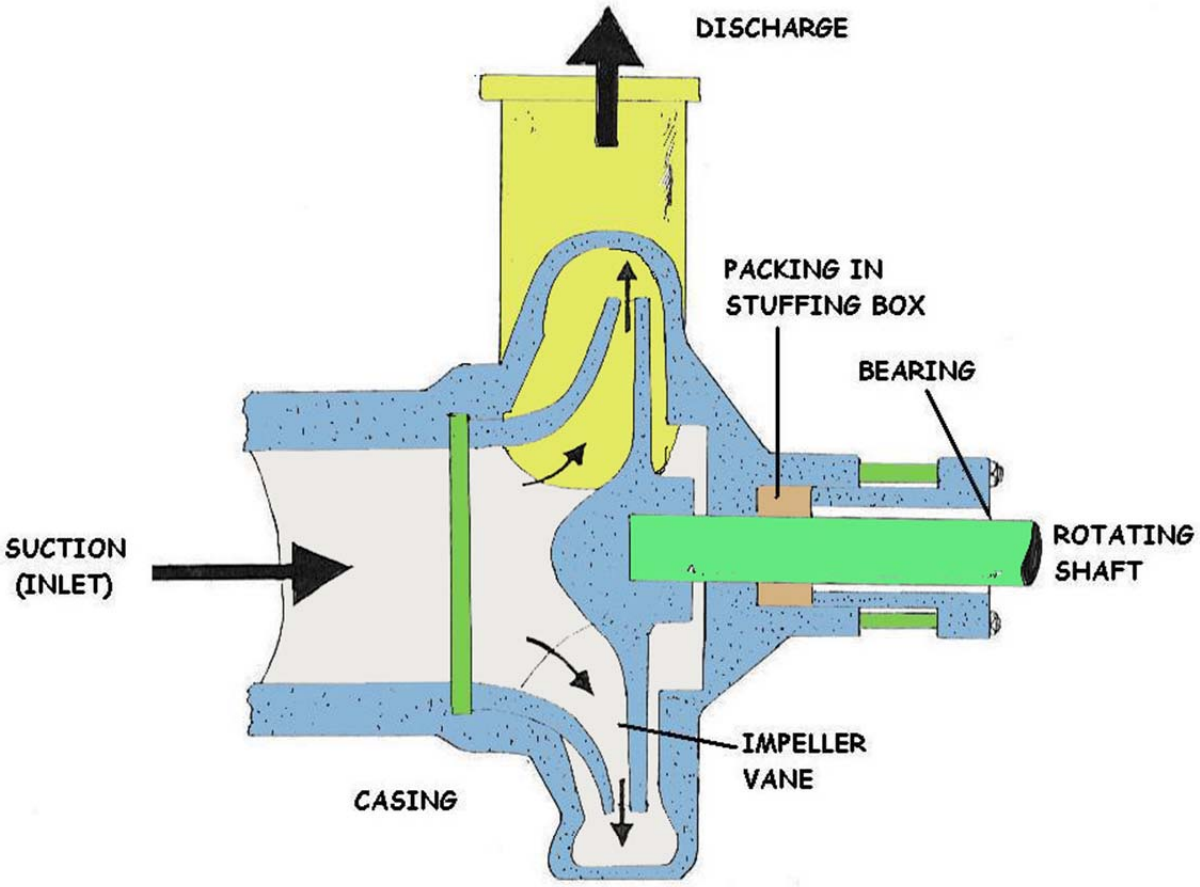
1. Remove all plugs and let the oil drain.
2. Check for metal shearing.
3. Replace the oil drain.
4. Add new oil until it is up to the oil level plug.
5. Replace the oil level and filter plug.

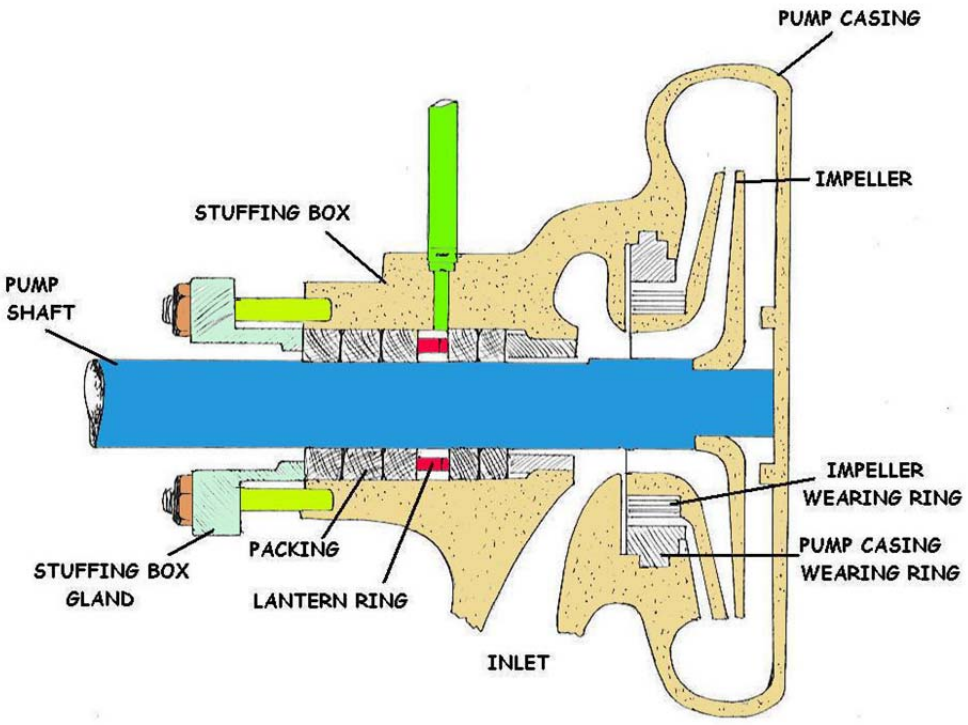
Never mix oils, since the additives of different oils when combined can cause breakdown of the oil.



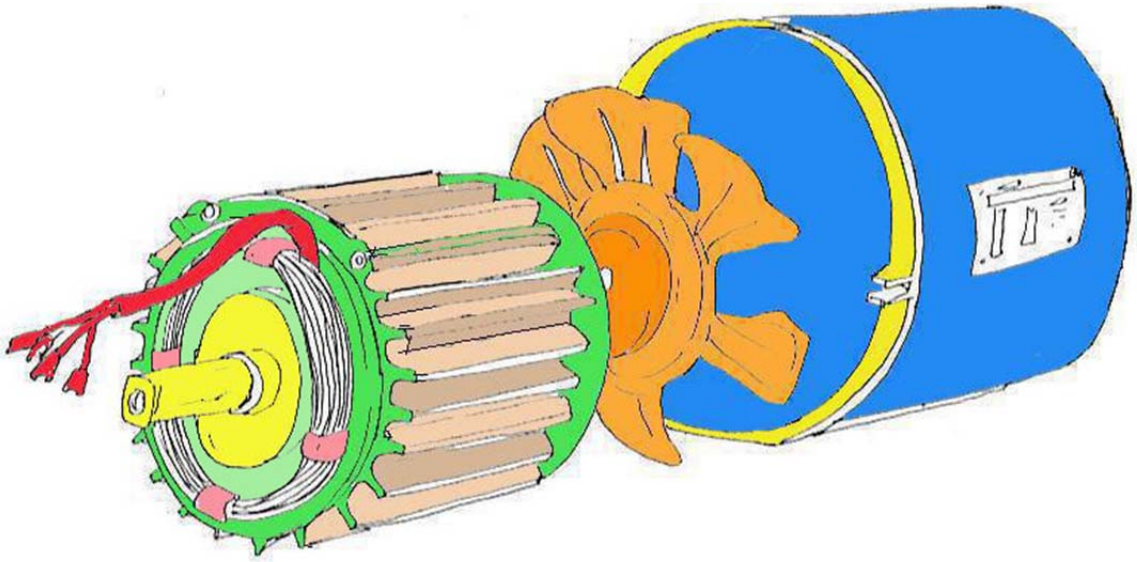
Finger is shown pointing to a Lantern Ring. This old school method of sealing a pump is still out there. Notice the packing on both sides of the ring. The packing joints need to be staggered and the purpose of this device is to allow air to the Stuffing Box.




DISCHARGE
PACKING IN
STUFFING BOX
BEARING
SUCTION
(INLET)
ROTATING
SHAFT
IMPELLER
VANE
CASING


PUMP CASING
IMPELLER
STUFFING BOX
PUMP
SHAFT
IMPELLER
WEARING RING
PUMP CASING
WEARING RING
PACKING
STUFFING BOX
GLAND
LANTERN RING
INLET

## 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.

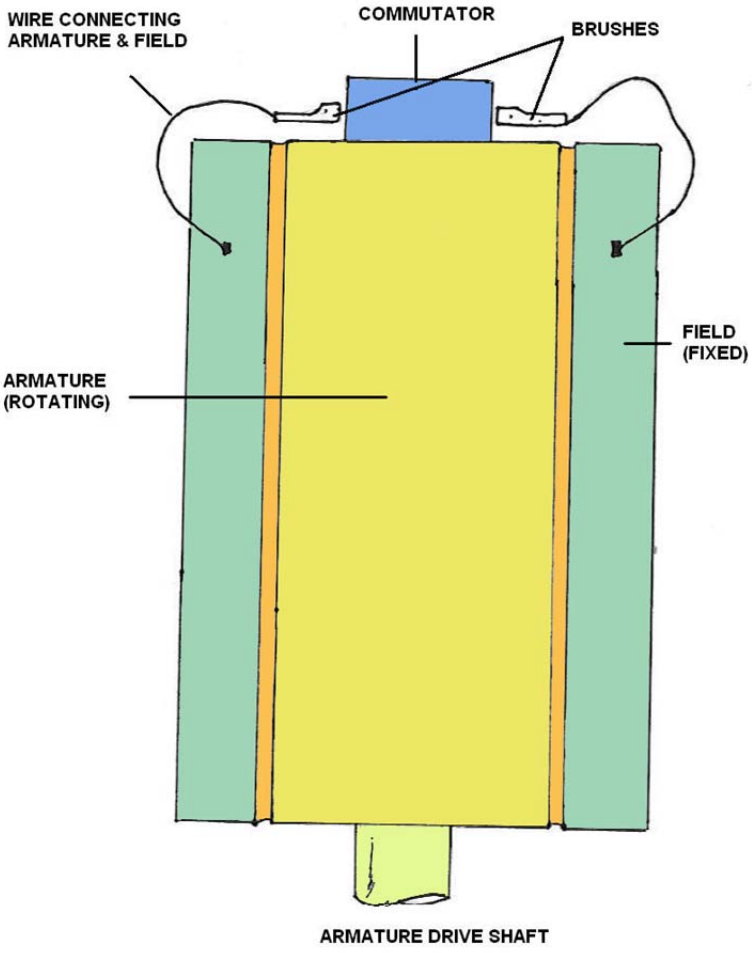



DIAGRAM SHOWING MECHANICAL CONSTRUCTION OF A DC SERIES WOUND MOTOR

**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.

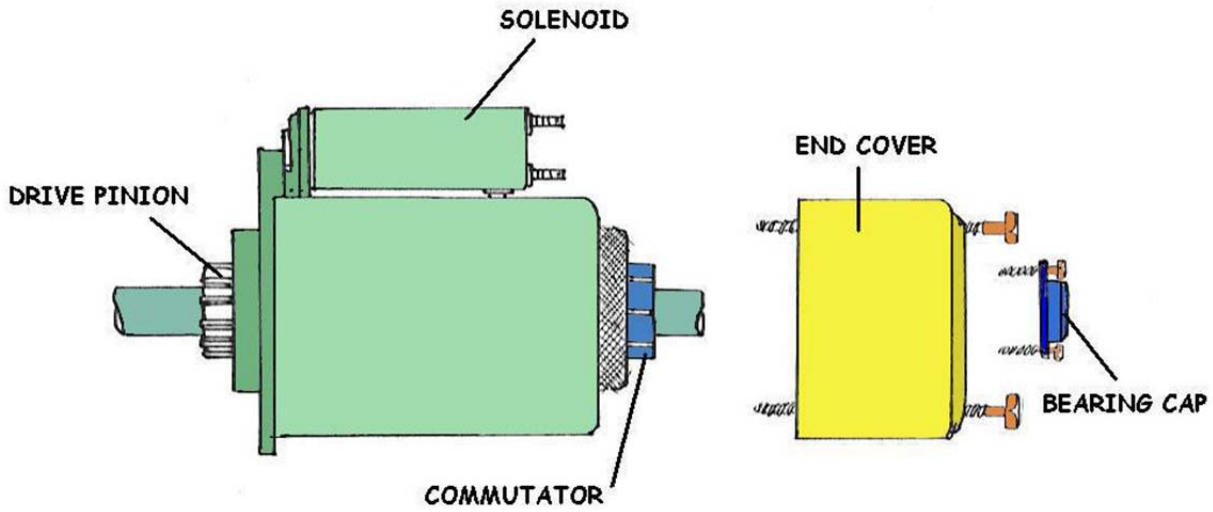
Modern DC brushless motors range in power from a fraction of a watt to many kilowatts. Larger brushless motors up to about 100 kW rating are used in electric vehicles. They also find significant use in high-performance electric model aircraft.

**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.

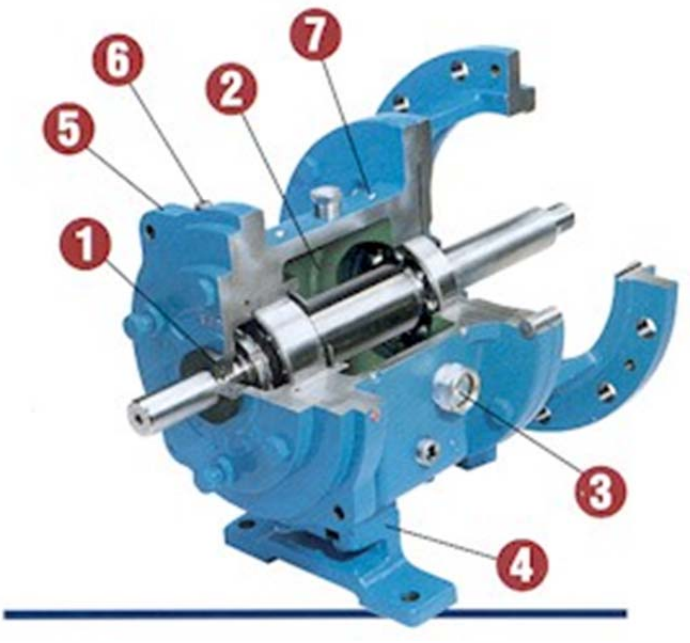
Remember that any coupling is a device in motion. If you have a 4-inch diameter coupling rotating at 1800 rpm, its outer surface is traveling about 20 mph. With that in mind, can you think of safety considerations?

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

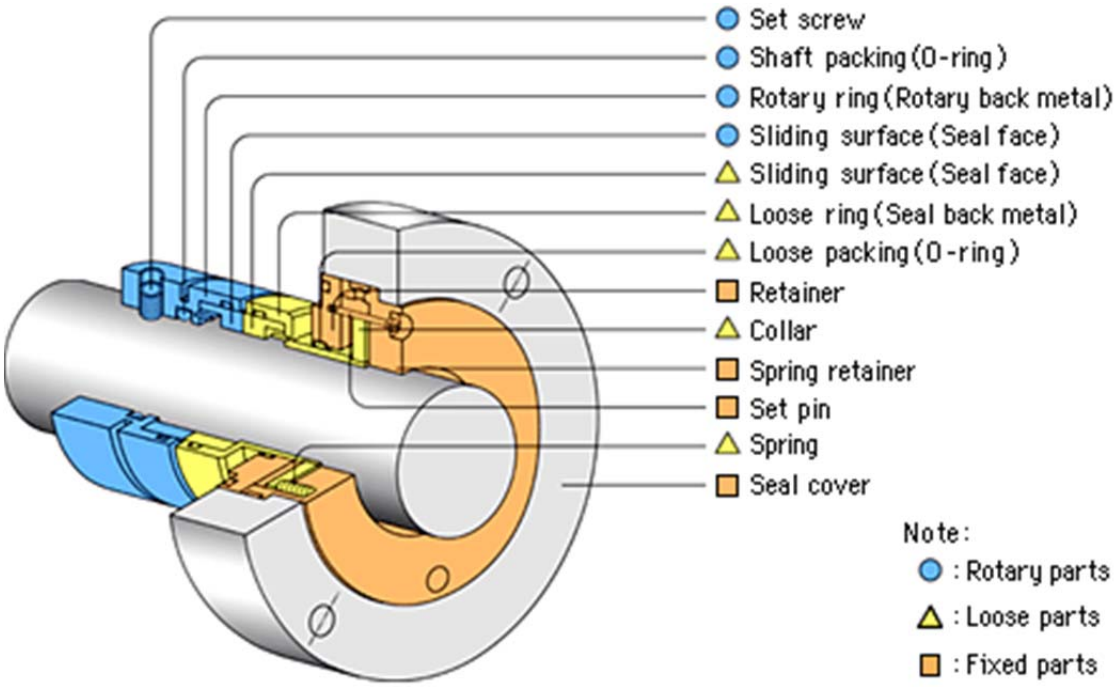
Mechanical seals are rapidly replacing conventional packing as the means of controlling leakage on rotary and positive-displacement pumps. Mechanical seals eliminate the problem of excessive stuffing box leakage, which causes failure of pump and motor bearings and motor windings.

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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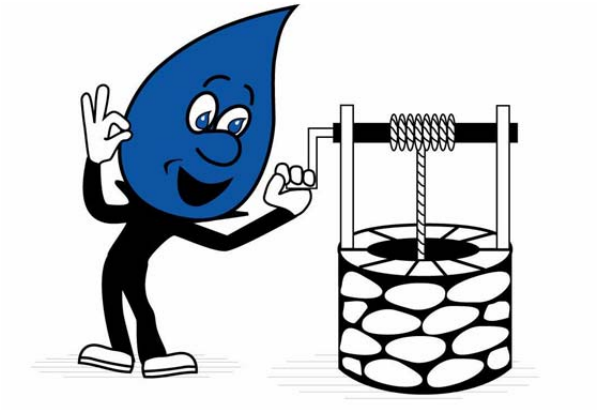
Mechanical shaft seals serve to ensure that liquid pressure is supplied to the seal faces under all conditions of operation. They also ensure adequate circulation of the liquid at the seal faces to minimize the deposit of foreign matter on the seal parts.

## 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.

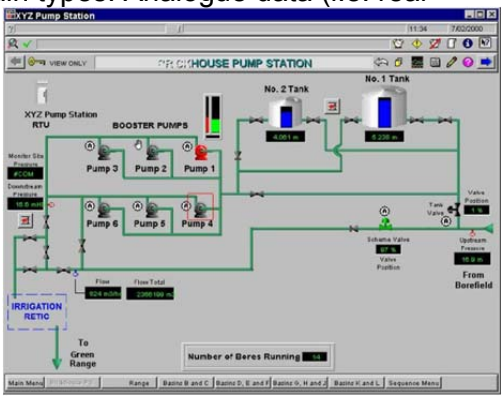
### What is Data Acquisition?

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.

## Safety Section

## Excavation & Trenching

This section outlines procedures and guidelines for the protection of employees working in and around excavations and trenches. This section requires compliance with OSHA Standards described in Subpart P (**CFR 1926.650**) for the construction industry.

Safety compliance is mandatory to ensure employee protection when working in or around excavations. The competent person(s) must be trained in accordance with the OSHA Excavation Standard, and all other programs that may apply (examples Hazard Communication, Confined Space, and Respiratory Protection), and must demonstrate a thorough understanding and knowledge of the programs and the hazards associated. All other employees working in and around the excavation must be trained in the recognition of hazards associated with trenching and excavating.

***REFERENCES***

- **29 CFR 1926.650, Subpart P - Excavations**
- **Excavation Equipment Manufacturer Safety Procedures**

***Trench Shield***

## Hazards

One of the reasons OSHA requires a competent person on-site during excavation & trenching are the numerous potential hazardous that may be encountered or created. Hazards include:

**Electrocution**
**Gas Explosion**
**Entrapment**
**Struck by equipment**
**Suffocation**

## Hazard Controls

Before any work is performed and before any employees enter the excavation, a number of items must be checked and ensured:

- Before any excavation, underground installations must be determined. This can be accomplished by either contacting the local utility companies or the local "one-call' center for the area. All underground utility locations must be documented on the proper forms. All overhead hazards (surface encumbrances) that create a hazard to employees must be removed or supported to eliminate the hazard.
- If the excavation is to be over 20 feet deep, it must be designed by a registered professional engineer who is registered in the state where work will be performed.
- Adequate protective systems will be utilized to protect employees. This can be accomplished through sloping, shoring, or shielding.
- The worksite must be analyzed in order to design adequate protection systems and prevent cave-ins. There must also be an excavation safety plan developed to protect employees.
- Workers must be supplied with and wear any personal protective equipment deemed necessary to assure their protection.
- All spoil piles will be stored a minimum of two (2) feet from the sides of the excavation. The spoil pile must not block the safe means of egress.
- If a trench or excavation is 4 feet or deeper, stairways, ramps, or ladders will be used as a safe means of access and egress. For trenches, the employee must not have to travel any more than 25 feet of lateral travel to reach the stairway, ramp, or ladder.
- No employee will work in an excavation where water is accumulating unless adequate measures are used to protect the employees.

- A competent person will inspect all excavations and trenches daily, prior to employee exposure or entry, and after any rainfall, soil change, or any other time needed during the shift. The competent person must take prompt measures to eliminate any and all hazards.
- Excavations and trenches 4 feet or deeper that have the potential for toxic substances or hazardous atmospheres will be tested at least daily. If the atmosphere is inadequate, protective systems will be utilized.
- If work is in or around traffic, employees must be supplied with and wear orange reflective vests. Signs and barricades must be utilized to ensure the safety of employees, vehicular traffic, and pedestrians.

**Competent Person Responsibilities**
The OSHA Standards require that the competent person must be capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and have authorization to take prompt corrective measures to eliminate them and, if necessary, to stop the work.

**A competent person is required to**:
- Have a complete understanding of the applicable safety standards and any other data provided.
- Assure the proper locations of underground installations or utilities, and that the proper utility companies have been contacted.
- Conduct soil classification tests and reclassify soil after any condition changes.
- Determine adequate protective systems (sloping, shoring, or shielding systems) for employee protection.
- Conduct all air monitoring for potential hazardous atmospheres.
- Conduct daily and periodic inspections of excavations and trenches.
- Approve design of structural ramps, if used.

## Excavation Safety Plan
An excavation safety plan is required in written form. This plan is to be developed to the level necessary to ensure complete compliance with the OSHA Excavation Safety Standard and state and local safety standards.

**Excavation safety plan factors:**
- Utilization of the local one-call system.
- Determination of locations of all underground utilities.
- Consideration of confined space atmosphere potential.
- Proper soil protection systems and personal protective equipment and clothing.
- Determination of soil composition and classification.
- Determination of surface and subsurface water.
- Depth of excavation and length of time it will remain open.

- Proper adherence to all OSHA Standards, this excavation and trenching safety program, and any other coinciding safety programs.

## Soil Classification and Identification

The OSHA Standards define soil classifications within the Simplified Soil Classification Systems, which consist of four categories: Stable rock, Type A, Type B, and Type C. Stability is greatest in stable rock and decreases through Type A and B to Type C, which is the least stable. Appendix A of the Standard provides soil mechanics terms and types of field tests used to determine soil classifications.

Stable rock is defined as natural solid mineral matter that can be excavated with vertical sides and remain intact while exposed.

**Type A soil is defined as:**

- Cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (**TSF**) or greater.
- Cemented soils like caliche and hardpan are considered Type A.

**Soil is NOT Type A if:**

- It is fissured.
- The soil is subject to vibration from heavy traffic, pile driving or similar effects.
- The soil has been previously disturbed.
- The material is subject to other factors that would require it to be classified as a less stable material.
- The exclusions for Type A most generally eliminate it from most construction situations.

**Type B soil is defined as:**

- Cohesive soil with an unconfined compressive strength greater than .5 TSF, but less than 1.5 TSF.
- Granular cohesion-less soil including angular gravel, silt, silt loam, and sandy loam.
- The soil has been previously disturbed, except soil classified as Type C soil.
- Soil that meets the unconfined compressive strength requirements of Type A soil, but is fissured or subject to vibration.
- Dry rock that is unstable.

**Type C soil is defined as**:

- Cohesive soil with an unconfined compressive strength of .5 TSF or less.
- Granular soils including gravel, sand and loamy sand.
- Submerged soil or soil from which water is freely seeping.
- Submerged rock that is not stable.

## Soil Test & Identification

The competent person will classify the soil type in accordance with the definitions in Appendix A based on at least one visual and one manual analysis. These tests should be run on freshly excavated samples from the excavation and are designed to determine stability based on a number of criteria: the cohesiveness, the presence of fissures, the presence and amount of water, the unconfined compressive strength, the duration of exposure, undermining, and the presence of layering, prior excavation and vibration.

The cohesion tests are based on methods to determine the presence of clay. Clay, silt, and sand are size classifications, with clay being the smallest sized particles, silt intermediate and sand the largest. Clay minerals exhibit good cohesion and plasticity (can be molded). Sand exhibits no elasticity and virtually no cohesion unless surface wetting is present. The degree of cohesiveness and plasticity depend on the amounts of all three types and water.
When examining the soil, three questions must be asked: Is the sample granular or cohesive? Fissured or non-fissured? What is the unconfined compressive strength measured in TSF?

**Methods of Testing Soils:**

- **Visual test:** If the excavated soil is in clumps, it is cohesive. If it breaks up easily, not staying in clumps, it is granular.
- **Wet manual test:** Wet your fingers and work the soil between them. Clay is a slick paste when wet, meaning it is cohesive. If the clump falls apart in grains, it is granular.
- **Dry strength test:** Try to crumble the sample in your hands with your fingers. If it crumbles into grains, it is granular. Clay will not crumble into grains, only into smaller chunks.
- **Pocket penetrometer test:** This instrument is most accurate when soil is nearly saturated. This instrument will give unconfined compressive strength in tons per square foot. The spring-operated device uses a piston that is pushed into a coil up to a calibration groove. An indicator sleeve marks and retains the reading until it is read. The reading is calibrated in tons per square foot (**TSF**) or kilograms per cubic centimeter.

Pocket Penetrometer

**Thumb Penetration Test**: The competent person attempts to penetrate a fresh sample with thumb pressure. If the sample can be dented, but penetrated only with great effort, it is Type A. If it can be penetrated several inches and molded by light pressure, it is Type C. Type B can be penetrated with effort and molded.

**Shearvane**: Measures the approximate shear strength of saturated cohesive soils. The blades of the vane are pressed into a flat section of undisturbed soil, and the knob is turned slowly until soil failure. The dial is read directly when using the standard vane. The results will be in tons per square foot or kilograms per cubic centimeter.

The competent person will perform several tests of the excavation to obtain consistent, supporting data along its depth and length. The soil is subject to change several times within the scope of an excavation and the moisture content will vary with weather and job conditions. The competent person must also determine the level of protection based on what conditions exist at the time of the test, and allow for changing conditions.

## Excavation Protection Systems

The three basic protective systems for excavations and trenches are sloping and benching systems, shoring, and shields. The protective systems shall have the capacity to resist without failure all loads that are intended or could reasonably be expected to be applied to or transmitted to the system.

Every employee in an excavation shall be protected from cave-ins by an adequate protective system.

**Exceptions to using protective system:**

- Excavations are made entirely in stable rock
- Excavations are less than 5 feet deep and declared safe by a competent person

**Sloping and Benching Systems**

There are four options for sloping:

- Slope to the angle required by the Standard for Type C, which is the most unstable soil type.
- The table provided in Appendix B of the Standard may be used to determine the maximum allowable angle (after determining the soil type).
- Tabulated data prepared by a registered professional engineer can be utilized.
- A registered professional engineer can design a sloping plan for a specific job.

Sloping and benching systems for excavations five (5) to twenty (20) feet in depth must be constructed under the instruction of a designated competent person.

Sloping and benching systems for excavations greater than twenty (20) feet must be designed and stamped by a registered professional engineer. Sloping and benching specifications can be found in Appendix B of the OSHA Standard (Subpart P).

## Shoring Systems

Shoring is another protective system or support system. Shoring utilizes a framework of vertical members (uprights), horizontal members (whales), and cross braces to support the sides of the excavation to prevent a cave-in. Metal hydraulic, mechanical, or timber shoring are common examples.

**The different examples of shoring are found in the OSHA Standard under these appendices:**

**APPENDIX C -** Timber Shoring for Trenches

**APPENDIX D -** Aluminum Hydraulic Shoring for Trenches

**APPENDIX E -** Alternatives to Timber Shoring

**Shield Systems (Trench Boxes)**

Shielding is the third method of providing a safe workplace. Unlike sloping and shoring, shielding does not prevent a cave-in. Shields are designed to withstand the soil forces caused by a cave-in and protect the employees inside the structure. Most shields consist of two flat, parallel metal walls that are held apart by metal cross braces.

Shielding design and construction is not covered in the OSHA Standards. Shields must be certified in design by a registered professional engineer and must have either a registration plate on the shield or registration papers from the manufacturer on file at the jobsite office.

***ANY REPAIRS OR MODIFICATIONS MUST BE APPROVED BY THE MANUFACTURER.***

**Safety Precautions for Shield Systems**

- Shields must not have any lateral movement when installed.
- Employees will be protected from cave-ins when entering and exiting the shield (examples - ladder within the shield or a properly sloped ramp at the end).
- Employees are not allowed in the shield during installation, removal, or during any vertical movement.
- Shields can be 2 ft. above the bottom of an excavation if they are designed to resist loads at the full depth and if there are no indications of caving under or behind the shield.
- The shield must extend at least 18 inches above the point where proper sloping begins (the height of the shield must be greater than the depth of the excavation).
- The open end of the shield must be protected from the exposed excavation wall. The wall must be sloped, shored, or shielded. Engineer designed end plates can be mounted on the ends of the shield to prevent cave-ins.

**Personal Protective Equipment**

It is **OSHA** policy for you to wear a hard hat, safety glasses, and work boots on the jobsite. Because of the hazards involved with excavations, other personal protective equipment may be necessary, depending on the potential hazards present (examples: goggles, gloves, and respiratory equipment).

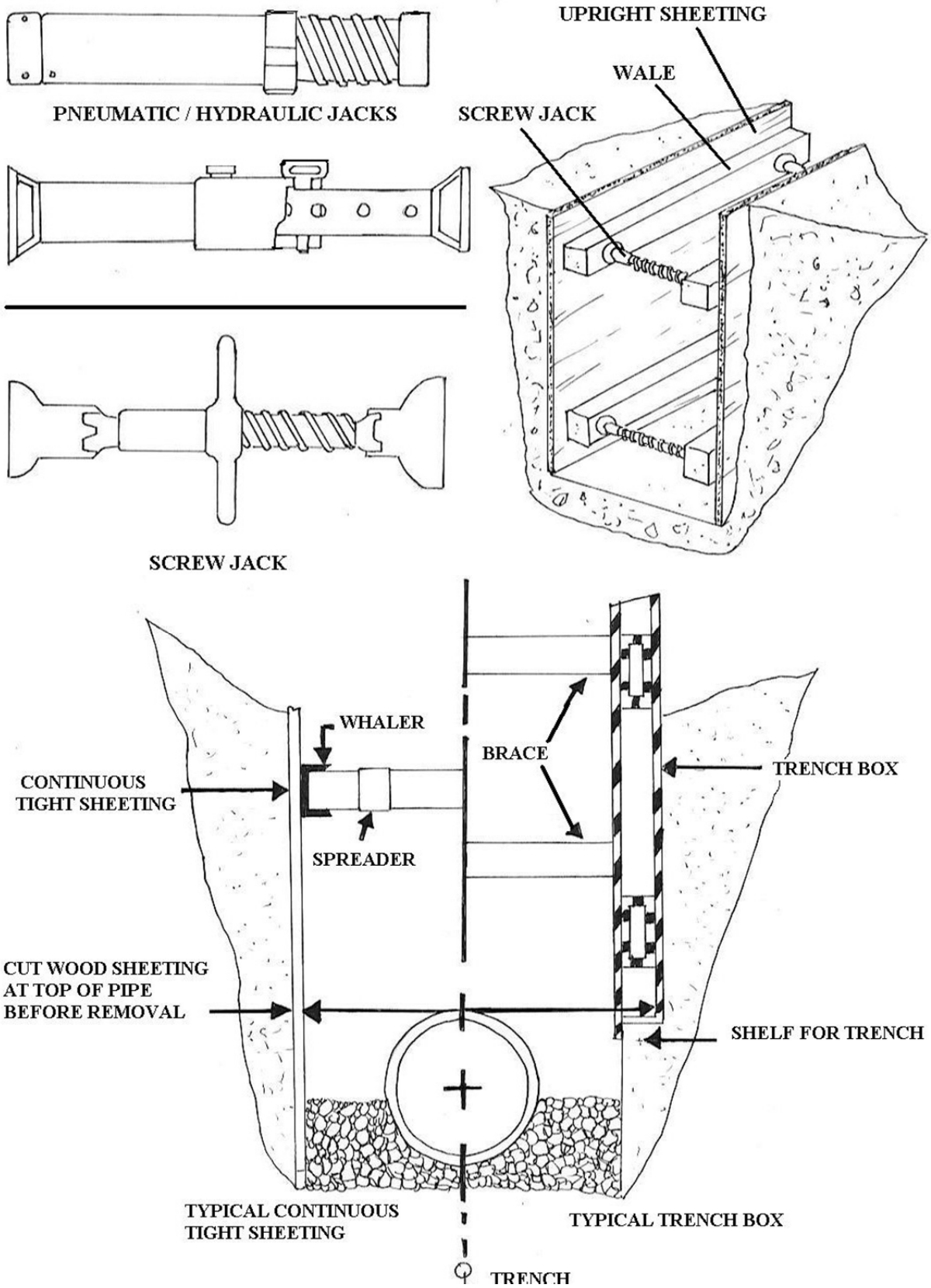
## Inspection

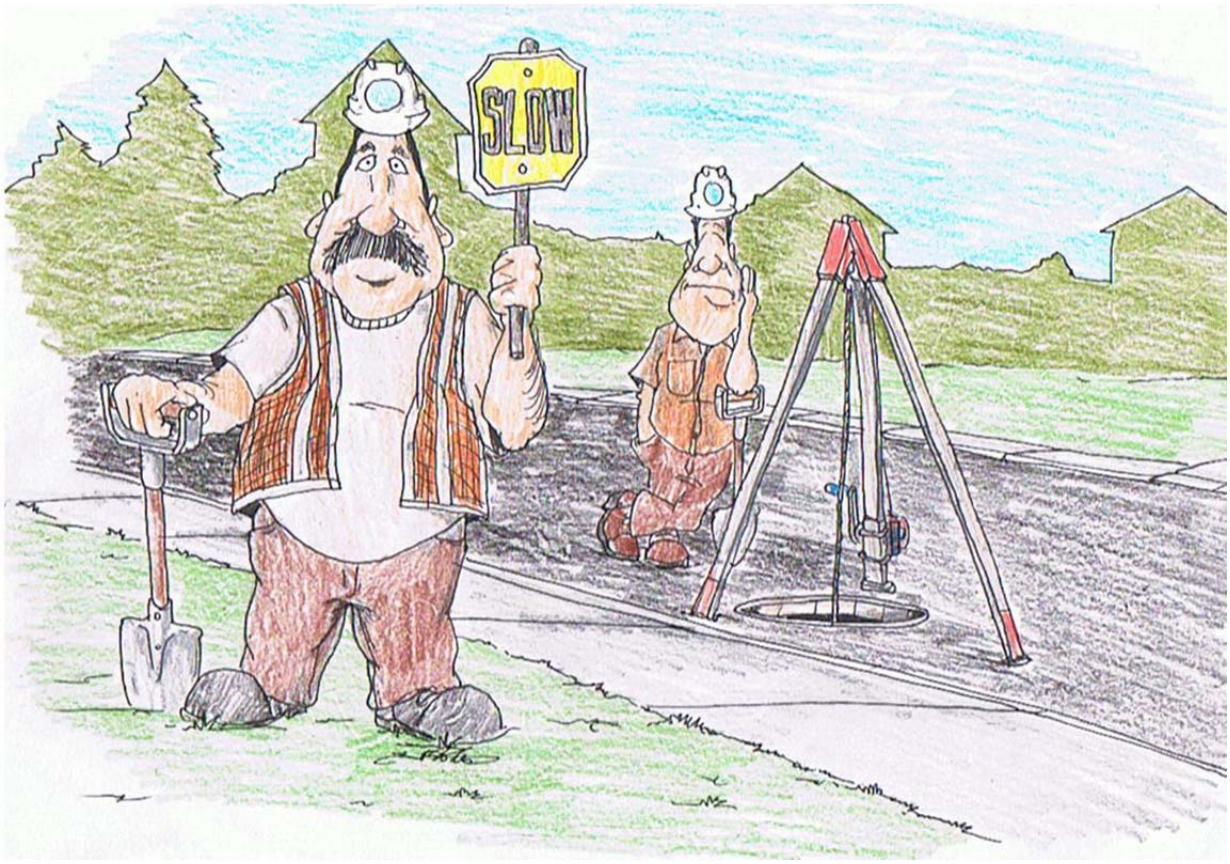
Daily inspection of excavations, the adjacent areas, and protective systems shall be made by the competent person for evidence of a situation that could result in a cave-in, indications of failure of protective systems, hazardous atmospheres or other hazardous conditions.

- All inspections shall be conducted by the competent person prior to the start of work and as needed throughout the shift.
- Inspections will be made after every rainstorm or any other increasing hazard.
- All documented inspections will be kept on file in the jobsite safety files and forwarded to the Safety Director weekly.
- A copy of the Daily Excavation Inspection form is located at the end of this program.

The competent person(s) must be trained in accordance with the OSHA Excavation Standard, and all other programs that may apply (examples Hazard Communication, Confined Space, and Respiratory Protection), and must demonstrate a thorough understanding and knowledge of the programs and the hazards associated.

All other employees working in and around the excavation must be trained in the recognition of hazards associated with trenching and excavating.


PNEUMATIC / HYDRAULIC JACKS
SCREW JACK
SCREW JACK
UPRIGHT SHEETING
WALE
SCREW JACK
WHALER
BRACE
CONTINUOUS
TIGHT SHEETING
SPREADER
TRENCH BOX
CUT WOOD SHEETING
AT TOP OF PIPE
BEFORE REMOVAL
SHELF FOR TRENCH
TYPICAL CONTINUOUS
TIGHT SHEETING
TYPICAL TRENCH BOX
TRENCH




The evaluator should also look for signs of bulging, boiling, or sloughing, as well as for signs of surface water seeping from the sides of the excavation or from the water table. If there is standing water in the cut, the evaluator should check for "quick" conditions. In addition, the area adjacent to the excavation should be checked for signs of foundations or other intrusions into the failure zone, and the evaluator should check for surcharging and the spoil distance from the edge of the excavation.

# One-Call Center, Underground Service Alert or Bluestakes

You are required to locate or call for proper buried utility locations before you dig or excavate. You will usually need a 48-hour notice before you excavate. Please check your local One-Call system.

Red means-Electricity, Yellow-Gas, Blue-Water. It would be very difficult to replace this water service line because of all the buried utilities.

Orange Telephone & Fiber Optics

## One-Call Program

According to federal safety statistics, damage from unauthorized digging is the major cause of natural gas pipeline failures. To prevent excavation damage to all utilities, including pipelines, all 50 states have instituted "**One Call**" Programs. The programs provide telephone numbers for excavation contractors to call before excavation begins.

The One Call operator will notify a pipeline company of any planned excavation in the vicinity of its pipeline so that the company can flag the location of the pipeline and assign personnel to be present during excavation, if necessary.

In a related effort, a joint government-industry team has developed a public education program entitled "**Dig Safely**". The team involves representatives from the U.S. Department of Transportation, gas and liquid pipeline companies, distribution companies, excavators, the insurance industry, one-call systems and the telecommunications industry. This campaign provides information to the general public concerning underground utilities and the danger of unknowingly digging into buried lines and cables.

The program has posters, brochures, and other printed materials available for use by interested organizations. For more information, contact www.digsafely.com.

Buried Telephone Cables. Always hand dig around this stuff. There will be ties that you cannot even use a shooter shovel because of the damage that may be caused.

***Confined Spaces are***

-large enough to allow entry of any body part, and

-limited or restricted entry or exit, and

-not designed for continuous employee occupancy

Permit Required Confined Spaces are confined spaces that have any of the following
-potential hazardous atmosphere
-material inside that may engulf or trap you
-internal design that could trap or asphyxiate you
-***any other serious safety or health hazard***

Entry Permits are required before you enter any "**Permit Required Confined Space**"

**Hazards include**

- Fire & Explosion
- Engulfment
- Asphyxiation
- Entrapment
- Slips & Falls
- Electric Shock
- Noise & Vibration
- Chemical Exposure
- Toxic Atmospheres
- Thermal / Chemical Burns

**Engineering Controls**

- Ventilation
- Locked Access
- Lighting

**Administrative Controls**

- Controlled Access
- Hazard Assessments
- Entry Permits & Procedures
- Signs & Lockout Tagout
- Training

**Smart Safety Rules**

Know what you are getting into.

Know how to get out in an emergency.

Know the hazards & how they are controlled.

Only authorized & trained personnel may enter a Confined Space or act as an attendant.

No smoking in Confined Space or near entrance or exit area.

Attendant must be present at all times.

Constant visual or voice communication must be maintained between the attendant and entrants.

No bottom or side entry will be made, or work conducted, below the level any hanging material or material which could cause engulfment.

Air and oxygen Monitoring is required before entering a Permit-Required Confined Space.

Ventilation & oxygen monitoring is required when welding is performed.

Entering a confined space with proper ventilation.

Service worker cutting abandoned utility conduit out of the way. Always call first and get the utility to show up to verify if you are able to cut an abandoned utility. I personally do not trust anything the other utilities will say or put in writing.

# Confined Space Entry Program

## Purpose

The Confined Space Entry Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

**Reference**: OSHA-Permit-Required Confined Spaces (**29 CFR 1910.146**).

## Scope

You are required to recognize the dangers and hazards associated with confined spaces, and this program is designed to assist you in the safety of and compliance with the OSHA standards associated with such.

Most communities will utilize the Fire Department for all rescues and additional assistance dealing with confined spaces, understanding that most Fire Department operations utilize additional in house SOG's/SOP's pertaining to such operations.

## Definitions

***Confined space:***

Is large enough or so configured that an employee can bodily enter and perform work.

Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).

Is not designed for continuous employee occupancy.

Permit required confined space (permit space), is a confined space that has one or more of the following characteristics:

1. Contains or has a potential to contain a hazardous atmosphere.

2. Contains a material that has the potential for engulfing an entrant.

3. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly covering walls or by a floor which slopes downward and tapers to a smaller cross-section.

4. Contains any other recognized serious safety or health hazard.

**Each Permit-Required Confined Space will be marked**

## "*Confined Space - Entry Permit Required*".

Examples of "*Permit Required Confined Spaces*." Make sure you comply with these Confined Space rules or face civil and/or criminal charges. Several states have criminally charged Supervisors and Attendants for the actions of the employees in a Confined Space/Permit Required Confined Space. *Don't risk death or the chance of going to jail in order to speed up your job!*

## Confined Space Hazards

Fatalities and injuries constantly occur among construction workers who, during the course of their jobs, are required to enter confined spaces. In some circumstances, these workers are exposed to multiple hazards, any of which may cause bodily injury, illness, or death.

Newspaper and magazine articles abound with stories of workers injured and killed from a variety of atmospheric factors and physical agents. Throughout the construction jobsite, contractors and workers encounter both inherent and induced hazards within confined workspaces.

**Inherent Hazards**
Inherent hazards, such as electrical, thermal, chemical, mechanical, etc., are associated with specific types of equipment and the interactions among them.

Examples include high voltage (shock or corona discharge and the resulting burns), radiation generated by equipment, defective design, omission of protective features (no provision for grounding non-current-carrying conductive parts), high or low temperatures, high noise levels, and high-pressure vessels and lines (rupturing with resultant release of fragments, fluids, gases, etc.).

Inherent hazards usually cannot be eliminated without degrading the system or equipment, or without making them inoperative. Therefore, emphasis must be placed on hazard control methods.

**Induced Hazards**
Induced hazards arise, and are induced from, a multitude of incorrect decisions and actions that occur during the actual construction process. Some examples are: omission of protective features, physical arrangements that may cause unintentional worker contact with electrical energy sources, oxygen-deficient atmospheres created at the bottom of pits or shafts, lack of safety factors in structural strength, and flammable atmospheres.

**Typical Examples of Confined Workspaces**
Following are typical examples of confined workspaces in construction which contain both inherent and induced hazards.

**Vaults**
A variety of vaults are found on the construction jobsite. On various occasions, workers must enter these vaults to perform a number of functions.

The restricted nature of vaults and their frequently below-grade location can create an assortment of safety and health problems.

**Oxygen-Deficient Atmosphere**
One of the major problems confronting construction workers while working in vaults is the ever-present possibility of an oxygen-deficient atmosphere.

**Explosive or Toxic Gases, Vapors, or Fumes**
While working in an electrical vault, workers may be exposed to the build-up of explosive gases such as those used for heating (propane). Welding and soldering produce toxic fumes which are confined in the limited atmosphere.

**Electrical Shock**
Electrical shock is often encountered from power tools, line cords, etc. In many instances, such electrical shock results from the fact that the contractor has not provided an approved grounding system or the protection afforded by ground-fault circuit interrupters or low-voltage systems.

**Purging**
In some instances, purging agents such as nitrogen and argon may enter the vault from areas adjacent to it. These agents may displace the oxygen in the vault to the extent that it will asphyxiate workers almost immediately.

**Materials Falling In and On**
A hazard normally considered a problem associated with confined spaces is material or equipment which may fall into the vault or onto workers as they enter and leave the vault.

Vibration could cause the materials on top of the vault to roll off and strike workers. If the manhole covers were removed, or if they were not installed in the first place, materials could fall into the vault, causing injury to the workers inside.

**Condenser Pits**
A common confined space found in the construction of nuclear power plants is the condenser pit. Because of their large size, they are often overlooked as potentially hazardous confined spaces.

These below-grade areas create large containment areas for the accumulation of toxic fumes, gases, and so forth, or for the creation of oxygen-deficient atmospheres when purging with argon, Freon, and other inert gases.

Other hazards will be created by workers above dropping equipment, tools, and materials into the pit.

**Manholes**
Throughout the construction site, manholes are commonplace. As means of entry into and exit from vaults, tanks, pits, and so forth, manholes perform a necessary function. However, these confined spaces may present serious hazards which could cause injuries and fatalities.

A variety of hazards are associated with manholes. To begin with, the manhole could be a dangerous trap into which the worker could fall. Often covers are removed and not replaced, or else they are not provided in the first place.

**Pipe Assemblies**
One of the most frequently unrecognized types of confined spaces encountered throughout the construction site is the pipe assembly. Piping of sixteen to thirty-six inches in diameter is commonly used for a variety of purposes.

For any number of reasons, workers will enter the pipe. Once inside, they are faced with potential oxygen-deficient atmospheres, often caused by purging with argon or another inert gas. Welding fumes generated by the worker in the pipe, or by other workers operating outside the pipe at either end, subject the worker to toxic atmospheres.

The generally restricted dimensions of the pipe provide little room for the workers to move about and gain any degree of comfort while performing their tasks. Once inside the pipe, communication is extremely difficult. In situations where the pipe bends, communication and extrication become even more difficult. Electrical shock is another problem to which the worker is exposed. Ungrounded tools and equipment or inadequate line cords are some of the causes. As well, heat within the pipe run may cause the worker to suffer heat prostration.

**Ventilation Ducts**
Ventilation ducts, like pipe runs, are very common at the construction site. These sheet metal enclosures create a complex network which moves heated and cooled air and exhaust fumes to desired locations in the plant.

Ventilation ducts may require that workers enter them to cut out access holes, install essential parts of the duct, etc. Depending on where these ducts are located, oxygen deficiency could exist. They usually possess many bends, which create difficult entry and exit and which also make it difficult for workers inside the duct to communicate with those outside it. Electrical shock hazards and heat stress are other problems associated with work inside ventilation ducts.

**Tanks**
Tanks are another type of confined workspace commonly found in construction. They are used for a variety of purposes, including the storage of water, chemicals, etc. Tanks require entry for cleaning and repairs. Ventilation is always a problem. Oxygen-deficient atmospheres, along with toxic and explosive atmospheres created by the substances stored in the tanks, present hazards to workers. Heat, another problem in tanks, may cause heat prostration, particularly on a hot day.

Since electrical line cords are often taken into the tank, the hazard of electrical shock is always present. The nature of the tank's structure often dictates that workers must climb ladders to reach high places on the walls of the tank.

**Sumps**
Sumps are commonplace. They are used as collection places for water and other liquids. Workers entering sumps may encounter an oxygen-deficient atmosphere.
Also, because of the wet nature of the sump, electrical shock hazards are present when power tools are used inside. Sumps are often poorly illuminated. Inadequate lighting may create an accident situation.

**Containment Cavities**
These large below-grade areas are characterized by little or no air movement. Ventilation is always a problem. In addition, the possibility of oxygen deficiency exists. As well, welding and other gases may easily collect in these areas, creating toxic atmospheres. As these structures near completion, more confined spaces will exist as rooms are built off the existing structure.

**Electrical Transformers**
Electrical transformers are located on the jobsite. They often contain a nitrogen purge or dry air. Before they are opened, they must be well vented by having air pumped in. Workers, particularly electricians and power plant operators, will enter these transformers through hatches on top for various work-related reasons. Testing for oxygen deficiency and for toxic atmospheres is mandatory.

**Heat Sinks**
These larger pit areas hold cooling water in the event that there is a problem with the pumps located at the water supply to the plant--normally a river or lake--which would prevent cooling water from reaching the reactor core.

When in the pits, workers are exposed to welding fumes and electrical hazards, particularly because water accumulates in the bottom of the sink.

Generally, it is difficult to communicate with workers in the heat sink, because the rebar in the walls of the structure deaden radio signals.

## Unusual Conditions

**Confined Space within a Confined Space**
By the very nature of construction, situations are created which illustrate one of the most hazardous confined spaces of all--a confined space within a confined space.

This situation appears as tanks within pits, pipe assemblies or vessels within pits, etc. In this situation, not only do the potential hazards associated with the outer confined space require testing, monitoring, and control, but those of the inner space also require similar procedures.

Often, only the outer space is evaluated. When workers enter the inner space, they are faced with potentially hazardous conditions. A good example of a confined space within a confined space is a vessel with a nitrogen purge inside a filtering water access pit.

Workers entering the pit and/or the vessel should do so only after both spaces have been evaluated and proper control measures established.

**Hazards in One Space Entering another Space**
During an examination of confined spaces in construction, one often encounters situations which are not always easy to evaluate or control. For instance, a room or area which classifies as a confined space may be relatively safe for work.

However, access passages from other areas outside or adjacent to the room could, at some point, allow the transfer of hazardous agents into the "***safe***" one. One such instance would be a pipe coming through a wall into a containment room.

Welding fumes and other toxic materials generated in one room may easily travel through the pipe into another area, causing it to change from a safe to an unsafe workplace. A serious problem with a situation such as this is that workers working in the "**safe**" area are not aware of the hazards leaking into their area. Thus, they are not prepared to take action to avoid or control it.

**Session Conclusion**
In this discussion, we have defined inherent and induced hazards in confined spaces. We have examined typical confined spaces on construction sites and we have described representative hazards within these confined spaces.

Death trap, no way out. No shoring.

# Permitted Confined Space Entry Program

**Definition of Confined Spaces Requiring an Entry Permit**
***Confined space:***

- ✓ Is large enough or so configured that an employee can bodily enter and perform work.
- ✓ Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- ✓ Is not designed for continuous employee occupancy.

**Purpose**
The Permit Required Space (**PRCS**) Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

Many workplaces contain confined spaces not designed for human occupancy which due to their configuration hinder employee activities including entry, work and exit. Asphyxiation is the leading cause of death in confined spaces.

**Subpart P applies to all open excavations in the earth's surface.**

- ✓ All trenches are excavations.
- ✓ All excavations are not trenches.

**Permit Required Confined Space Entry General Rules**

***During all confined space entries, the following safety rules must be strictly enforced:***

1. Only authorized and trained employees may enter a confined space or act as safety watchmen/attendants.

2. No smoking is permitted in a confined space or near entrance/exit area.

3. During confined space entries, a watchmen or attendant must be present at all times.

4. Constant visual or voice communication will be maintained between the safety watchmen and employees entering a confined space.

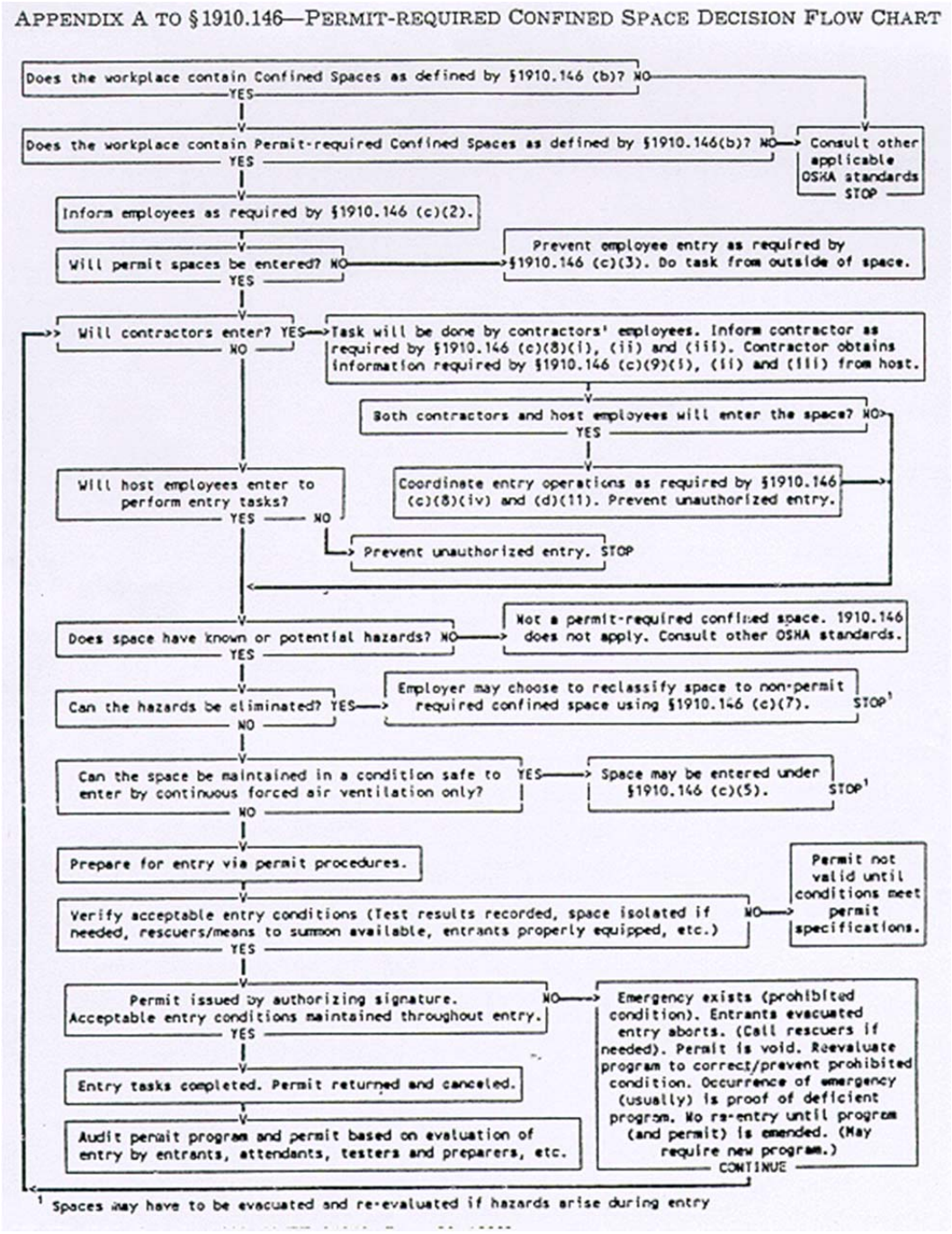
5. No bottom or side entry will be made or work conducted below the level any hanging material or material which could cause engulfment.

6. Air and oxygen monitoring is required before entering any permit-required confined space. Oxygen levels in a confined space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator. Additional ventilation and oxygen level monitoring is required when welding is performed. The monitoring will check oxygen levels, explosive gas levels and carbon monoxide levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (**LEL**).

7. To prevent injuries to others, all openings to confined spaces will be protected by a barricade when covers are removed.

## Appendix A to §1910.146
### Permit-Required Confined Space Decision Flow Chart

Note: Appendices A through F serve to provide information and non-mandatory guidelines to assist employers and employees in complying with the appropriate requirements of this section.




[58 FR 4549, Jan. 14, 1993; 58 FR 34846, June 29, 1993; 63 FR 66039, Dec. 1, 1998]

Here is a small clip-on style multi-purpose gas meter. We tied a string to lower the meter in the confined space to get a gas reading before entering.

## Confined Space Entry Permit *Example*

| | | | |
|---|---|---|---|
| Date & Time Issued | | Date & time Expires | |
| Space I.D. | | Supervisor | |
| Equipment Affected | | Task | |
| Standby Team | | | |
| Pre-Entry Atmospheric Checks | Time (am - pm) | | |
| | Oxygen | | |
| | Explosive ( % LEL) | | |
| | Toxic (PPM) | | |
| | Testers Signature | | |

| Pre-entry Fluid System Isolation | Yes | No |
|---|---|---|
| Pumps /lines blinded, blocked, disconnected | | |
| Ventilation Source Established | | |
| Mechanical Forced Air | | |
| Natural Ventilation | | |
| Post Ventilation Pre-Entry Atmospheric Checks | | |
| Time | | |
| Oxygen (%) | | |
| Explosive ( % LEL | | |
| Toxic (PPM) | | |
| Tester Signature | | |
| Communication Procedures Established per specific Confined Space SOP | | |
| Rescue Procedures established per specific Confined Space SOP | | |

| Training Verification - for the following persons & space to be entered | | | | | YES | NO | |
|---|---|---|---|---|---|---|---|
| All persons entering Confined Space | | | | | | | |
| All persons acting as Supervisor for the Entry | | | | | | | |
| All persons assigned backup positions | | | | | | | |
| All persons assigned to monitor access and interior activities | | | | | | | |
| All persons assigned to emergency rescue team | | | | | | | |
| Equipment on Scene | YES | NO | NA | | YES | NO | NA |
| Gas Monitor | | | | Life Line | | | |
| Safety Harness | | | | Hoisting Equipment | | | |
| Fall Arrest Gear | | | | Powered Comm. Eq. | | | |
| SCBAs | | | | Air Line Respirators | | | |
| Protective Clothing | | | | Elect Gear Properly Rated | | | |

| Periodic Atmospheric Checks | | | | |
|---|---|---|---|---|
| Time (am - pm) | | | | |
| Oxygen | | | | |
| Explosive ( % LEL) | | | | |
| Toxic (PPM) | | | | |
| Testers Signature | | | | |

A review of the work authorized by this permit and the information contained on this Entry Permit. Written instructions and safety procedures have been received and are understood. Entry cannot be approved if any squares are marked in the "**No**" column. This permit is not valid unless all appropriate items are completed.

Permit Prepared By: (Supervisor) _____

Approved By: (Unit Supervisor) _____

**This permit to be kept at job site.**

Return job site copy to Safety Office following job completion.

Copies: Safety Office, Unit Supervisor, Job site

# Confined Space Duties & Responsibilities

**Examples of assignments**

**Employees**

- Follow program requirements.
- Report any previously un-identified hazards associated with confined spaces.
- Do not enter any confined spaces that have not been evaluated for safety concerns.

**Management**

- Provide annual Confined Space training to all employees that may need confined space training.
- Ensure confined space assessments have been conducted.
- Annually review this program and all Entry Permits.

**Rescue or Training Department**

- Ensure proper training for entry & rescue teams.
- Provide proper equipment for entry & rescue teams.
- Ensure all permit required confined spaces are posted.
- Evaluate rescue teams and service to ensure they are adequately trained and prepared.
- Ensure rescue team at access during entry into spaces with Immediately Dangerous to Life or Health (IDLH) atmospheres.
- Provide annual confined space awareness training to all employees that may need confined space awareness training.

**Entry Supervisor**
Entry supervisors are responsible for the overall permit space entry and must coordinate all entry procedures, tests, permits, equipment and other relevant activities.

***The following entry supervisor duties are required***:
Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure.

Verify by checking that the appropriate entries have been made on the permit, all tests specified by the permit have been conducted, and that all procedures and equipment specified by the permit are in place before endorsing the permit and allowing entry to begin.

Terminate the entry and cancel the permit when the entry is complete or there is a need for terminating the permit.

Verify that rescue services are available and that the means for summoning them are operable.

Remove unauthorized persons who enter or attempt to enter the space during entry operations.

Determine whenever responsibility for a permit space entry operation is transferred and at intervals dictated by the hazards and operations performed within the space that entry operations remain consistent with the permit terms and that acceptable entry conditions are maintained.

**Entry Attendants**

At least one attendant is required outside the permit space into which entry is authorized for the duration of the entry operation. Responsibilities include:

- To know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure
- To be aware of possible behavioral effects of hazard exposure on entrants
- To continuously maintain an accurate count of entrants in the permit space and ensures a means to accurately identify authorized entrants
- To remain outside the permit space during entry operations until relieved by another attendant (once properly relieved, they may participate in other permit space activities, including rescue if they are properly trained and equipped).
- To communicate with entrants as necessary to monitor entrant status and alert entrants of the need to evacuate.
- To monitor activities inside and outside the space to determine if it is safe for entrants to remain in the space; orders the entrants to immediately evacuate if: the attendant detects a prohibited condition, detects entrant behavioral effects of hazard exposure, detects a situation outside the space that could endanger the entrants; or if the attendant cannot effectively and safely perform all the attendant duties.
- To summon rescue and other emergency services as soon as the attendant determines the entrants need assistance to escape the permit space hazards.
- To perform non-entry rescues as specified by that rescue procedure and entry supervisor and not to perform duties that might interfere with the attendants' primary duty to monitor and protect the entrants.

## Entering a Confined Space

This space requires an emergency retrieval system, continuous air monitoring, and safety watch or two-way communication for safe entry.

Donning the personal protective equipment (**PPE**) necessary for confined space entry.

The full-body harness provides fully adjustable leg and shoulder straps for worker comfort and proper fit.

Stamped steel sliding back D-ring and sub-pelvic strap provide optimum force distribution.

Example of a "***D-Ring***" and fall protection harness used when entering a confined space. The D-Ring provides a compatible anchor point for connecting devices such as lanyards or retractable lifelines. The shock absorbing lanyard provides a deceleration distance during a fall to reduce fall arrest forces for extra protection against injury.

Tripod-retrieval assembly in use for an entry into one of the many confined spaces.

Checking the cable tension and inertial locking mechanism of the retrieval assembly.

Correct use of this device prevents free-falls greater than 2 feet.

The entrant descends into the space as the attendant critiques the operation.

Dramatic rescue simulation using the tripod-retrieval system.

The entrant is now safely out of the space and is ready to return to his many other projects after this simulated exercise.

## Duties of the Person Authorizing or in Charge of the Entry

***The person who authorizes or is in charge of the permit entry confined space must comply with the following:***

**1.** Make certain that all pre-entry requirements as outlined on the permit have been completed before any worker is allowed to enter the confined space.
**2.** Make certain that any required pre-entry conditions are present.
**3.** If an in-plant/facility rescue team is to be used in the event of an emergency, make sure they would be available. If your Employer does not maintain an in-plant rescue team, dial 911 on any telephone for the Rescue Squad.
**4.** Make sure that any communication equipment which would be used to summon either the in-plant rescue team or other emergency assistance is operating correctly.
**5.** Terminate the entry upon becoming aware of a condition or set of conditions whose hazard potential exceeds the limits authorized by the entry permit.

If the person who would otherwise issue an entry permit is in charge of the entry and present during the entire entry, then a written permit is not required if that person uses a checklist as provided in the section on "***Permits***".

This person may also serve as the attendant at the site.

**Special Considerations During A Permit Required Entry**

Certain work being performed in a permit entry confined space could cause the atmosphere in the space to change. Examples of this are welding, drilling, or sludge removal. In these situations, air monitoring of the confined space should be conducted on a continuous basis throughout the time of the entry.

If the workers leave the confined space for any significant period of time, such as for a lunch or other break, the atmosphere of the confined space must be retested before the workers reenter the confined space.

## Unauthorized Persons

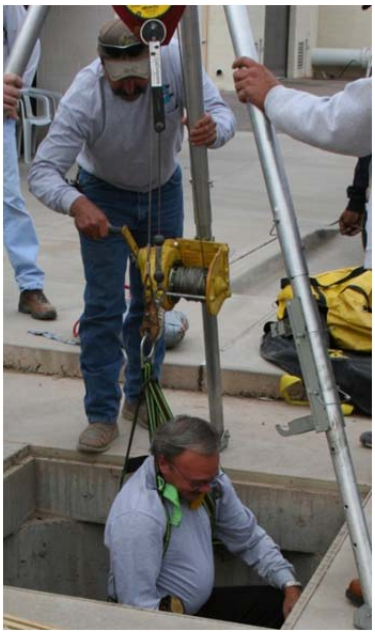
**Take the following actions when unauthorized persons approach or enter a permit space while entry is under way:**

1. Warn the unauthorized persons that they must stay away from the permit space,

2. Advise unauthorized persons that they must exit immediately if they have entered the space, and

3. Inform the authorized entrants and the entry supervisor if unauthorized persons have entered the permit space.

## Entrants



All entrants must be authorized by the entry supervisor to enter permit spaces, have received the required training, have used the proper equipment, and observed the entry procedures and permit requirements.

The following entrant duties are required:
Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure;

Properly use the equipment required for safe entry;
Communicate with the attendant as necessary to enable the attendant to monitor the status of the entrants and to enable the attendant to alert the entrants of the need to evacuate the space if necessary;

Alert the attendant whenever; the entrant recognizes any warning signs or symptoms of exposure to a dangerous situation, or any prohibited condition is detected; and Exit the permit space as quickly as possible whenever the attendant or entry supervisor gives an order to evacuate the permit space, the entrant recognizes any warning signs or symptoms of exposure to a dangerous situation, the entrant detects a prohibited condition, or an evacuation alarm is activated.

## Hazards

- ✓ **Explosive / Flammable Atmospheres**
- ✓ **Toxic Atmospheres**
- ✓ **Engulfment**
- ✓ **Asphyxiation**
- ✓ **Entrapment**
- ✓ **Slips & falls**
- ✓ **Chemical Exposure**
- ✓ **Electric Shock**
- ✓ **Thermal / Chemical Burns**
- ✓ **Noise & Vibration**

## Hazard Control

**Engineering Controls**

- ➢ Locked entry points
- ➢ Temporary ventilation
- ➢ Temporary Lighting

**Administrative Controls**

- ➢ Signs
- ➢ Employee training
- ➢ Entry procedures
- ➢ Atmospheric Monitoring
- ➢ Rescue procedures
- ➢ Use of prescribed Personal Protective Equipment

**Entry Standard Operating Procedures**

This program outlines:

- ➢ Hazards
- ➢ Hazard Control & Abatement
- ➢ Acceptable Entry Conditions
- ➢ Means of Entry
- ➢ Entry Equipment Required
- ➢ Emergency Procedures

## Permit Required Confined Space Entry General Rules

**During all confined space entries, the following safety rules must be strictly enforced:**

1. Only authorized and trained employees may enter a confined space or act as safety watchman/attendant.

2. No smoking is permitted in a confined space or near entrance/exit area.

3. During confined space entries, a watchman must be present at all times.

4. Constant visual or voice communication will be maintained between the safety watchman/attendant and employees entering a confined space.

5. No bottom or side entry will be made or work conducted below the level of any hanging material or material which could cause engulfment.

6. Air and oxygen monitoring is required before entering any permit-required confined space. Oxygen levels in a confined space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator. Additional ventilation and oxygen level monitoring is required when welding is performed.

The monitoring will check oxygen levels, explosive gas levels and carbon monoxide levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (**LEL**), or 10% of a specific gas explosive limit.

7. To prevent injuries to others, all openings to confined spaces will be protected by a barricade when covers are removed.

**Confined Space Entry Procedures**

***Each employee who enters or is involved in the entry must:***

1. Understand the procedures for confined space entry

2. Know the Hazards of the specific space

3. Review the specific procedures for each entry

4. Understand how to use entry and rescue equipment

**Confined Space Entry Permits**

Confined Space Entry Permits must be completed before any employee enters a permit-required confined space. The permit must be completed and signed by an authorized member of management before entry.

Permits will expire before the completion of the shift or if any pre-entry conditions change.

Permits will be maintained on file for 12 months.

## Contractor Entry

All work by non-company employees that involves the entry into confined spaces will follow the procedures of this program. The information of this program and specific hazards of the confined spaces to be entered will be provided to contractor management prior to commencing entry or work.

### Important Rescue Service Questions

What is the availability of the rescue service?

Is it unavailable at certain times of the day or in certain situations?

What is the likelihood that key personnel of the rescue service might be unavailable at times?

If the rescue service becomes unavailable while an entry is underway, does it have the capability of notifying the employer so that the employer can instruct the attendant to abort the entry immediately?

# Confined Space Training

## *Training for Confined Space Entry includes*:

1. Duties of entry supervisor, entrant and attendants
2. Confined space entry permits
3. Hazards of confined spaces
4. Use of air monitoring equipment
5. First aid and CPR training
6. Emergency action & rescue procedures
7. Confined space entry & rescue equipment
8. Rescue training, including entry and removal from representative spaces

**Confined Space Training and Education**
OSHA's General Industry Regulation, §1910.146 Permit-required confined spaces, contains requirements for practices and procedures to protect employees in general industry from the hazards of entry into permit-required confined spaces. This regulation does not apply to construction.

OSHA's Construction Safety and Health Regulations Part 1926 do not contain a permit-required confined space regulation. Subpart C, §1926.21 Safety training and education specifies training for personnel who are required to enter confined spaces and defines a "***confined or enclosed space***." These requirements are shown below.

**§1926.21 Safety training and education. (Partial)**
(b)(6)(i) All employees required to enter into confined or enclosed spaces shall be instructed as to the nature of the hazards involved, the necessary precautions to be taken, and in the use of protective and emergency equipment required. The employer shall comply with any specific regulations that apply to work in dangerous or potentially dangerous areas.

(ii) For purposes of paragraph (b)(6)(i) of this section, "***confined or enclosed space***" means any space having a limited means of egress, which is subject to the accumulation of toxic or flammable contaminants or has an oxygen deficient atmosphere. Confined or enclosed spaces include, but are not limited to, storage tanks, process vessels, bins, boilers, ventilation or exhaust ducts, sewers, underground utility vaults, tunnels pipelines, and open top spaces more than 4 feet in depth such as pits, tubs, vaults, and vessels.

OSHA's Construction Regulations also contain requirements dealing with confined space hazards in underground construction (Subpart S), underground electric transmission and distribution work (§1926.956), excavations (Subpart P), and welding and cutting (Subpart J).

Further guidance may be obtained from American National Standard ANSI Z117.1-1989, Safety Requirements for Confined Spaces. This standard provides minimum safety requirements to be followed while entering, exiting and working in confined spaces at normal atmospheric pressure. This standard does not pertain to underground mining, tunneling, caisson work or other similar tasks that have established national consensus standards.

# 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.

An evolving or giving off of gas, heat, etc. **evolutional**, adjective ev·o·lu·tion·al·ly, adverb Synonyms 1. unfolding, change, progression, metamorphosis. Antonyms 1. stasis, inactivity, changelessness.

**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.:** Material Safety Data Sheet. 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.

**PLUNGER:** See Surge-block.

**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.

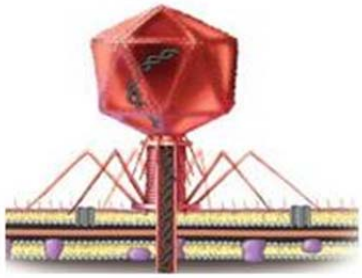
A cross completely blown out. A major job. Good thing it wasn't under the blacktop.

## Microorganism Appendix

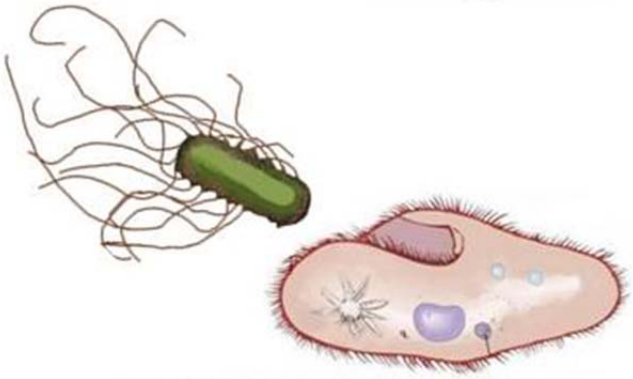
COCCI
(SPHERICAL)

SPIRILLI
(SPIRAL)

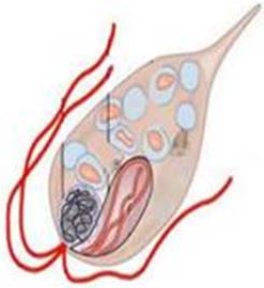
BACILLI
(ROD-SHAPED)



VIRUSES



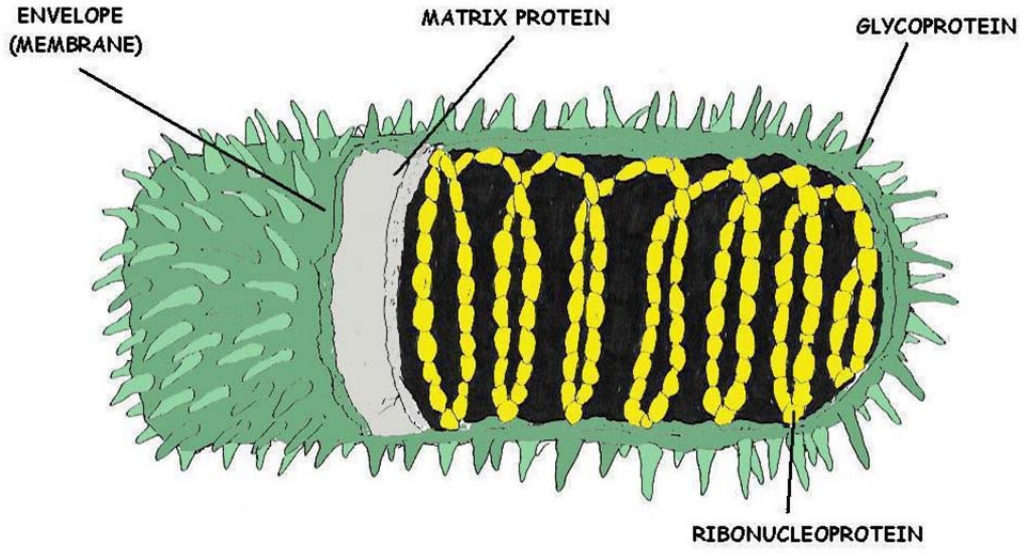
BACTERIA



PROTOZOA

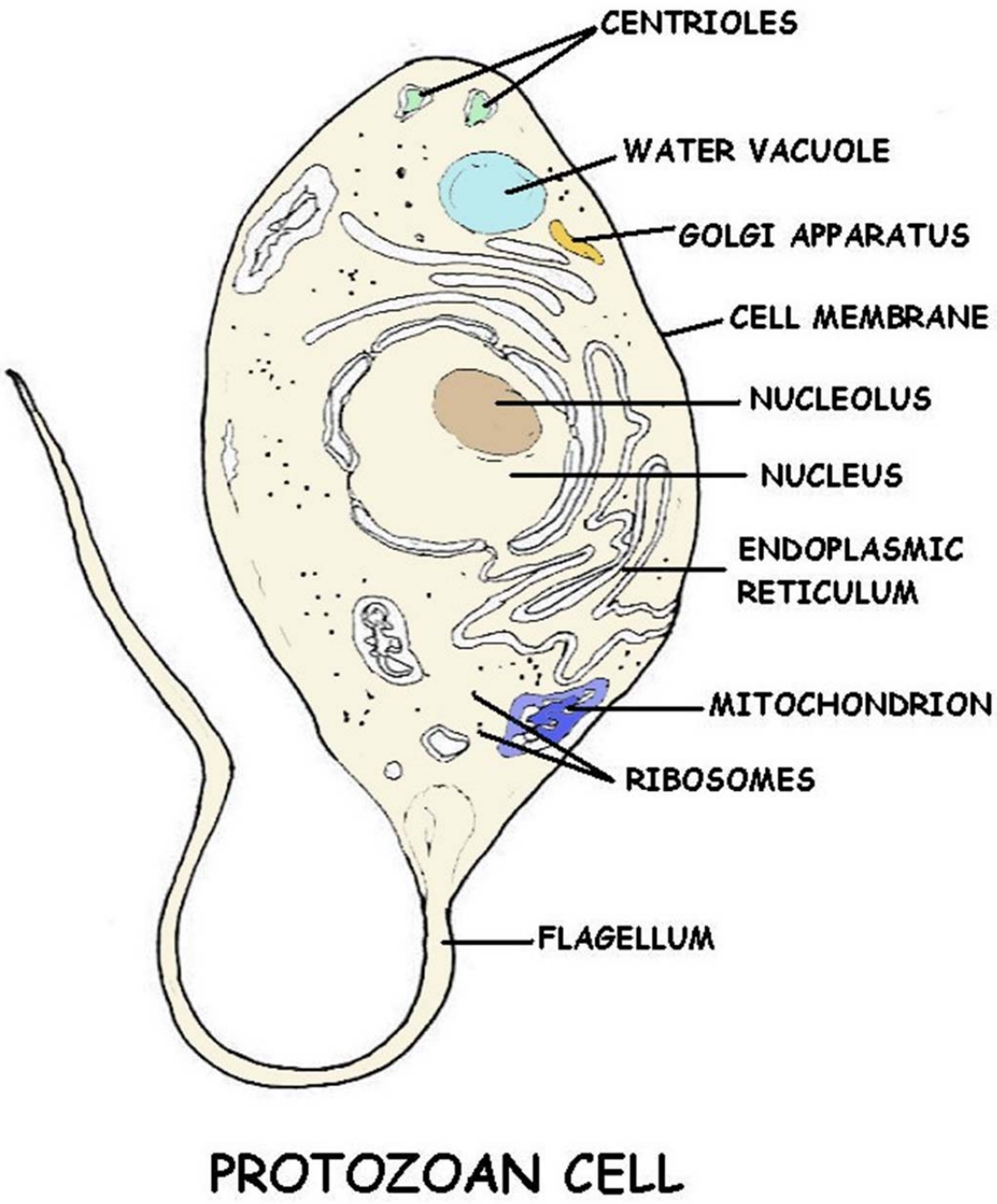
# BACTERIA TYPES

**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).

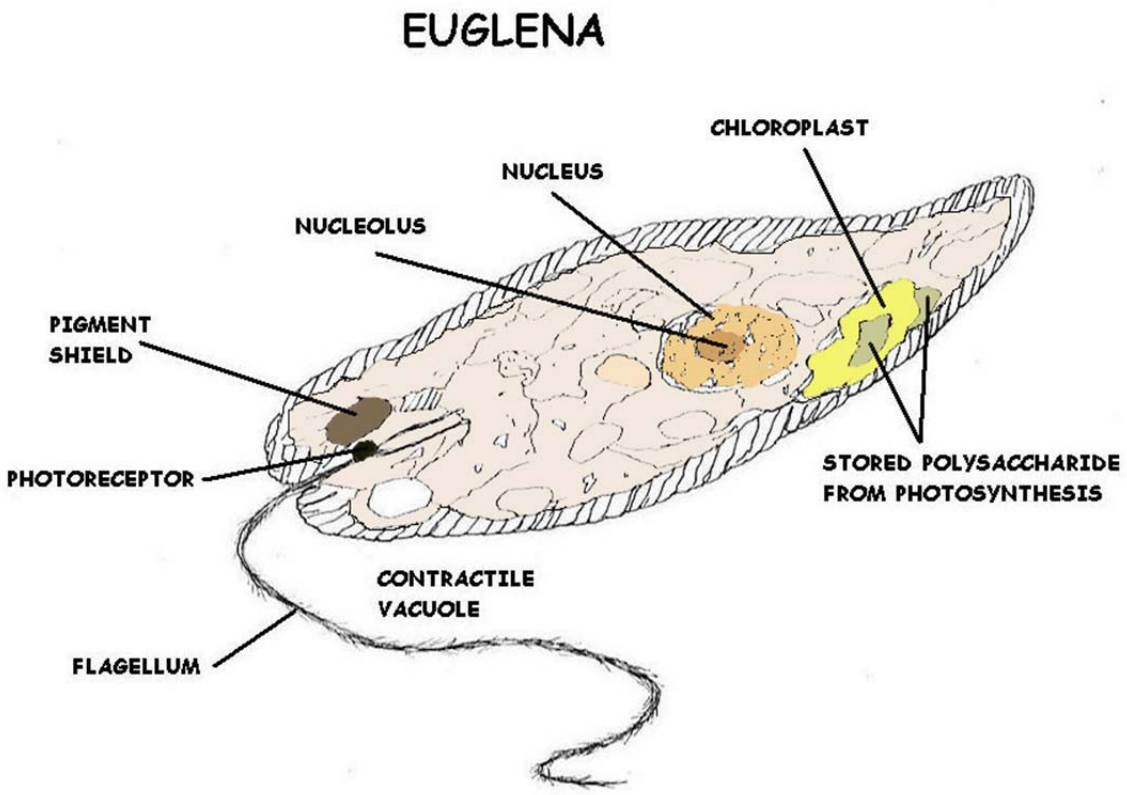
**Sub-groups**
Protozoa have traditionally been divided on the basis of their means of locomotion, although this is no longer believed to represent genuine relationships:
* Flagellates (e.g. Giardia lambia)
* Amoeboids (e.g. Entamoeba histolytica)
* Sporozoans (e.g. Plasmodium knowlesi)
* Apicomplexa
* 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



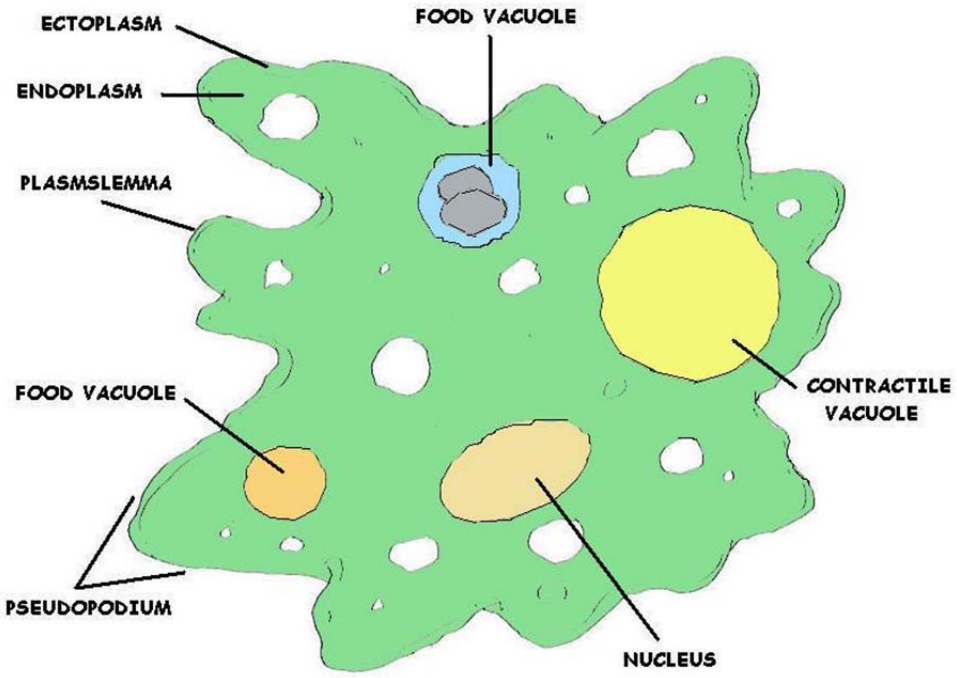

The diverse assemblage of organisms that carry out all of their life functions within the confines of a single, complex eukaryotic cell are called protozoa.

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).

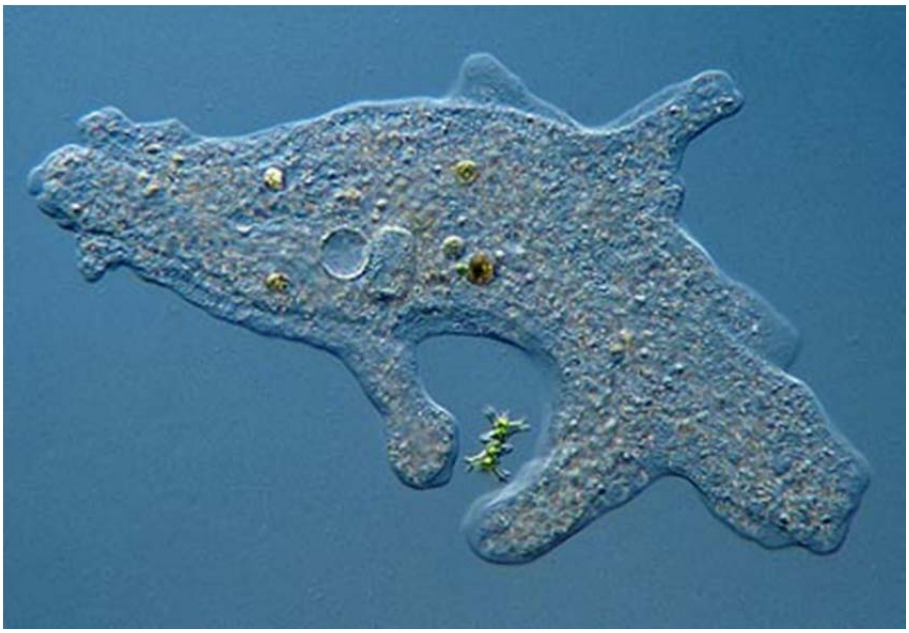
**Free-living Protozoa**

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 chapters.

**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.

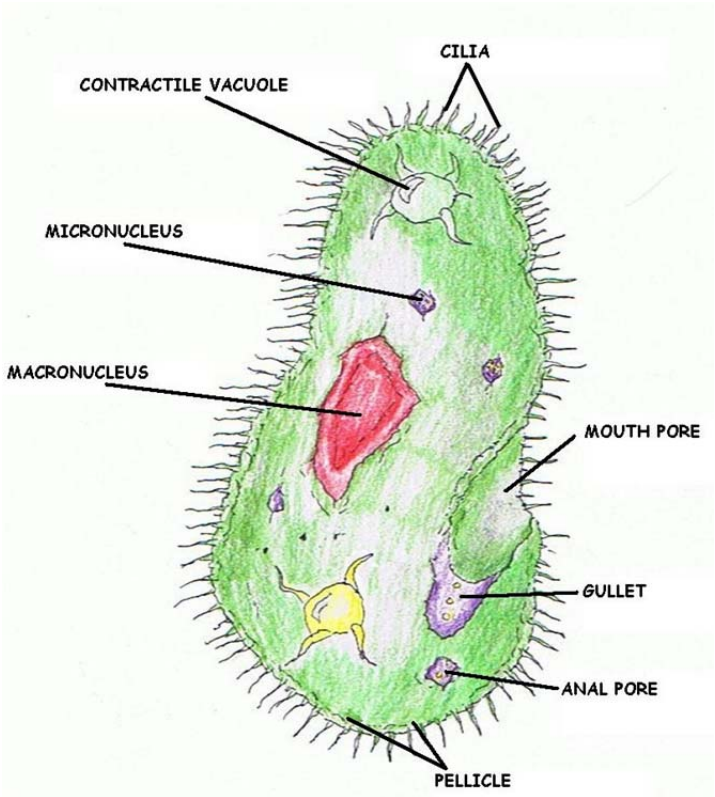
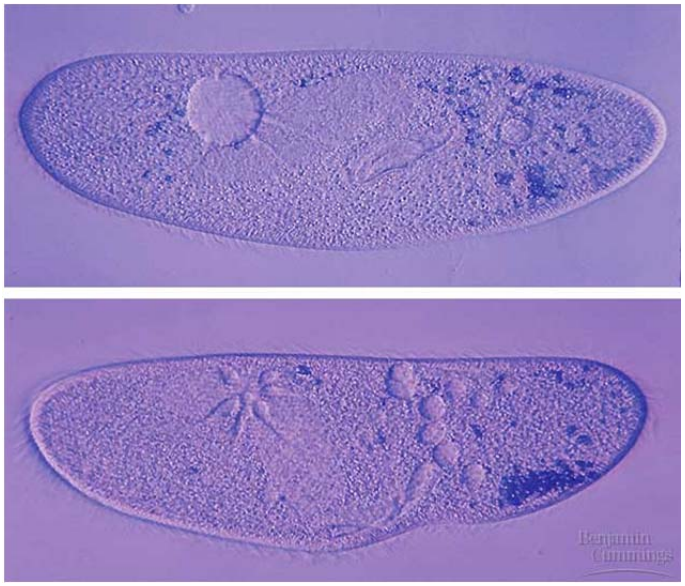



**Figure 1**. A diagram of *Paramecium* sp. with major organelles indicated.



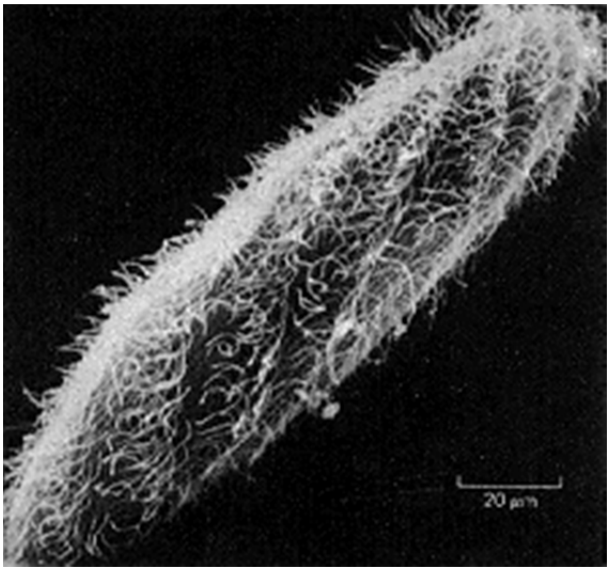
**Contractile Vacuoles**

**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).



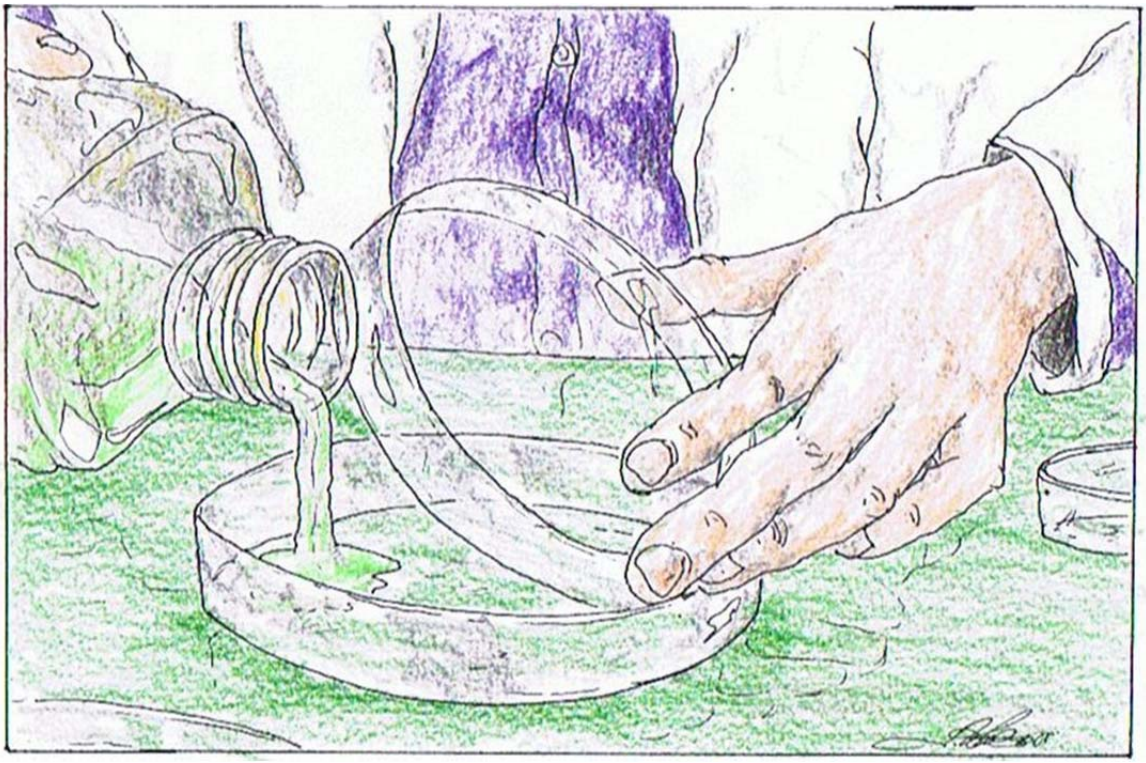
## Protozoan Diseases

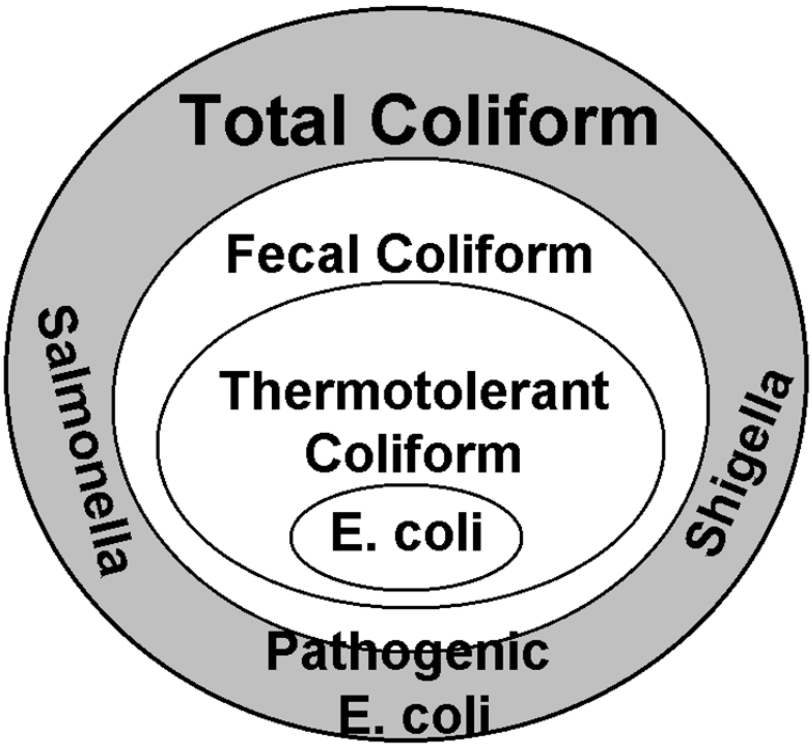
Protozoan pathogens are larger than bacteria and viruses, but still microscopic. They invade and inhabit the gastrointestinal tract. Some parasites enter the environment in a dormant form, with a protective cell wall called a "***cyst***." The cyst can survive in the environment for long periods of time 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.

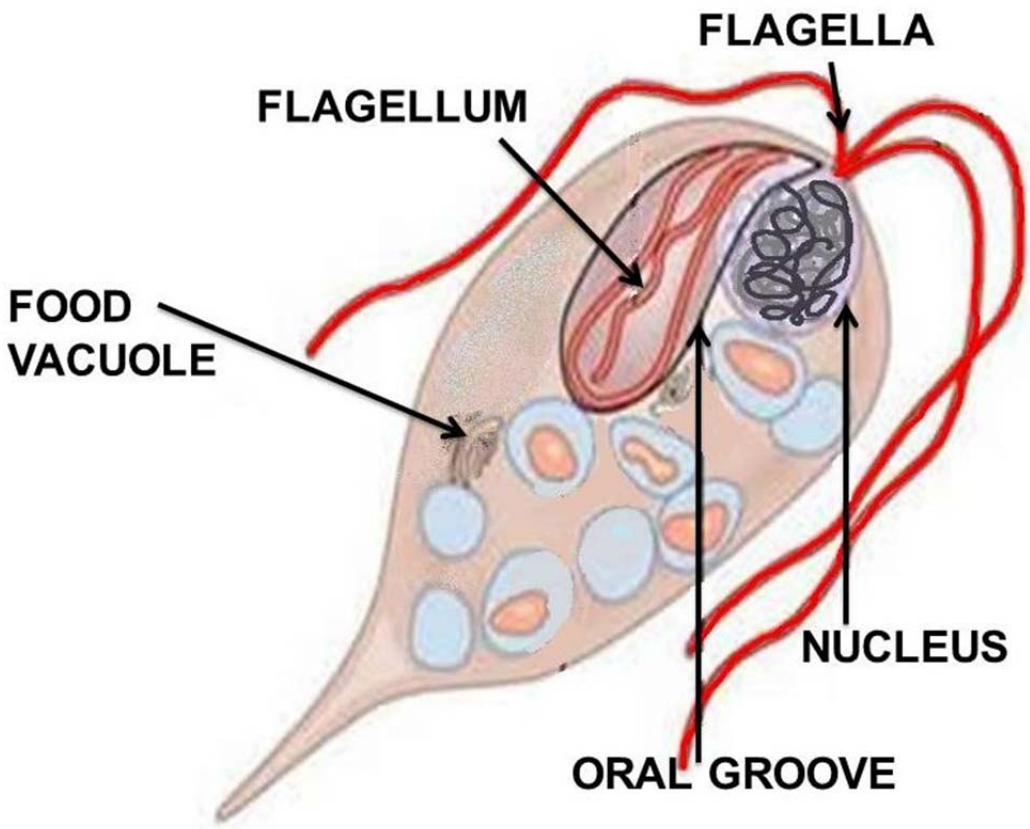
**Cryptosporidiosis**
Cryptosporidiosis is an example of a protozoan disease that is common worldwide, but was only recently recognized as causing human disease. The major symptom in humans is diarrhea, which may be profuse and watery. The diarrhea is associated with cramping abdominal pain. General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



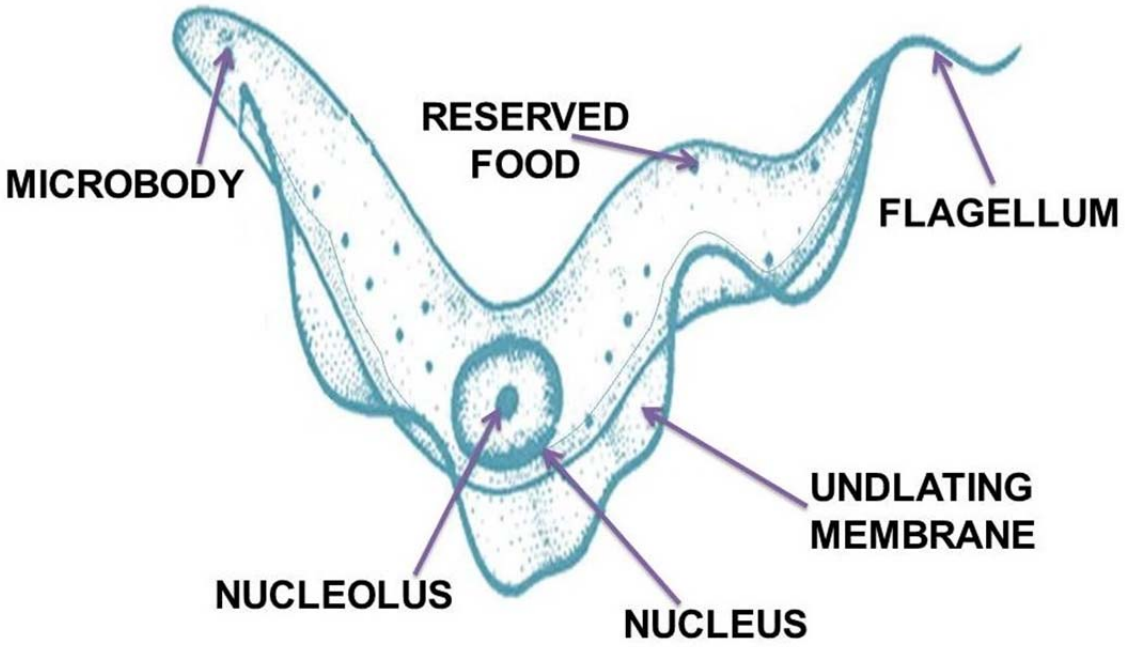

Giardia lamblia (synonymous with Lamblia intestinalis and Giardia duodenalis) is a flagellated protozoan parasite that colonizes and reproduces in the small intestine, causing giardiasis. The giardia parasite attaches to the epithelium by a ventral adhesive disc, and reproduces via binary fission. Giardiasis 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.

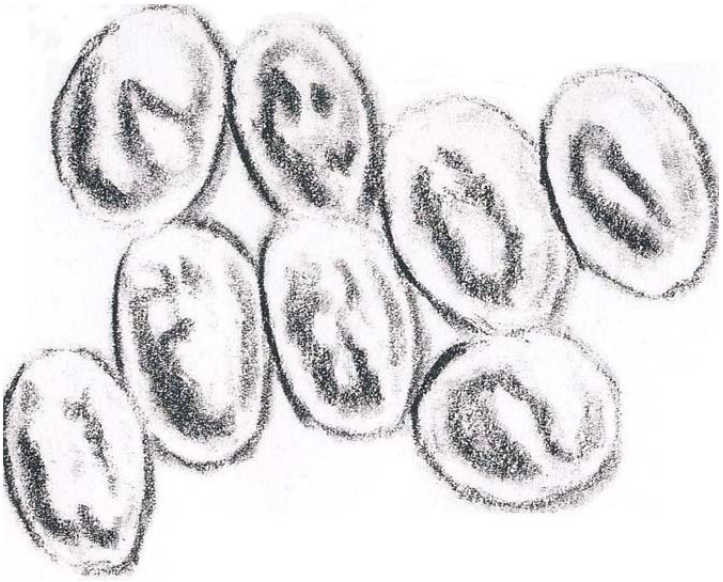
The life cycle begins with a non-infective cyst being excreted with feces of an infected individual. Once out in the environment, the cyst becomes infective. A distinguishing characteristic of the cyst is 4 nuclei and a retracted cytoplasm. Once ingested by a host, the trophozoite emerges to an active 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

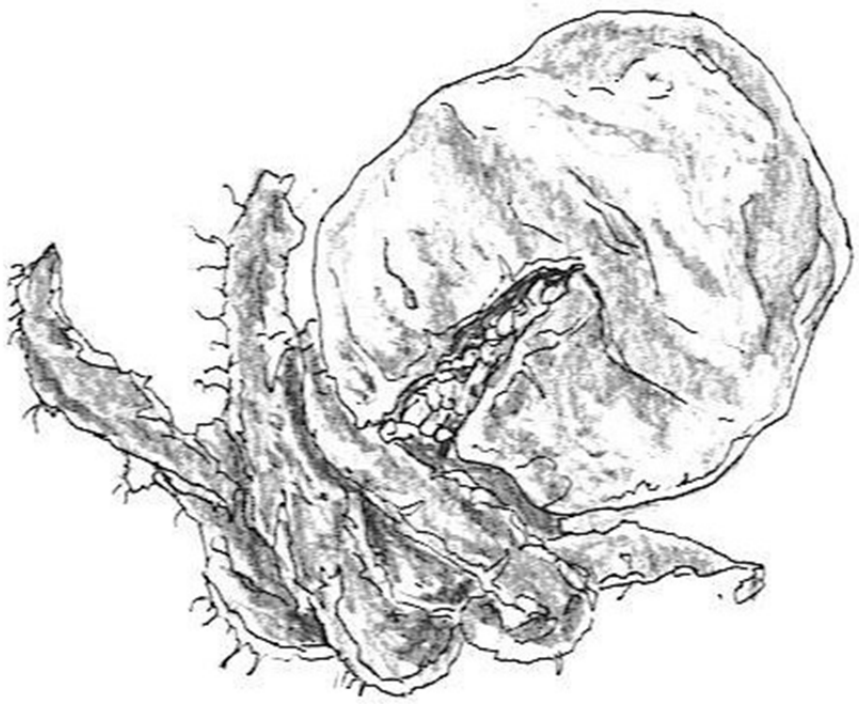


Cryptosporidium is a protozoan pathogen of the Phylum Apicomplexa and causes a diarrheal illness called cryptosporidiosis. Other apicomplexan pathogens include the malaria parasite Plasmodium, and Toxoplasma, the causative agent of toxoplasmosis. Unlike Plasmodium, which transmits via a mosquito vector, 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.



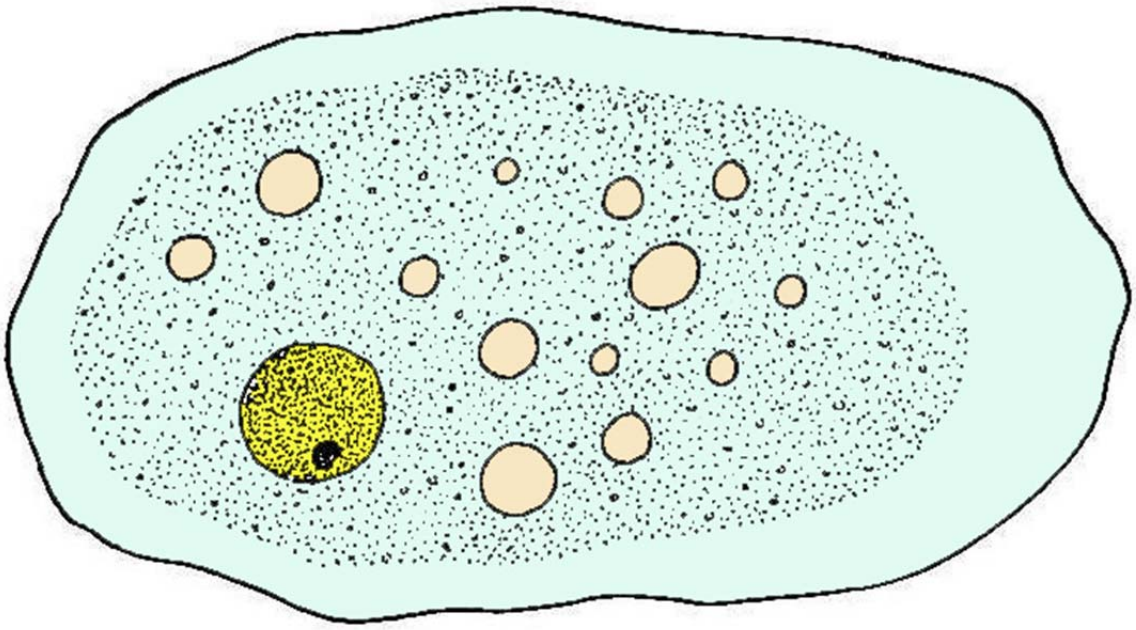
# CRYPTO-PARVUM

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).

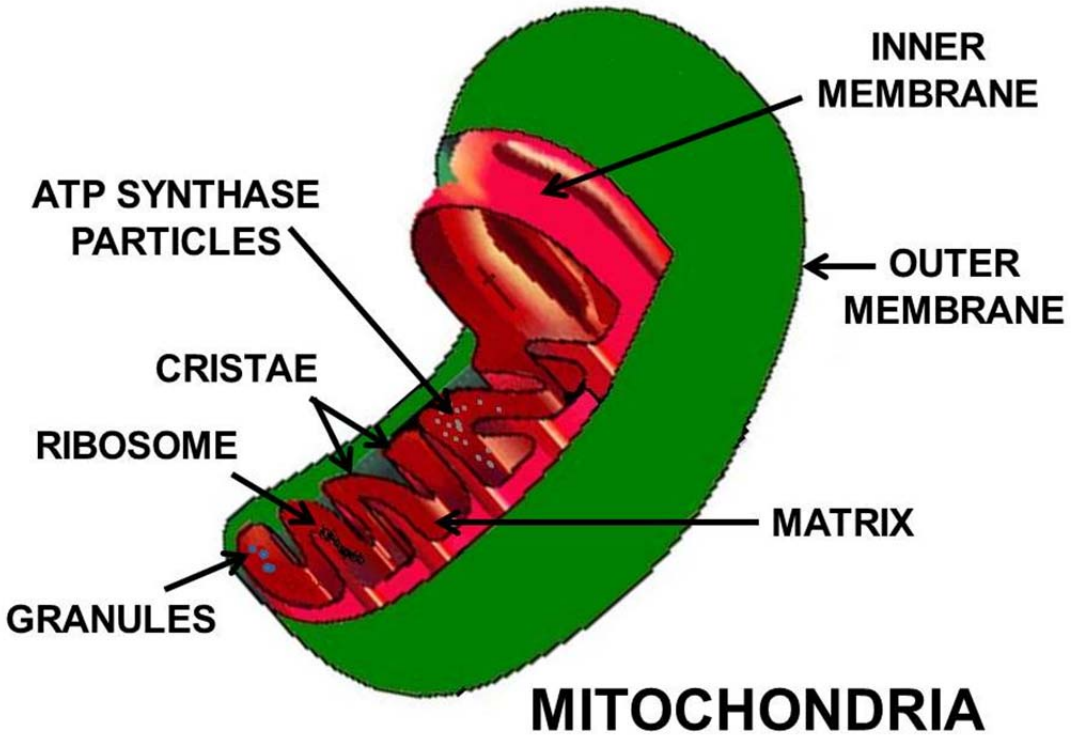
## Entamoeba histolytica



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.

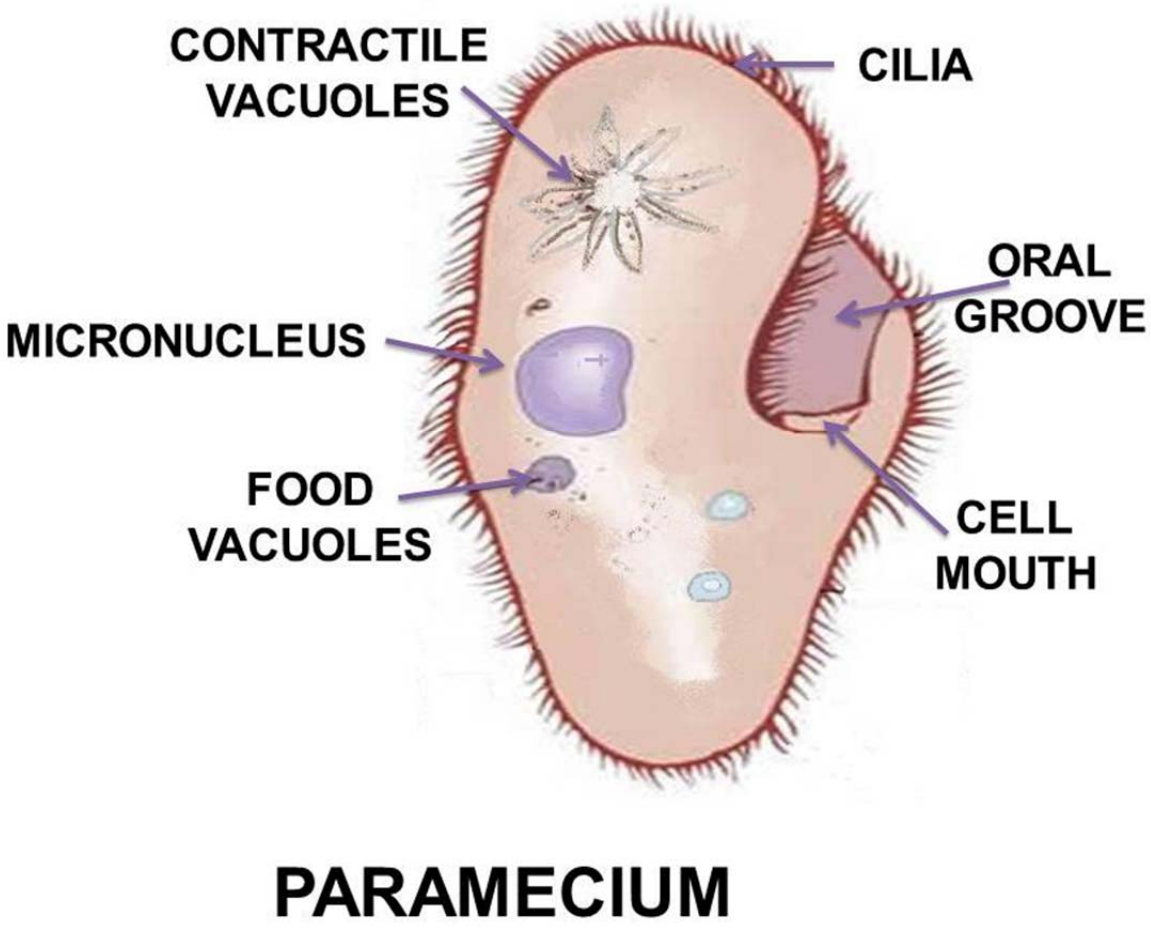
On average, about one in 10 people who are infected with *E. histolytica* becomes sick from the infection. The symptoms often are quite mild and can include loose stools, stomach pain, and stomach cramping. Amebic dysentery is a severe form of amebiasis associated with stomach pain, bloody stools, and 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



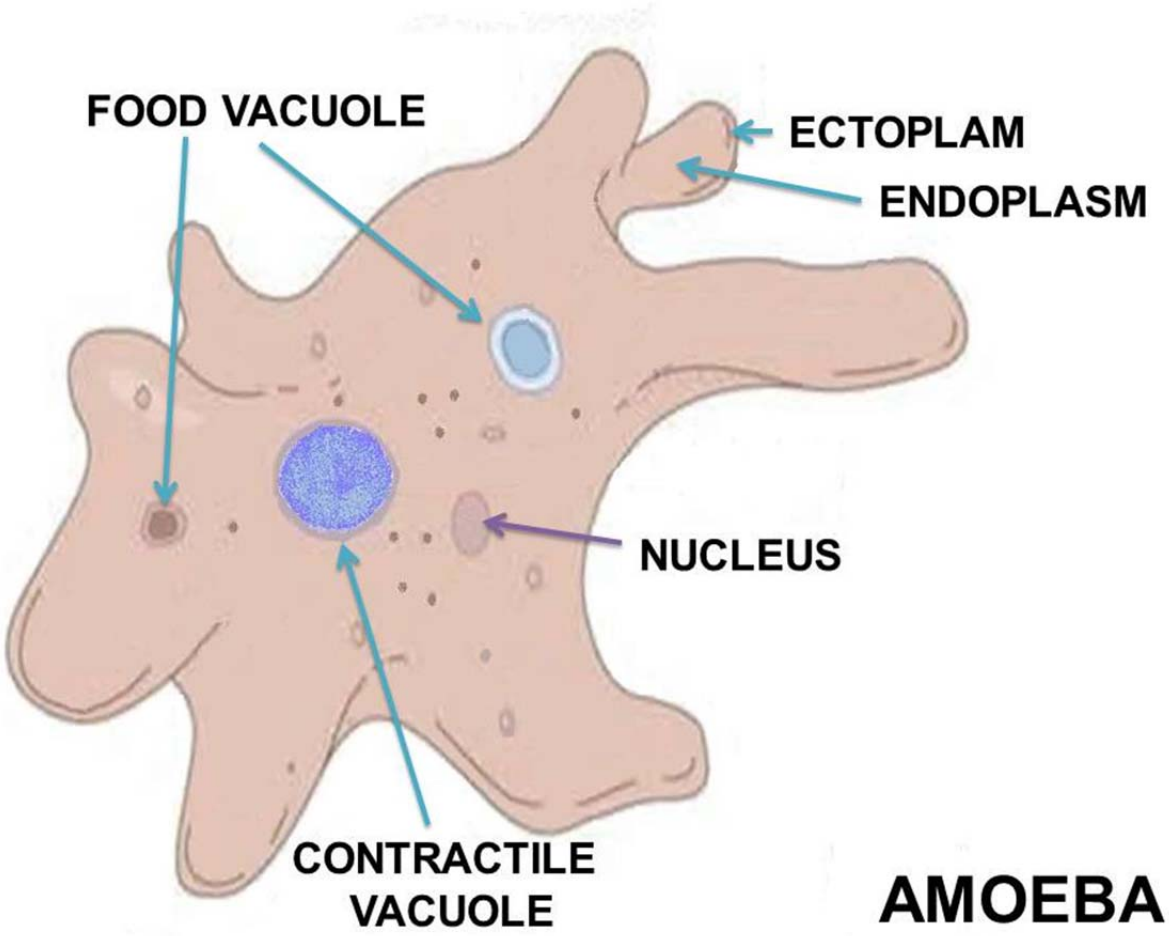

**Mitochondria**

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.



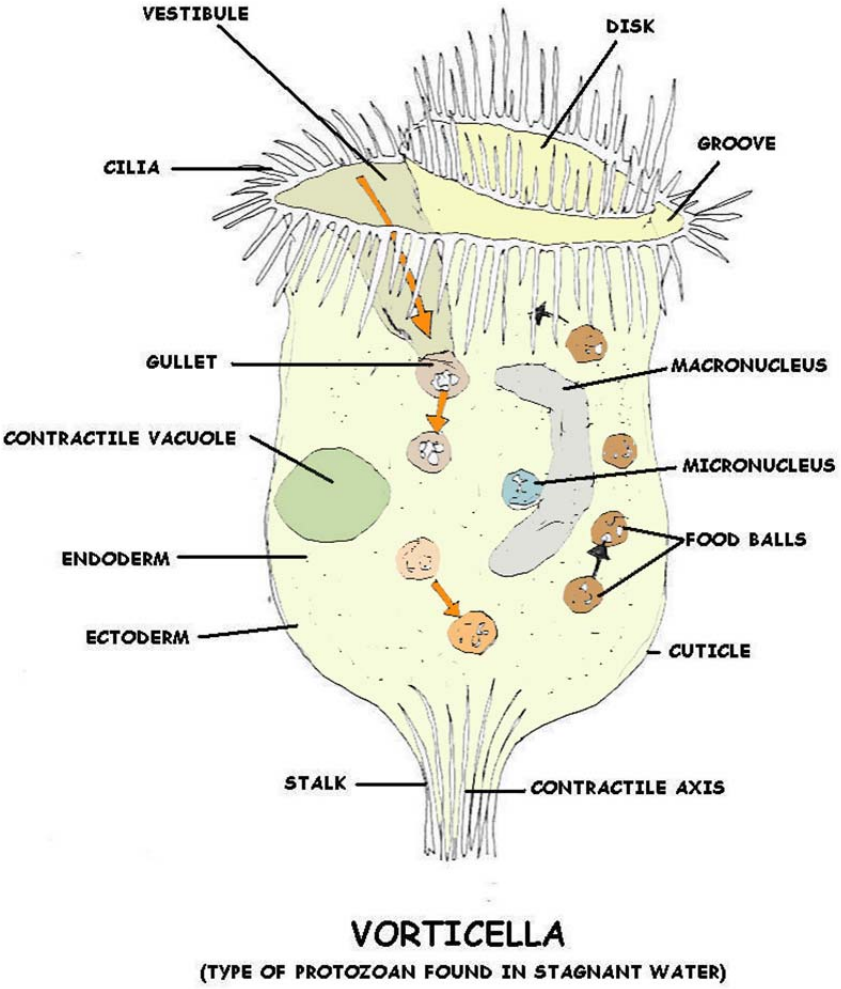

## Paramecia

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

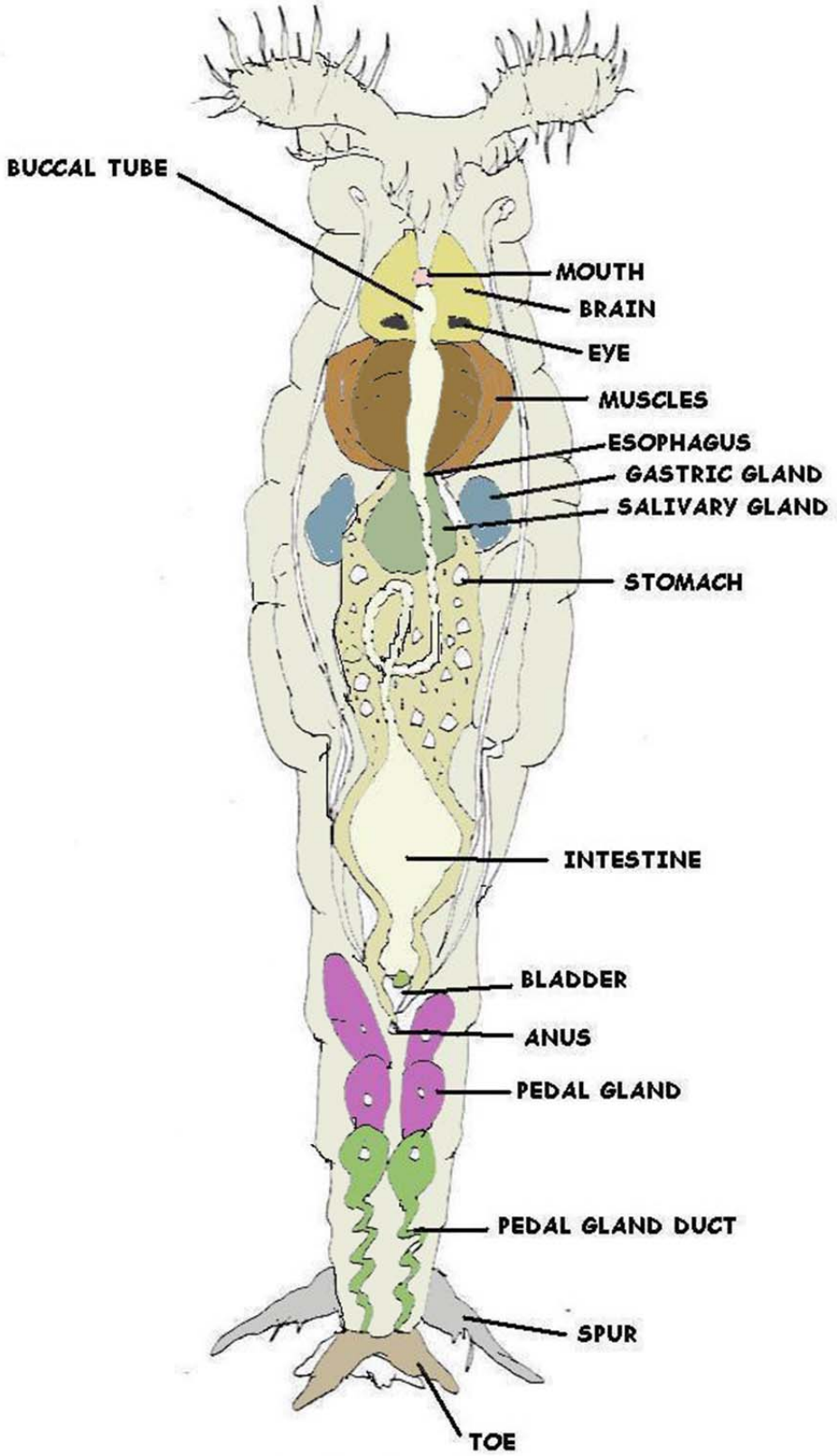
Amoeba (sometimes amœba or ameba, plural amoebae) is a genus of protozoa that moves by means of pseudopods, and is well-known as a representative unicellular organism. The word amoeba or ameba is variously used to refer to it and its close relatives, now grouped as the Amoebozoa, or to all protozoa that 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.

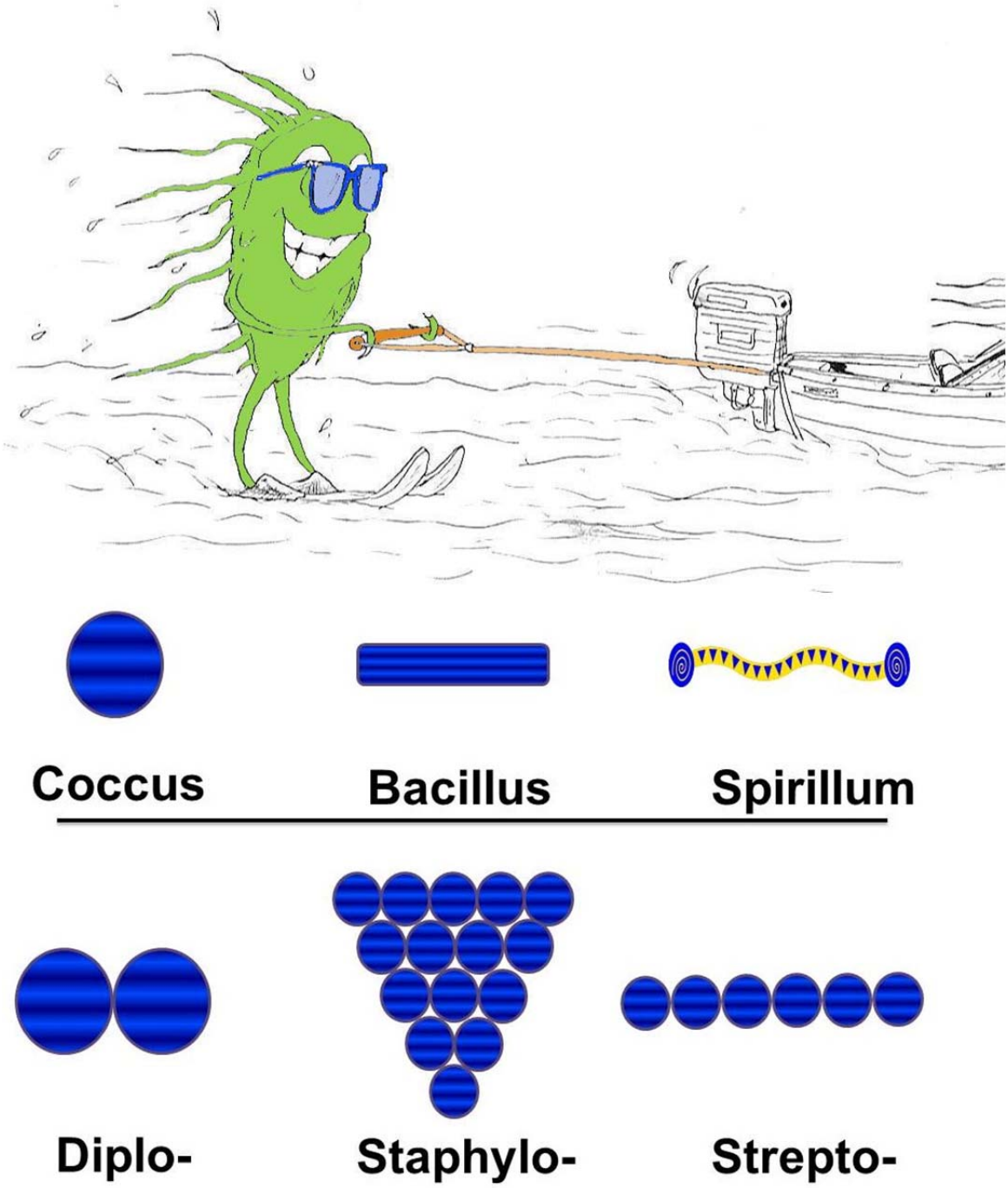
Bdelloid rotifers are unable to produce resting eggs, but many can survive prolonged periods of adverse conditions after desiccation. This facility is termed anhydrobiosis, and organisms with these capabilities are termed anhydrobionts. Under drought conditions, bdelloid rotifers contract into an inert 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 |

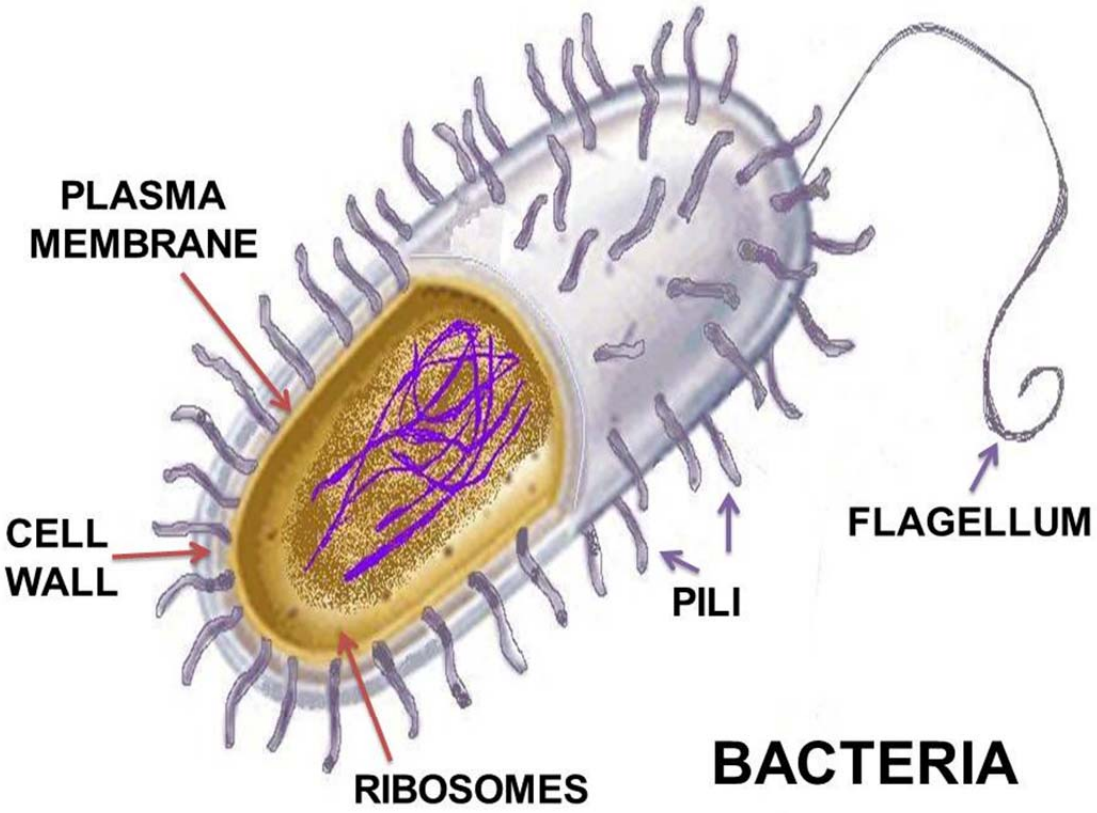
Notes:

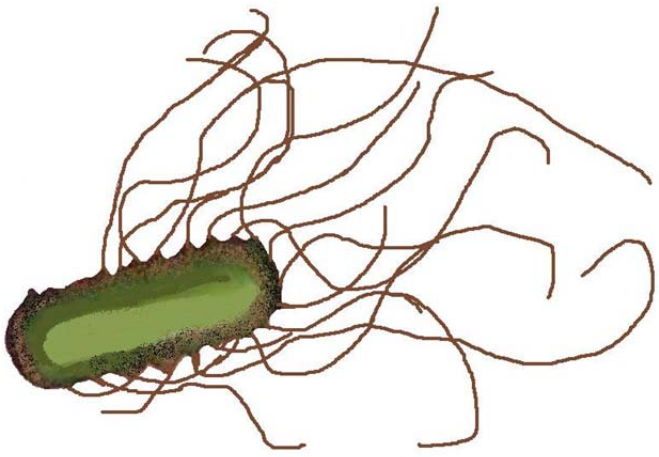
*1 http://www.cdc.gov/ncidod/dvrd/revb/gastro/norovirus.htm
http://www.cdc.gov/mmwr/preview/mmwrhtml/rr5009a1.htm



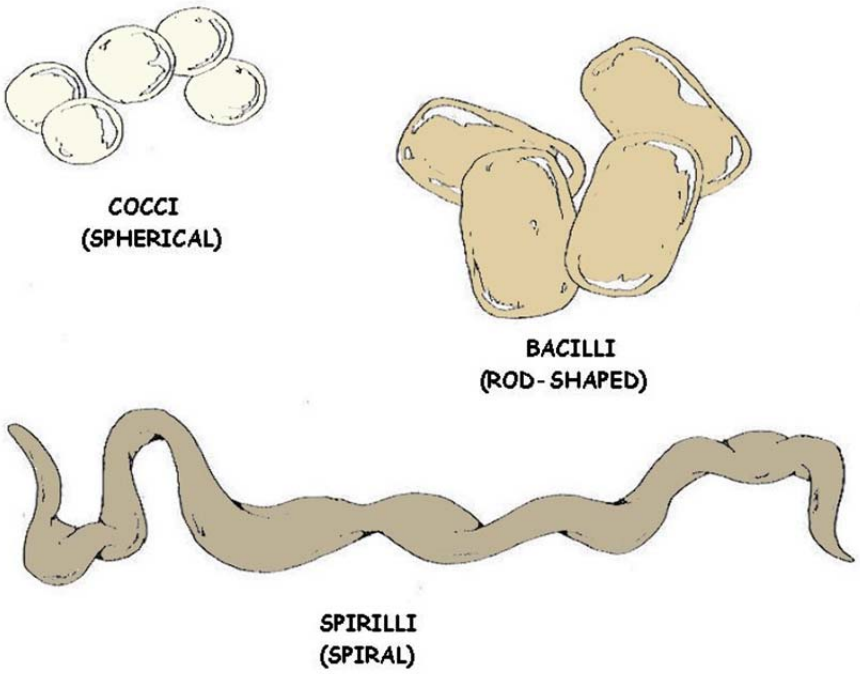

Bacteria Types

## Bacteria Section



**Peritrichous Bacteria**

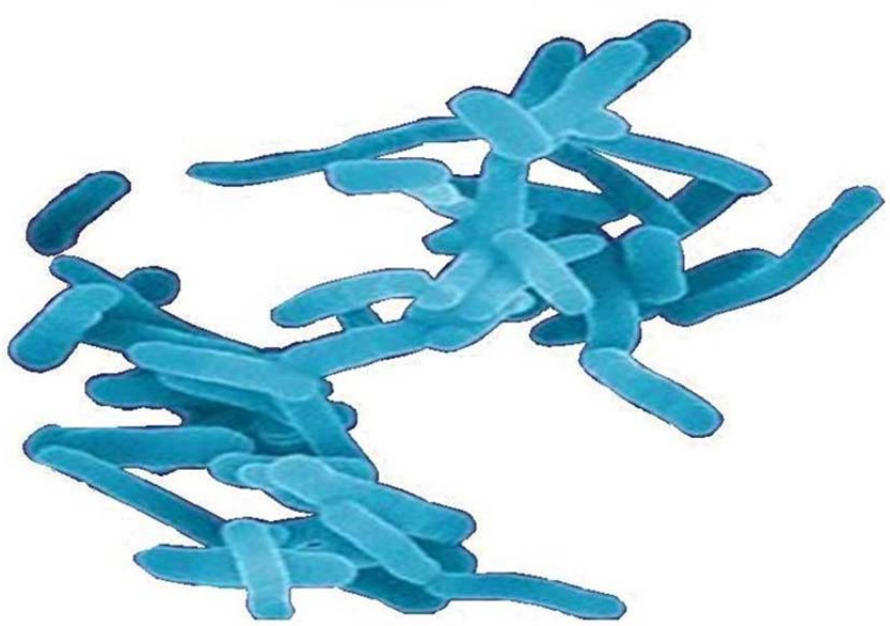



## BACTERIA TYPES

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



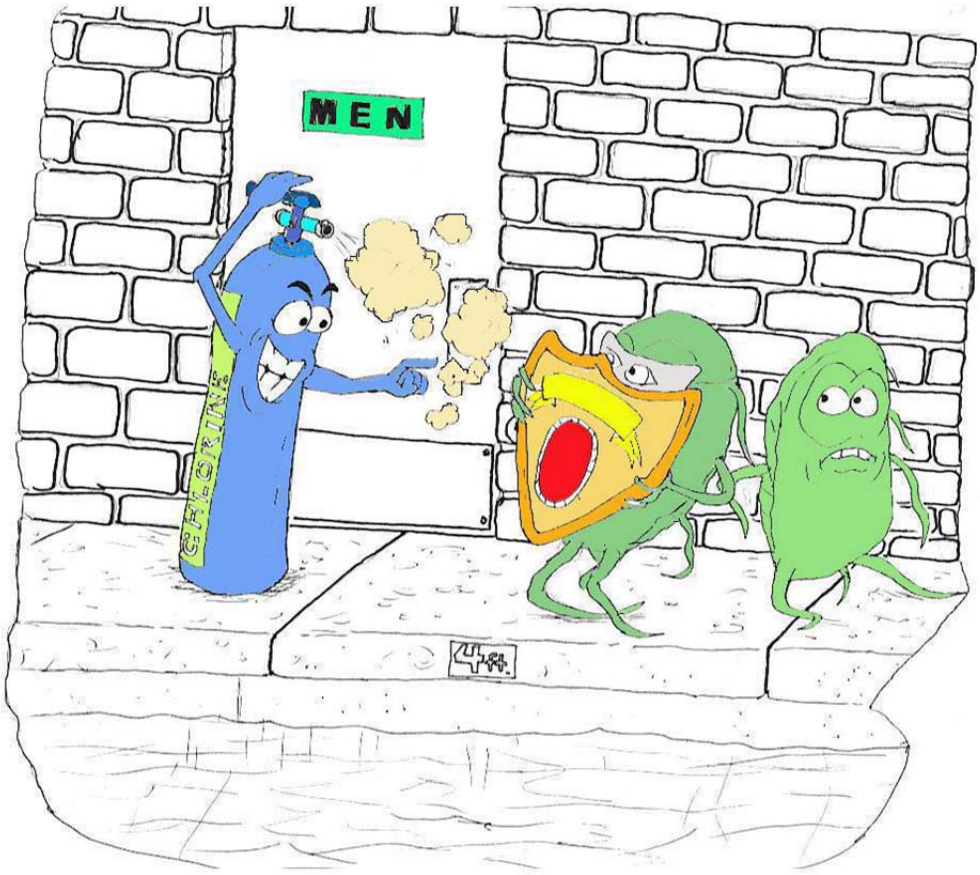
# SHIGELLA DYSENTERIAE

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.

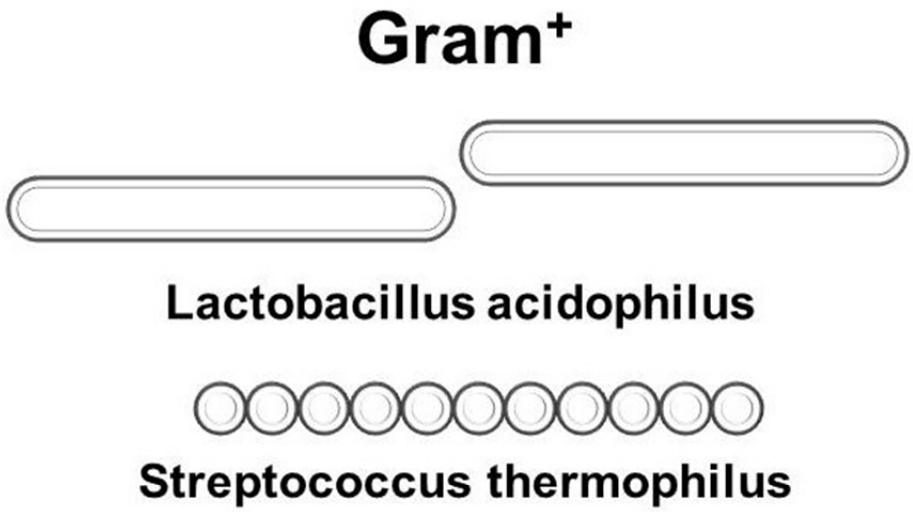
Shigella invades the host through epithelial cells of the large intestine. Using a Type III secretion system acting as a biological syringe, the bacterium injects IpaD protein into cell, triggering bacterial invasion and the subsequent lysis of vacuolar membranes using IpaB and IpaC proteins. It utilizes 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.

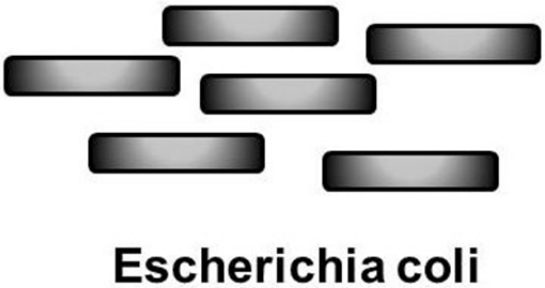
The most common symptoms are diarrhea, fever, nausea, vomiting, stomach cramps, and straining to have a bowel movement. The stool may contain blood, mucus, or pus (e.g. dysentery). In rare cases, young children may have seizures. Symptoms can take as long as a week to show up, but most often begin two 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.


MEN
CHLORINE

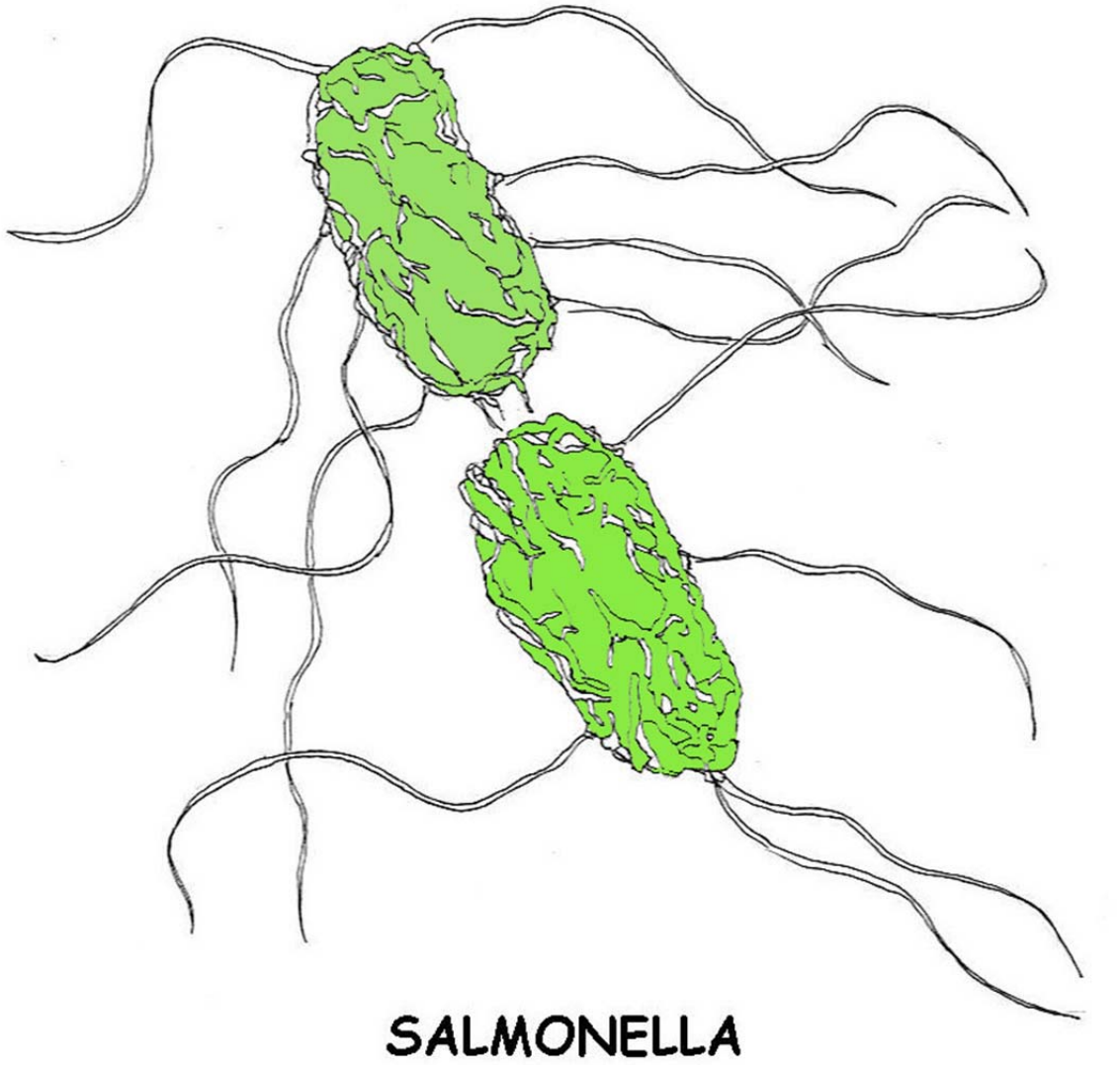
| Type | Characteristics |
|---|---|
| **Acetic acid** | Rod-shaped, gram-negative, aerobic; highly tolerant of acidic conditions; generate organic acids |
| **Actinomycete** | Rod-shaped or filamentous, gram-positive, aerobic; common in soils; essential to growth of many plants; source of much of original 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



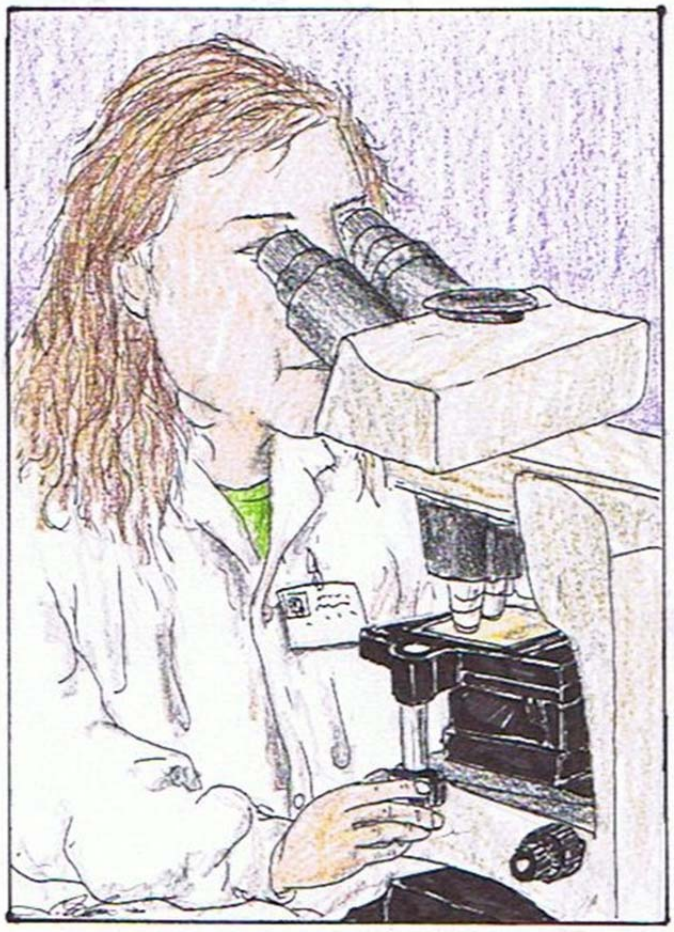

Salmonella is a Gram-negative bacterium. It is found in many turtles and other reptiles. In clinical laboratories, it is usually isolated on MacConkey agar, XLD agar, XLT agar, DCA agar, or Önöz agar. Because they cause intestinal infections and are greatly outnumbered by the bacteria normally found 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.

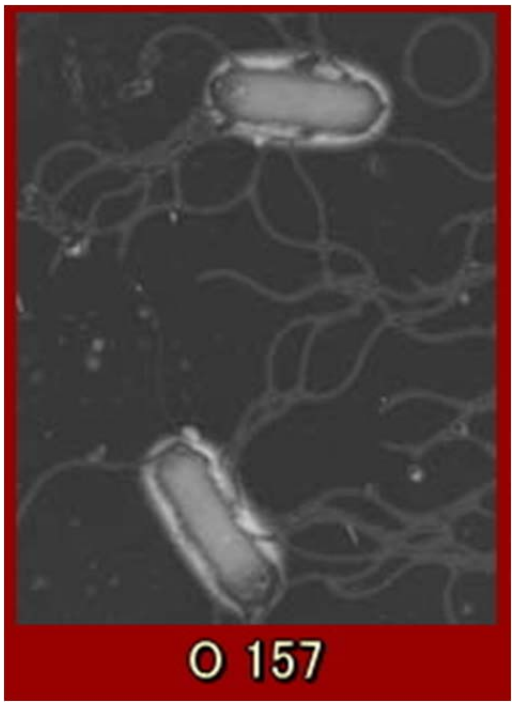
Salmonella Typhi instead of the more technically correct designation, Salmonella enterica subspecies enterica serovar Typhi.

# 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.

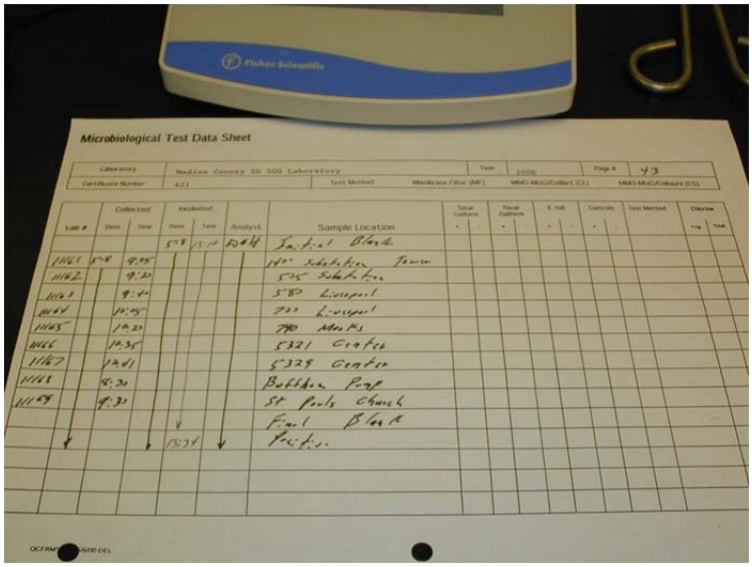
The more closely related the animal, the more likely pathogens excreted with their feces can infect us. Human feces are the biggest concern, because anything which infects one human could infect another. There isn't currently a quantitative method for measuring specifically human fecal bacteria (expensive 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.

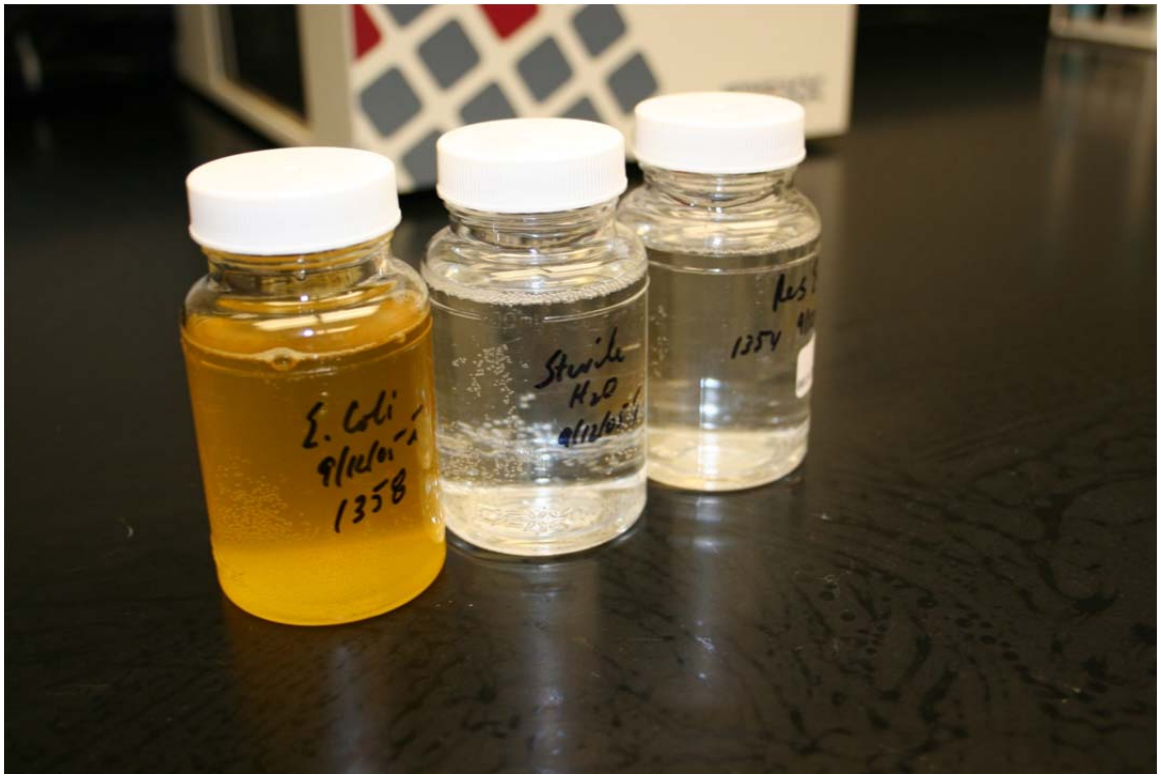
Under the Safe Drinking Water Act, the EPA requires public water systems to monitor for coliform bacteria. Systems analyze first for total coliform, because this test is faster to produce results. Any time that a sample is positive for total coliform, the same sample must be analyzed for either fecal 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.

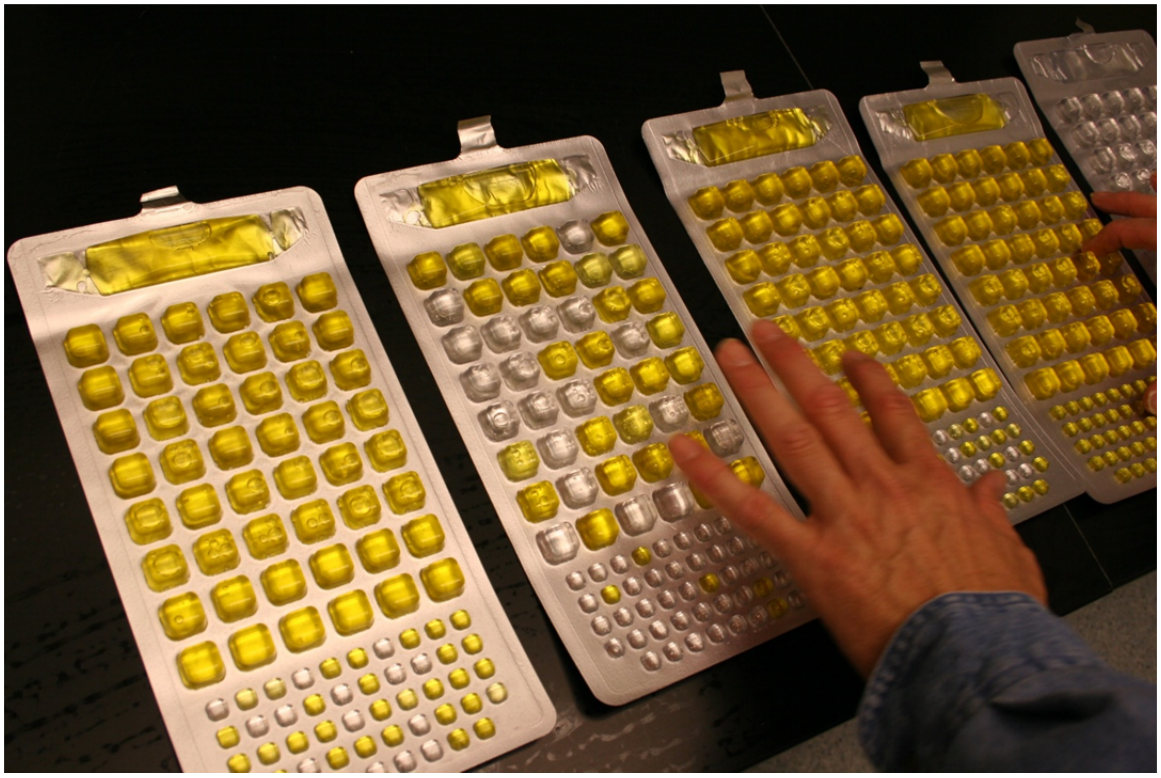



**How is *E. coli* O157:H7 spread?**
The organism can be found on a small number of cattle farms and can live in the intestines of healthy cattle. Meat can become contaminated during slaughter, and organisms can be thoroughly mixed into beef when it is ground. Bacteria present on a cow's udders or on 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).

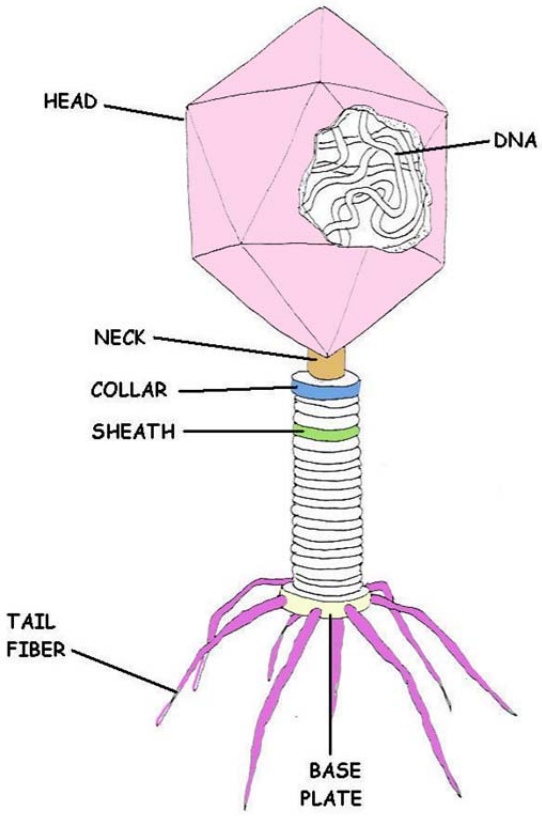
| | |
|---|---|
| *Legionella anisa* | *Legionella bozemanii* sg 1 & 2 |
| *Legionella dumoffi* | *Legionella feeleii* sg 1 & 2 |
| *Legionella gormanii* | *Legionella hackeliae* sg 1 & 2 |
| *Legionella jordanis* | *Legionella longbeachae* sg 1& 2 |
| *Legionella maceachernii* | *Legionella micdadei* |
| *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.

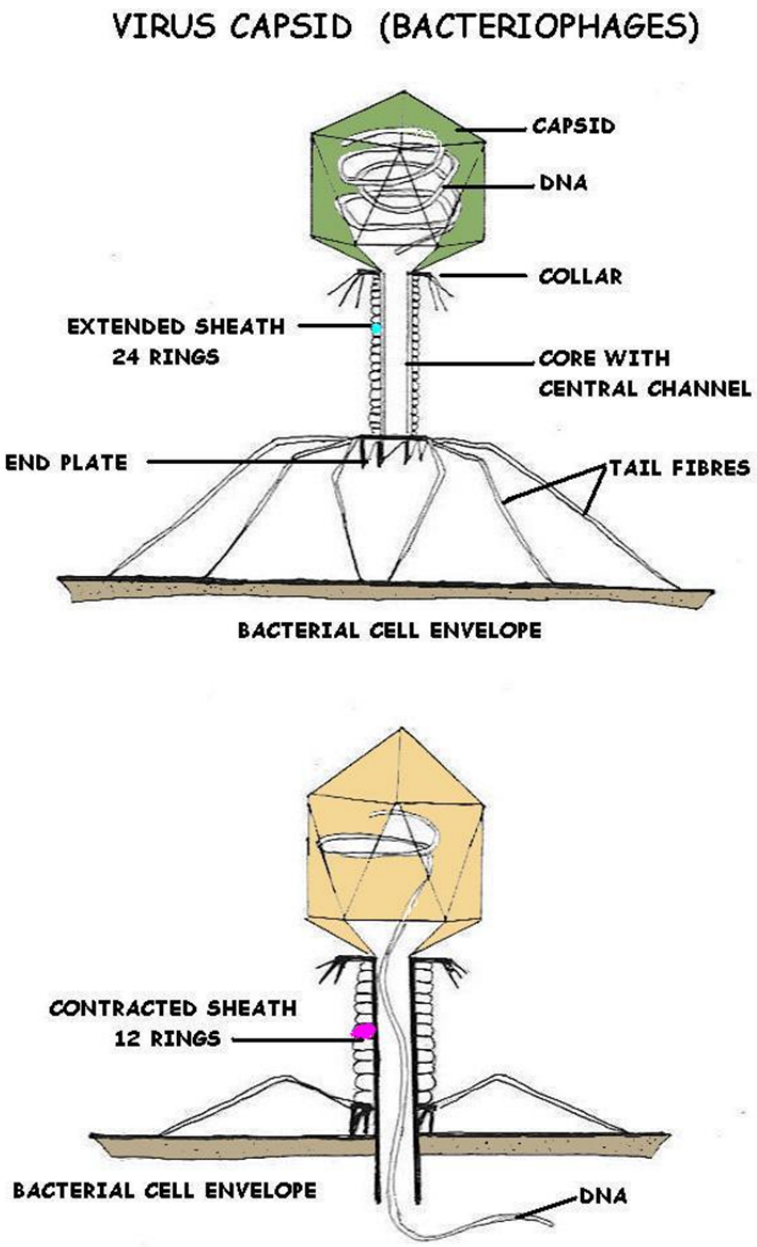



## Bacteriophage

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.

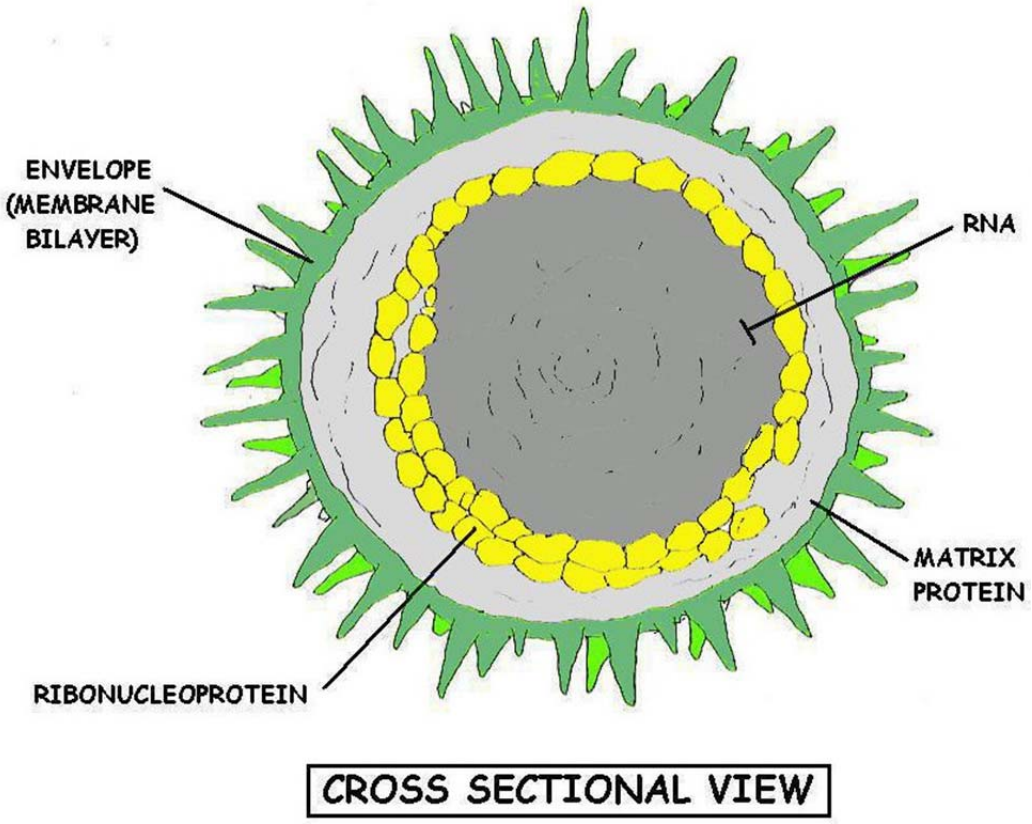



**Release of Virions**

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.




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.

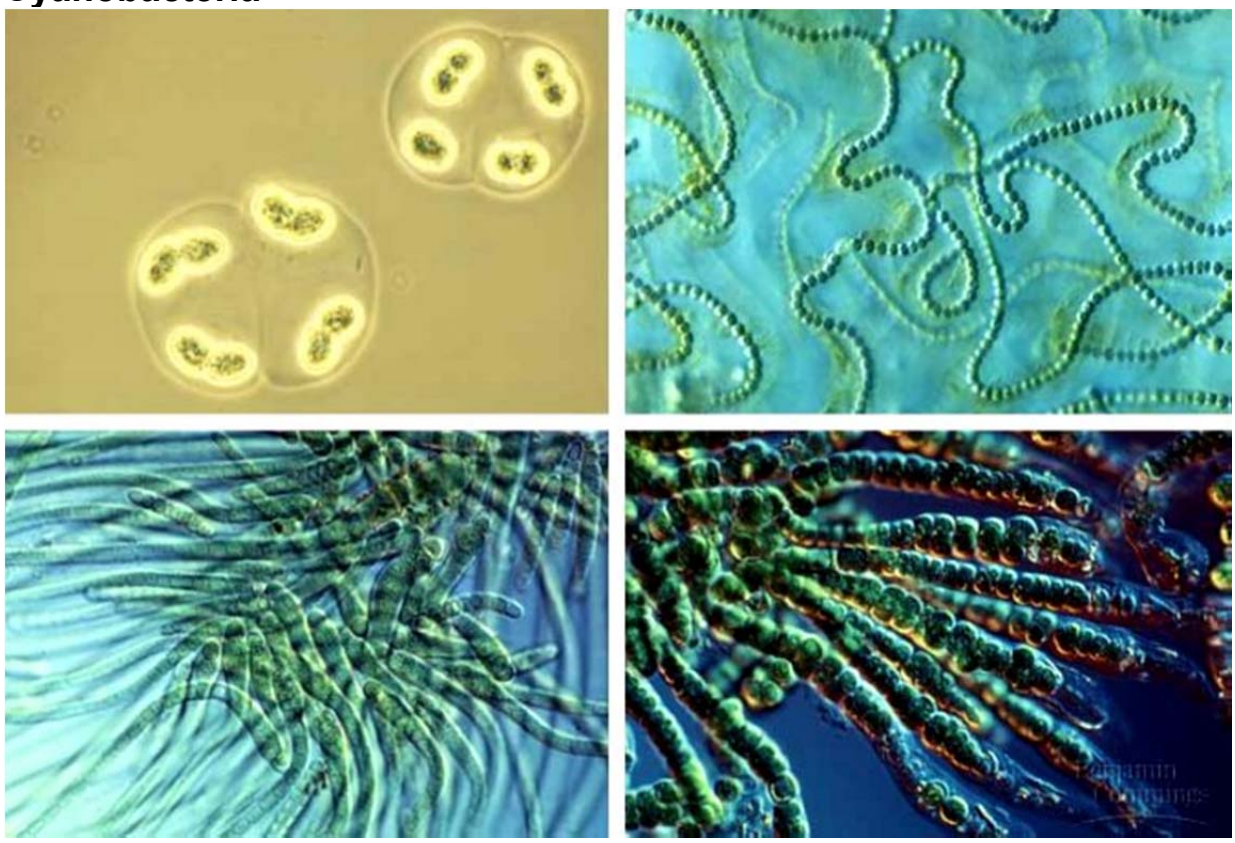
Some icosahedral and helical animal viruses are enclosed in a lipid envelope acquired when the virus buds through host-cell membranes. Inserted into this envelope are glycoproteins that the viral genome directs the cell to make; these molecules bind virus particles to susceptible host cells.

**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

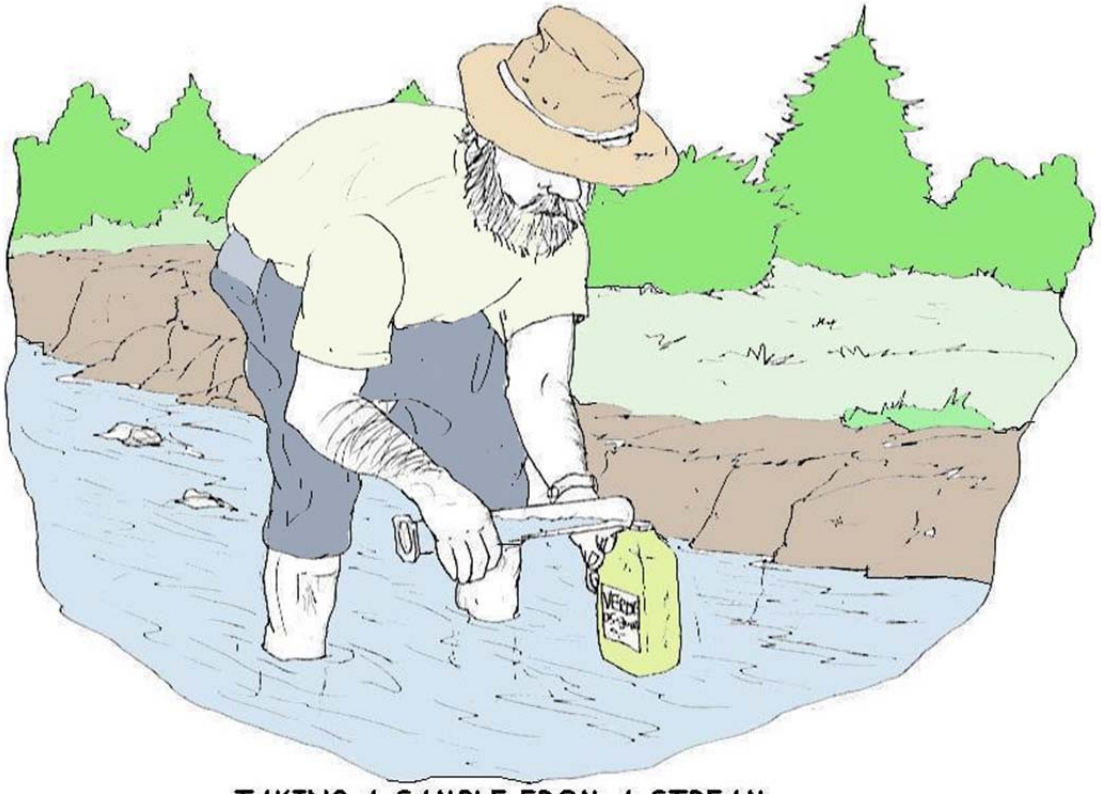
Cyanobacteria, also known as blue-green algae, blue-green bacteria or Cyanophyta, is a phylum of bacteria that obtain their energy through photosynthesis. The name "cyanobacteria" comes from the color of the bacteria (Greek: kyanós = blue). They are a significant component of the marine nitrogen cycle 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.

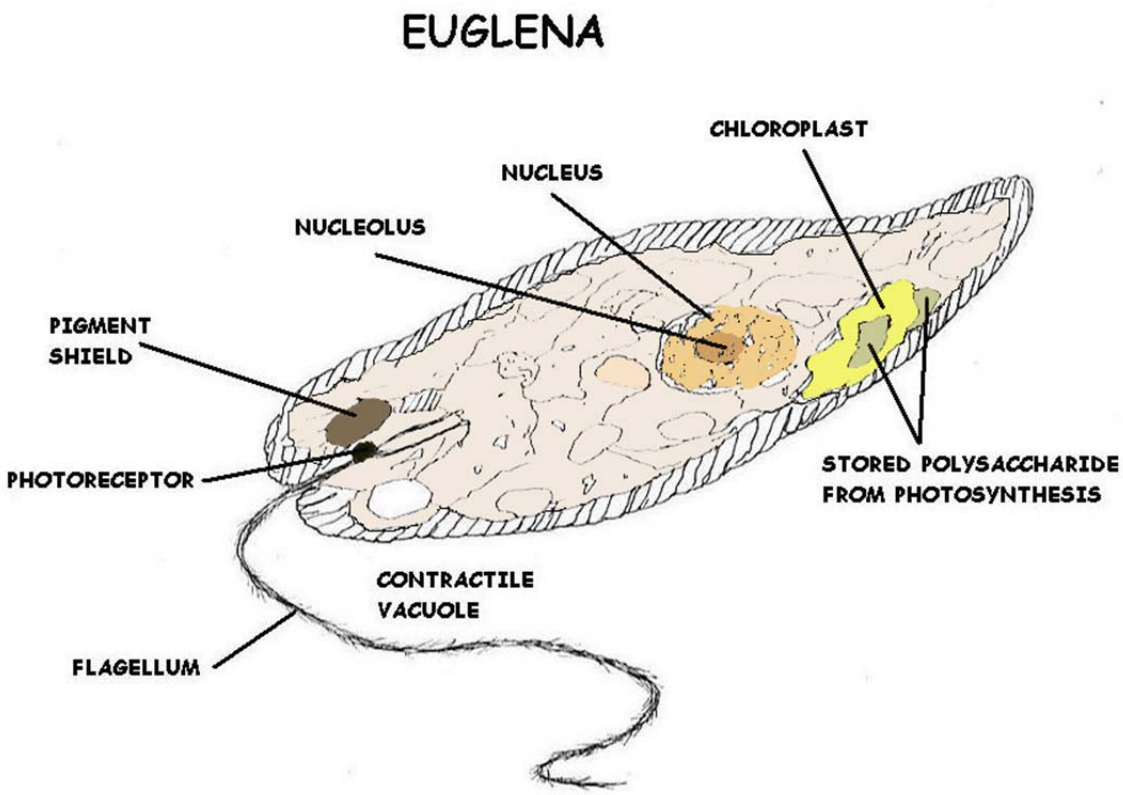
The rice paddies of Asia, which produce about 75% of the world's rice, could not do so were it not for healthy populations of nitrogen-fixing cyanobacteria in the rice paddy fertilizer too.

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.

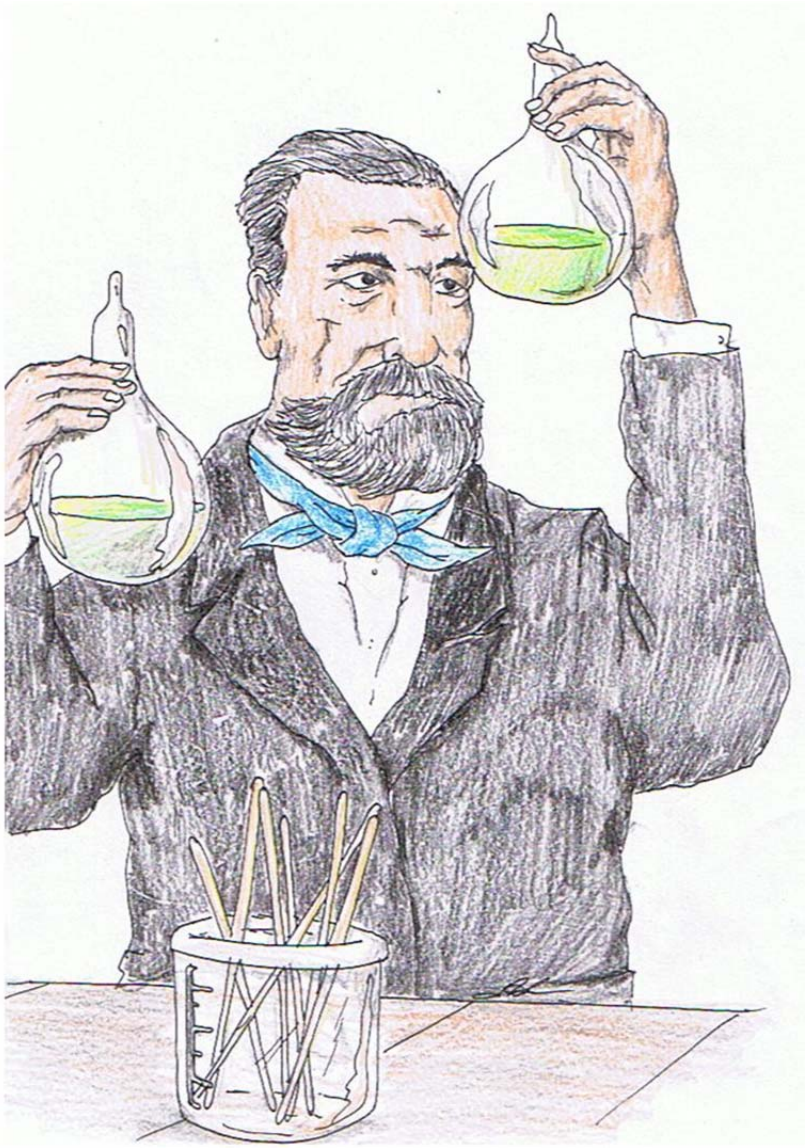
Euglena gracilis has a long hair-like thing that stretches from its body. You need a very powerful microscope to see it. This is called a flagellum, and the euglena uses it to swim. It also has a red eyespot. Euglena gracilis uses its eyespot to locate light. Without light, it cannot use its chloroplasts 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.

OREOS
BOMBS
MIKE ROBES'
ICE CREAM

## Common Water Treatment and Distribution Chemicals

| Chemical Name | Common Name | Chemical Formula |
|---|---|---|
| Aluminum hydroxide | | $Al(OH)_3$ |
| Aluminum sulfate | Alum, liquid | $AL_2(SO_4)3 \cdot 14(H_2O)$ |
| 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 | $Ca(OCl)_2 \cdot 4H_2O$ |
| 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 | $CuSO_4 \cdot 5H_2O$ |
| 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.

# 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
***AKA* Solids Applied Formula** = Flow X Dose X 8.34 ***Professor Rusty's Favorite Math Formula Please memorize***

**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)

$\tau Q$ = Allowable time for decrease in pressure from 3.5 PSU to 2.5 PSI
$\tau q$ = 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
$\theta$ = .0030 cfm air loss per square foot of internal pipe surface
$\delta$ = Pipe diameter (inches)
L = Pipe Length (feet)

$$V = \frac{1.486}{\nu} R^{2/3} S^{1/2}$$

V = Velocity (ft./sec.)
$\nu$ = 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

If you are poor at math, don't be embarrassed come to a TLC review class.

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.

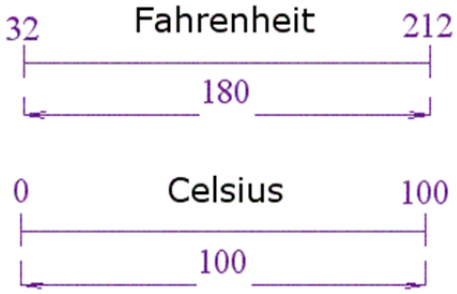
26. How many grams equal 4,500 mg?

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' = _____ cu.ft. (27cu.ft./cu.yrd.)

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**

## REFERENCES


Benenson, Abram S., editor. 1990. *Control of Communicable Diseases in Man.* 15th ed. Baltimore: Victor Graphics, Inc.

Bick, H. 1972. Ciliated protozoa. An illustrated guide to the species used as biological indicators in freshwater biology. World Health Organization, Geneva. 198 pp.

Born, Stephen M., Douglas A. Yanggen, and Alexander Zaporozec. *A Guide to Groundwater Quality Planning and Management for Local Governments*. Wisconsin Geological and Natural History Survey, Madison, WI, 1987.

Cairns, J., and J.A. Ruthven. 1972. A test of the cosmopolitan distribution of fresh-water protozoans. Hydrobiologia 39:405-427.

Cairns, J., and W.H. Yongue. 1977. Factors affecting the number of species of freshwater protozoan communities. Pages 257-303 in J. Cairns, ed. Aquatic microbial communities. Garland, New York.

Cairns, J., G.R. Lanza, and B.C. Parker. 1972. Pollution related structural and functional changes in aquatic communities with emphasis on freshwater algae and protozoa. Proceedings of the National Academy of Sciences 124:79-127.

Concern, Inc. *Groundwater: A Community Action Guide*. Washington, D.C., 1989.

Cross, Brad L and Jack Schulze. *City of Hurst (A Public Water Supply Protection Strategy)*. Texas Water Commission, Austin, TX, 1989.

Curds, C.R. 1992. Protozoa and the water industry. Cambridge University Press, MA. 122 pp.

Curtis, Christopher and Teri Anderson. *A Guidebook for Organizing a Community Collection Event: Household Hazardous Waste*. Pioneer Valley Planning Commission and Western Massachusetts Coalition for Safe Waste Management, West Springfield, MA, 1984.

Curtis, Christopher, Christopher Walsh, and Michael Przybyla. *The Road Salt Management Handbook: Introducing a Reliable Strategy to Safeguard People & Water Resources*. Pioneer Valley Planning Commission, West Springfield, MA, 1986.

Fenchel, T. 1974. Intrinsic rate increase: the relationship with body size. Oecologia 14:317-326.

Fenchel, T., T. Perry, and A. Thane. 1977. Anaerobiosis and symbiosis with bacteria in free-living ciliates. Journal of Protozoology 24:154-163.

Foissner, W. 1987. Soil protozoa: fundamental problems, ecological significance, adaptations in ciliates and testaceans, bioindicators, and guide to the literature. Progress in Protistology 2:69-212.

Foissner, W. 1988. Taxonomic and nomenclatural revision of Stádecek's list of ciliates (Protozoa: Ciliophora) as indicators of water quality. Hydrobiologia 166:1-64.

Foster, Laurence, M.D. 1985. “Waterborne Disease - It’s Our Job to Prevent It”. PIPELINE newsletter, Oregon Health Division, Drinking Water Program, Portland, Oregon 1(4 ): 1-3.

Foster, Laurence, M.D. 1990. “Waterborne *Disease,” Methods for the Investigation and Prevention of Waterborne Disease Outbreaks.* Ed. Gunther F. Craun. Cincinnati: U.S. Environmental Protection Agency.

Giese, A.C. 1973. Blepharisma. Stanford University Press, CA. 366 pp.

Gordon, Wendy. *A Citizen's Handbook on Groundwater Protection*. Natural Resources Defense Council, New York, NY 1984.

Harrison, Ellen Z. and Mary Ann Dickinson. *Protecting Connecticut's Groundwater: A Guide to Groundwater Protection for Local Officials*. Connecticut Department of Environmental Protection, Hartford, CT, 1984.

Hrezo, Margaret and Pat Nickinson. *Protecting Virginia's Groundwater A Handbook for Local Government Officials*. Virginia Polytechnic Institute and State University, Blacksburg, VA, 1986.

Jaffe, Martin and Frank Dinovo. *Local Groundwater Protection*. American Planning Association, Chicago, IL, 1987.

Kreier, J.P., and J.R. Baker. 1987. Parasitic protozoa. Allen and Unwin, Boston, MA. 241 pp.
Laybourn, J., and B.J. Finlay. 1976. Respiratory energy losses related to cell weight and temperature in ciliated protozoa. Oecologia 44:165-174.
Lee, C.C., and T. Fenchel. 1972. Studies on ciliates associated with sea ice from Antarctica. II. Temperature responses and tolerances in ciliates from Antarctica, temperate and tropical habitats. Archive für Protistenkunde 114:237-244.
Loomis, George and Yael Calhoon. "Natural Resource Facts: Maintaining Your Septic System." University of Rhode Island, Providence, RI, 1988.
Macozzi, Maureen. *Groundwater- Protecting Wisconsin's Buried Treasure*. Wisconsin Department of Natural Resources, Madison, WI, 1989.
Maine Association of Conservation Commissions. *Ground Water... Maine's Hidden Resource*. Hallowell, ME, 1985.
Massachusetts Audubon Society "Local Authority for Groundwater Protection." Groundwater Information Flyer #4. Lincoln, MA, 1984.
Massachusetts Audubon Society. "Groundwater and Contamination: From the Watershed into the Well." Groundwater Information Flyer # 2. Lincoln, MA, 1984.
Massachusetts Audubon Society. "Mapping Aquifers and Recharge Areas." Groundwater Information Flyer # 3. Lincoln, MA, 1984.
Massachusetts Audubon Society. "Road Salt and Groundwater Protection." Groundwater Information Flyer # 9. Lincoln, MA, 1987.
McCann, Alyson and Thomas P Husband. "Natural Resources Facts: Household Hazardous Waste." University of Rhode Island, Providence, RI; 1988.
Miller, David W. *Groundwater Contamination: A Special Report*. Geraghty & Miller, Inc., Syosset, NY 1982.
Montagnes, D.J.S., D.H. Lynn, J.C. Roff, and W.D. Taylor. 1988. The annual cycle of heterotrophic planktonic ciliates in the waters surrounding the Isles of Shoals, Gulf of Maine: an assessment of their trophic role. Marine Biology 99:21-30.
Mullikin, Elizabeth B. *An Ounce of Prevention: A Ground Water Protection Handbook for Local Officials*. Vermont Departments of Water Resources and Environmental Engineering, Health, and Agriculture, Montpelier, VT, 1984.
Murphy, Jim. "Groundwater and Your Town: What Your Town Can Do Right Now." Connecticut Department of Environmental Protection, Hartford, CT.
National Research Council. *Ground Water Quality Protection: State and Local Strategies.* National Academy Press, Washington, D.C., 1986.
New England Interstate Water Pollution Control Commission. "Groundwater: Out of Sight Not Out of Danger." Boston, MA, 1989.
Niederlehner, B.R., K.W. Pontasch, J.R. Pratt, and J. Cairns. 1990. Field evaluation of predictions of environmental effects from multispecies microcosm toxicity test. Archives of Environmental Contamination and Toxicology 19:62-71.
Noake, Kimberly D. Guide to *Contamination Sources for Wellhead Protection*. Draft. Massachusetts Department of Environmental Quality Engineering, Boston, MA, 1988.
Office of Drinking Water. *A Local Planning Process for Groundwater Protection*. U.S. EPA, Washington, D.C., 1989.
Office of Ground-Water Protection. *Guidelines for Delineation of Wellhead Protection Areas*. U.S. EPA, Washington, D.C., 1987.
Office of Ground-Water Protection. *Survey of State Ground Water Quality Protection Legislation Enacted From 1985 Through 1987*. U.S. EPA, Washington, D.C., 1988.
Office of Ground-Water Protection. *Wellhead Protection Programs. - Tools for Local Governments.* U.S. EPA, Washington, D.C., 1989.
Office of Ground-Water Protection. *Wellhead Protection: A Decision-Makers' Guide.* U.S. EPA, Washington, D.C., 1987

Office of Pesticides and Toxic Substances. *Citizen's Guide to Pesticides.* U.S. EPA, Washington, D.C., 1989.
Office of Underground Storage Tanks. *Musts for USGS. - A Summary of the New Regulations for Underground Storage Tank Systems.* U.S. EPA, Washington, D.C., 1988.
Ohio Environmental Protection Agency. *Ground Water.* Columbus, OH.
Redlich, Susan. *Summary of Municipal Actions for Groundwater Protection in the New England/New York Region.* New England Interstate Water Pollution Control Commission, Boston, MA, 1988.
Southern Arizona Water Resources Association. "Water Warnings: Our Drinking Water.... It Takes Everyone to Keep It Clean." Tucson, AZ.
Sponenberg, Torsten D. and Jacob H. Kahn. *A Groundwater Primer for Virginians.* Virginia Polytechnic Institute and State University, Blacksburg, VA, 1984.
Taylor, W., and R. Sanders. 1991. Protozoa. Pages 37-93 in J.H. Thorp and A.P. Covich, eds. Ecology and classification of North American freshwater invertebrates. Academic Press, New York.
Texas Water Commission. "On Dangerous Ground: The Problem of Abandoned Wells in Texas." Austin, TX, 1989.
Texas Water Commission. *The Underground Subject: An Introduction to Ground Water Issues in Texas.* Austin, TX, 1989.
U.S. Environmental Protection Agency. *Seminar Publication: Protection of Public Water Supplies from Ground-Water Contaminants.* Center for Environmental Research Information, Cincinnati, OH, 1985.
Waller, Roger M. *Ground Water and the Rural Homeowner.* U.S. Geological Survey, Reston, VA, 1988.

## Water Distribution Review Section *Practice Exam*

The answers to this section are in the rear of this section. This is an excellent study tool for an Operator Certification Exam or a final review for the assignment.

1. In general, any _____pump can be designed with a multistage configuration. Each stage requires an additional _____ and casing chamber in order to develop increased pressure, which adds to the pressure developed by the preceding stage.
A. Submersible, Diffuser
B. Centrifugal, Impeller
C. Displacement, Volute
D. Centrifugal, Foot valve
E. None of the above

2. The axial-flow pump is often referred to as a _____.
A. Propeller Pump
B. Submersible Pump
C. Hydraulic pump
D. None of the above

3. In all centrifugal pumps, there must be a flow restriction between the _____ discharge and _____ areas that will prevent excessive circulation of water between the two parts.
A. Wear ring & Foot valve
B. Impeller & Suction
C. Lantern Ring & Shaft Sleeve
D. Packing rings & Shaft

4. This type of valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate.
A. Double Check
B. PVB
C. Air Relief
D. Ball
E. Altitude-Control Valve

5. When a pump operates under suction, the impeller inlet is actually operating in a vacuum. Air will enter the water stream along the shaft if the packing does not provide an effective seal. It may be impossible to tighten the packing sufficiently to prevent air from entering without causing excessive heat and wear on the packing and shaft or shaft sleeve. To solve this problem, a _____ is placed in the Stuffing Box.
A. Lantern Ring
B. Packing Gland
C. Sanitary seal
D. Wye
E. None of the above

6. If the pump must operate under high suction head, the suction pressure itself will compress the packing rings regardless of the operator's care. Packing will then require frequent replacement. Most manufacturers recommend using _____ for low-suction head conditions as well.
A. Mechanical Seals
B. Graphite
C. Vibration devices
D. Flow controls
E. All of the above

7. The mechanical seal is designed so that it can be hydraulically balanced. The result is that the wearing force between the machined surfaces does not vary regardless of the suction head. Most seals have an operating life of _____.
A. 5,000 to 20,000 hours
B. 50,000
C. 75,000
D. 1 million hours

8. The speed at which the magnetic field rotates is called the motor's synchronous speed. It is expressed in revolutions per minute. For a motor that operates on an electric power system having a frequency of 60Hz, the maximum synchronous speed is 3,600 rpm, or 60 revolutions per second. In other words, because the electric current changes its flow direction 60 times a second, the rotor can rotate 60 times per second. This speed is achieved by:
A. The Starting Current
B. Squirrel cage
C. A two-pole motor
D. A three phase stator
E. All of the above

9. _____ is a condition in which the pressure in the distribution system is less than atmospheric pressure. In other words, something is "sucked" into the system because the main is under a vacuum.
A. Backsiphonage
B. Backpressure

10. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are:
A. Types of valves
B. Methods of telemetry
C. Common types of level sensors
D. Out dated methods of measuring flows
E. All of the above

11. Which of the following is a correct statement concerning a single phase motor?
A. If it is a split-phase motor, the motor will not have windings.
B. A repulsion-induction motor is very simple and less expensive than other single phase motors.
C. Will have a capacitor start motor has a high starting torque and a high starting current.
D. All of the above
E. None of the above

12. A chlorine demand test from a well water sample produces a result of 1.2 mg/L. The water supplier would like to maintain a chlorine residual of 0.2 mg/L throughout the system. What should be the chlorine dose in mg/L from either a chlorinator or a hypochlorinator?
A. 1.2
B. 0.2
C. 1.0
D. 1.4

13. The vacuum created by a chlorine ejector moves through this device. This device prevents water from back feeding or entering the vacuum-regulator portion of the chlorinator.
A. Rate valve
B. The ejector
C. Interconnection manifold
D. Check valve assembly
E. Rotameter

14. Uniforms and proper credentials aid meter readers and operators that work close to private property because they help:
A. Readily identify personnel
B. Cash pay checks
C. Alter behavior
D. All of the above

15. Which of the following is responsible for the enforcement of building regulations?
A. The Crew Leader
B. The Building Inspector
C. The Supervisor
D. Depends if anyone is around

16. A water storage facility should be able to provide water for the _____ and _____ demands.
A. Typical, Fire
B. Average, Peak
C. Fire, Peak
D. Maximum, Minimum
E. CMOM, CAFO

17. What is the peak demand?
A. The maximum momentary load placed on a water treatment plant, pumping station or distribution system.
B. The total demand for water during the period of time divided by the number of days in that time period.
C. None of the above

18. Surge tanks are used to control:
A. Water Hammer
B. Chlorine Demand
C. Backpressure
D. Backwash
E. CAFO

19. On most kilowatt meters, the current kilowatt load is indicated by:
A. The Primary or Binder dial
B. Current load dial
C. Disk revolutions
D. None of the above

20. This special type of check valve is located at the bottom end of the suction on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.
A. Prime Valve
B. Foot
C. Impeller

21. Distribution system water quality can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. What customer complaint is sometimes solved by the installation of air relief valves?
A. Taste and odors
B. Milky water
C. MIB
D. Constipation

22. What does HPC mean?
A. Halogenated Particle Count
B. Heterotrophic plate count
C. Hard Particle Count
D. Heterotrophic Particle Count

23. Which of the following pumps consists of an impeller fixed on a rotating shaft that is enclosed in a casing, and has an inlet and discharge connection? As the rotating impeller spins the liquid around, force builds up enough pressure to force the water through the discharge outlet.
A. Booster
B. Centrifugal
C. Submersible
D. Rotator

24. What is a limitation of hydropneumatic tanks?
A. Do not provide much storage during average demands
B. Do not provide much storage to meet peak demands during power outages
C. Very limited time to do repairs on equipment
D. Both B & C

25. Why would a pump engineer design a system that would use multiple pumps for a parallel operation?
A. To provide for a fluctuating demand
B. To provide an increased discharge head
C. To reduce the friction coefficient on a larger pump for greater efficiency
D. All of the above

26. When the superintendent is inspecting the plans for a new ground water storage tank, the superintendent should pay attention to the inlet and outlet of this tank. What design factor should be noticed?
A. The outlet and inlet should be on opposite sides of the tank
B. The inlet must be twice the size of the outlet
C. The outlet must be twice the size of the inlet
D. The outlet and inlet should be on the top
E. CMOM

27. Water quality in a storage facility could degrade due to excessive water age caused by low demands for water and short-circuiting within the distribution storage reservoir. Which of the following are not other reasons for water quality degradation?
A. Sampling program
B. Poor design
C. Inadequate maintenance
D. Improperly applied coating and linings

28. Transmitting equipment requires installation where temperature will not exceed:
A. 100°F.
B. 100°C.
C. 130°C.
D. 130°F.

29. For a dead-end line of over 2,000 feet, the design criteria would dictate a minimum pipe diameter of _____ inches.
A. 4
B. 8
C. 6

30. A diaphragm element being used as a level sensor would be used in conjunction with:
A. Pressure Sensor
B. Manometer
C. Rotometer
D. Redwood plug
E. HTH

31. Inspection of magnetic flow meter instrumentation should include:
A. Checking EMF on the hemisphere transducer
B. Checking for corrosion or insulation deterioration
C. Placing a bucket of water for your feet
D. Polarity multiplexing

32. The most frequent problem that affects a liquid pressure-sensing device is:
A. Air accumulation at the sensor
B. Greenhouse effect
C. Freezing
D. Sensing solenoid failure
E. CAFO

33. Which of the following is **NOT** a pressure sensing device?
A. Helical Sensor
B. Bourdon Tube
C. Campos Gauge
D. Bellows Sensor

34. Telemetering systems must often transmit more than one signal. Which of the following is **NOT** a means for transmitting multiple signals?
A. Pulse-duration modulation
B. Polling
C. Scanning
D. Multiplexing

35. The Strain Gauge is a common measuring device used for a variety of changes such as head. As the pressure in the system changes, the diaphragm expands which changes the length of the wire attached. This change of length of the wire changes the _____of the wire, which is then converted to head.
A. Resistance
B. Voltage
C. Current
D. None of the above

36. Any equipment that utilizes water for cooling, lubrication, washing or as a solvent is always susceptible to:
A. Cross connections
B. An operator falling in to it
C. Garden hoses and backpressure
D. All of the above

37. When installing a vacuum breaker backflow device, the operator must make sure that:
A. It is 12 inches above the lowest discharge outlet
B. It is 2 inches above the air gap
C. It is 12 inches above the highest discharge outlet
D. It is made of brass

38. Which of the following statements is true concerning a double check backflow assembly?
A. A Double Check is approved for high contamination/pollution and backpressure
B. A double check will stop backsiphonage
C. A double check has a relief valve
D. A double check is redundant

39. Which of the following statements best describe the operation of a reduced pressure principal backflow assembly device?
A. The relief valve will open and drain if a pressure differential occurs between the two checks
B. The spring loaded diaphragm is below the second check valve
C. The air relief will open at 15 PSI
D. All of the above

40. Which of the following has the greatest potential hazard of contamination if a cross connection occurs?
A. Sugar machine
B. Commercial food processors
C. Swimming pools
D. Pesticide mixing tanks

41. What is the most likely consequence if a backsiphonage condition causes a cross connection and pressure is then restored to the system?
A. Probably dirty water
B. There will be no contamination
C. Backpressure
D. The distribution system downstream of the cross connection will be contaminated

42. A common abbreviation on plan and profile drawings is “PI”. What does this stand for?
A. Point of Increase
B. Point of Tap
C. Point of Instruction
D. Point of Intersection

43. Galvanized pipes are unsuitable for most services because:
A. Easily bent
B. Improper threads
C. Galvanic corrosion
D. Palatability problems

44. If valve and hydrant maps are to be effective, the maps must:
A. Provide measurements to appurtenances from permanent references/tie and measure
B. Show as-builts
C. Have the Operator’s name on the each valve
D. Show the size the stem

45. An effective cross-connection control program should focus on two major sources of problems. These will include:
A. Firefighting equipment/Pollutional sources
B. Garden Hoses/ Air Gaps
C. Customer plumbing problems/Auxiliary water sources
D. All of the above

46. What is the name of a map that an operator would use on a day to day basis that provides detailed drawings of distribution zones, but does not show all the system components?
A. Leak survey maps
B. Sectional Maps
C. Comprehensive maps

47. Intersection indexes can be prepared by:
A. Alphabetizing street names
B. Assigning numbers to each intersection
C. scada
D. SCATA
E. CMOM

48. What is the advantage of a "**Wet Tap**" over a "**Dry Tap**" ?
A. You have more chances of contamination
B. You do not need a shut down for a corp/saddle installation
C. A ball peen hammer is all you need
D. The installation time is increased.

49. Why would an operator place a screen before a backflow prevention assembly?
A. Prevent debris from fouling the assembly
B. Prevent small animals from entering the assembly
C. To allow the passage of air
D. To keep insects out of the air relief

50. A single-phase motor is receiving adequate power and the run windings are operable, but the motor will not start, what could be the problem?
A. The switch is closed
B. There is a problem with the stator
C. There is a problem with the start winding
D. There is a problem with the Rotor Monitor

51. Who has the responsibility for insuring that water contamination due to cross connections does not occur?
A. EPA
B. The Health Dept
C. Federal Government
D. The water utility
E. All of the above

52. Pigs traveling at speeds of 10 fps will likely result in:
A. Excessive wearing of the pig
B. SOCs and BOD reduction
C. Leaks in the water line
D. Complete removal of the tubercles
E. MIB

53. When cleaning or swabbing a water line, the velocity should be:
A. 2-4 fps
B. 10-20 fps
C. 20 PPM
D. 5 gallons per minute

54. Of the following answers, which is an acceptable way to launch pigs?
A. Using a fire hydrant
B. Using a taping tool
C. Tying the pig up, and having an Operator 1 using a backhoe
D. Using a high pressure air compressor, or PTO

55. Mechanical seals consist of two machined and polished surfaces which must contact each other. This contact is maintained by:
A. Spring pressure
B. Water pressure

56. What is the main reason for having an updated comprehensive map of the entire water distribution system?
A. To help identify and record sections that need improvement or development
B. To show all of the other utilities and their locations
C. To help develop a per capita use plan
D. To make work for the Valveman

57. Valve and hydrant maps using an intersection method of indexing will typically have a scale of:
A. 1 mile per inch
B. 1/25
C. 20-30 feet per inch
D. 1/2

58. Water audits can be performed in order to account for the water in the system. What should be the first step in a water audit?
A. Measure flow in to each quarter-section
B. Pump test
C. A 24 hour measure of all the water entering the system
D. Dye test

59. Which of the following types of motors would be expected to have the lowest demand for starting current?
A. Wound-rotor induction motor
B. Squirrel Cage induction motor
C. Rotor Synch motor
D. None of the Above

60. The purpose of a sump on a vertical turbine pump is used to maintain adequate:
A. Liquid above the suction level
B. Pressure for the foot valve
C. Backpressure
D. Cavitation diffusion

61. This term is used to describe head pressure or energy lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restrictions by fittings.
A. C Factor
B. Friction Losses
C. Pressure
D. Pressure Head
E. None of the above

62. Continuous leakage from a mechanical seal indicates:
A. An abnormal condition
B. A normal condition
C. Packing needs to be tightened
D. Mechanical gland needs to be replaced
E. All of the above

63. When you are shutting a large valve, which of the following valves will reduce high pressure that can be present?
A. Gate valve
B. Bypass valve
C. Binder device
D. Inserting Valve

64. What is the most likely choice for the result of grease coming into contact with the windings of a motor?
A. The winding insulation may deteriorate
B. The overloads will trip
C. There will be a phase monitor problem
D. The torque converter will fail

65. If the pH of water from a dead-end line begins to drop, it is most likely an indication that:
A. Anaerobic conditions are present
B. The main is being flushed regularly
C. There is a redwood plug in the main
D. None of the above

66. An electric motor that has a frequency of 60Hz will have a maximum synchronous speed of:
A. 600 rpms
B. 3600 rpms
C. 3000 rpms
D. None of the Above

67. As the wear ring inside a centrifugal pump loses tolerance between the impeller and wear ring, the efficiency of the pump will:
A. Remain the same
B. Fluctuates with the velocity of water
C. Increases
D. Decreases
E. None of the above

68. Multistage centrifugal pumps can discharge high pressure water. The pressure increases with the number of stages, but what happens to the capacity/ flow of the pump?
A. The flow is decreased by 25% for each stage
B. The flow will remain the same through each stage
C. The flow will double with each stage
D. The flow is cut in half

69. What is the function of speed controls on valve actuators?
A. A SCADA function
B. To prevent a water hammer
C. To prevent backflow
D. A measuring device
E. All of the above

70. Dry-barrel fire hydrants with unplugged drains should be inspected:
A. Twice a year
B. Prior to installation
C. By placing a stethoscope on the stem
D. With the gate valve closed and pressure induced through an outlet nozzle

71. With remote manual control, the operator is also required to turn a switch or push a button to operate equipment. Control devices which actuate equipment by inducing a _____in the device are commonly known as _____.
A. Electric charge, SCADA
B. Magnetic field, Solenoids
C. Electric charge, Full Duplexing switches
D. EMF, Helical Sensors
E. Pressure change, Diaphragms

72. Thrust protection from thrust blocks should:
A. To kick the pipe in place
B. Partially cradle the protected pipe and to equally distribute the force
C. Be part all thread and 500 pounds of cement
D. Not poured in trenches near fire hydrants

73. Cement-mortar linings of water mains have been effectively used on nearly all pipe diameters. However, the most cost effective use of this procedure is generally for water lines of_____ or greater.
A. 8 Inches
B. 12 Inches
C. 18 Inches
D. 48 Inches

74. What design criteria of water distribution systems is based upon the Hazen-Williams formula?
A. Pipe Size
B. Fire control capacities
C. Pressure head requirements
D. Never heard of this guy, all of the above

75. Which of the following problems may occur during periods of high flow or a fire when the waterline's pressure has dropped drastically?
A. Negative pressure in parts of the system
B. Water hammer
C. Low velocity throughout the system
D. All of the above

76. This type of valve which controls water pressure operates by restricting flows. They are used to deliver water from a high pressure to a low pressure system. The pressure downstream from the valve regulates the amount of flow. Usually, these valves are of the globe design and have a spring-loaded diaphragm that sets the size of the opening.
A. Pressure Regulation Valve
B. A Butterfly Valve
C. Reduced Pressure
D. Check Valve

77. What is the intent of a designer when multiple water pumps are installed for paralleled operation?
A. To increase the discharge head
B. To provide for a fluctuating demand/or for if one pump is out of service
C. To increase the water force

78. During an inspection of your water storage facility, how should you inspect the Cathodic protection system?
A. Check the anode's condition and the connections
B. Check the system with a Megger
C. Check the dielectric converter
D. Check the voltage level

79. The concentration of polyphosphates that is used for corrosion control in storage tanks is typically _____ or less.
A. 5 mg/L
B. 15 mg/L
C. 20 mg/L
D. 50 PPM

80. The most accurate method of measuring chlorine residual concentrations is:
A. The Walker method
B. Combined residual analysis
C. The DPD procedure
D. Amperometric titration
E. CMOM

81. According to the manual, external corrosion of steel water storage facilities can be reduced with a coating of:
A. Zinc or aluminum coatings
B. Lead coatings
C. Petroleum coatings
D. Latex coatings

82. All storage facilities should be regularly sampled to determine the quality of water which enters and leaves the facility. One tool or piece of measuring equipment is the Jackson turbidimeter. What is the function of this device?
A. A visual method to measure cloudiness in water
B. An instrumental method based on deflected light
C. Both 1 & 2
D. None of the above

83. The effects of water freezing in storage tanks can be minimized by:
A. Adding drinking water antifreeze
B. Adding solar heaters
C. Alternating water levels in the tank
D. Adding slaked lime
E. All of the above

84. Which of the following is a not a major concern when checking water levels in a storage tank?
A. The venting of air
B. Excessive water demands
C. Stale water
D. Backsiphonage

85. If an overflow occurs on a storage tank, the operator should first check:
A. Bac-t samples
B. Backpressure
C. The altitude-control valve
D. Pump velocity

86. What is most frequent type of accident(s) encountered by water distribution personnel?
A. Sprains and strains
B. An Operator 1 running a tamper over a foot
C. Slips and falls
D. Sunburns and hangovers
E. ERGO

87. If a thrust block of another utility is discovered in your path while excavating, you should:
A. Call the Engineer and place all thread on the thrust block
B. Be careful and alter the thrust block so that you can do the work
C. Do not alter the existing thrust block in any way
D. Do your work and pour concrete
E. File a NPDES

88. Right to Know Laws state that the employer has the responsibility to provide the employees with information about:
A. CDLs
B. The information about health hazards and chemical handling
C. The amount of each chemical to use in each application
D. The method of disposal for the product
E. CAFO

89. Safe entry into a confined space requires that:
A. All entrants be First aid trained and able to hold their breaths
B. All entrants wear watches to remind them of the time limit
C. All entrants wear a harness and safety line
D. A rescue squad is standing by.
E. All of the above

90. If an operator is working inside a storage tank and suddenly faints or has a serious problem, there should be:
A. Smelling salts available
B. Two handheld radios
C. Two people outside standing by to remove the injured operator

## Answers to Review Section

1. B
2. A
3. B
4. E
5. A
6. A
7. A
8. C
9. A
10. C
11. C
12. D
13. D
14. A
15. B
16. B
17. A
18. A
19. C
20. B
21. B
22. B
23. B
24. D
25. A
26. A
27. A
28. D
29. B
30. A
31. B
32. A
33. C
34. A
35. A
36. A
37. C
38. B
39. A
40. D
41. D
42. D
43. C
44. A
45. C
46. B
47. B
48. B
49. A
50. C
51. D
52. A
53. A
54. A
55. A
56. A
57. C
58. C
59. A
60. A
61. B
62. A
63. B
64. A
65. A
66. B
67. D
68. B
69. B
70. D
71. B
72. B
73. C
74. A
75. A
76. A
77. B
78. A
79. A
80. D
81. A
82. A
83. C
84. A
85. C
86. A
87. C
88. B
89. C
90. C

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