

Second Edition

Water and Wastewater Treatment

*A Guide for the
Nonengineering Professional*



Joanne E. Drinan
Frank R. Spellman



CRC Press
Taylor & Francis Group

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Contents

Preface.....xv
Acknowledgments xvii
About the authorsxix
On the cover: Pepacton Reservoir.....xxi

Section I: Introduction

Chapter 1 Current issues in water and wastewater treatment operations 3
Water is the new oil 3
 Characteristics of water 5
 Water use 6
Publicly owned treatment works: Cash cows or cash dogs? 10
New regulations: The paradigm shift..... 11
Multiple-barrier concept 13
 Multiple-barrier approach: Wastewater operations 15
Challenges facing water and wastewater operations 18
 Compliance with new, changing, and existing regulations 19
 Sustaining infrastructure..... 20
 Sustaining energy 25
 Privatization or reengineering 28
 Benchmarking 32
 Benchmarking: The process..... 34
 Maintaining a viable workforce 37
 Upgrading security 37
Consequences of 9/11 39
Summary 43
References and recommended reading 43

Section II: Basics of water treatment

Chapter 2 Water regulations, parameters, and characteristics	49
Purpose: Quality parameters for water	49
Purpose: Water treatment	49
Water quality: Federal regulations	49
Drinking water regulations	49
Water quality characteristics	51
Physical water quality characteristics	51
Solids in water	53
Turbidity	53
Color	54
Taste and odor	55
Temperature	56
Chemical water quality characteristics	56
Total dissolved solids (TDS)	56
Alkalinity	57
Hardness	57
Fluorides	57
Metals	58
Organics	58
Inorganics	60
Nutrients	60
pH	62
Chlorides	62
Biological water quality characteristics	62
Bacteria	63
Viruses	63
Algae	65
Protozoa	66
Worms (helminths)	67
Indicator organisms	67
Coliforms	68
Summary	69
References and recommended reading	69
 Chapter 3 Water purification: System overview	 71
Process purpose: Water purification	71
Water treatment unit processes	71
Summary	72
Reference and recommended reading	74
 Chapter 4 Sources, intake, and screening	 75
Introduction: Water sources	75

Water sources.....	75
Surface water supplies.....	76
Groundwater supply.....	78
Watershed management programs.....	79
Process purpose: Intake and screening.....	79
Process equipment: Intake.....	81
Surface and groundwater intake.....	82
Process equipment: Screening.....	83
Trash screens (rakes).....	83
Traveling water screens.....	84
Drum screens.....	85
Bar screens.....	85
Passive screens.....	85
Summary.....	87
 Chapter 5 Coagulation and flocculation	89
Process purpose: Coagulation and flocculation.....	89
Coagulant chemicals.....	90
Coagulant types.....	90
Coagulant aids.....	91
Process operation: Coagulation.....	92
Process operation: Flocculation.....	92
Summary.....	93
References and recommended reading.....	93
 Chapter 6 Sedimentation	95
Process purpose: Sedimentation.....	95
Process equipment.....	95
Process operation.....	95
Summary.....	97
 Chapter 7 Filtration	99
Process purpose: Filtration.....	99
Process equipment.....	99
Slow sand filtration systems.....	100
Rapid sand filtration systems.....	101
Other common filtration systems.....	103
Summary.....	104
 Chapter 8 Disinfection	105
A Sherlock Holmes at the pump.....	105
Dr. John Snow.....	105
Cholera.....	105
Flashback to London, 1854.....	106

Pump handle removal—to water treatment (disinfection)	107
Process purpose: Disinfection.....	109
Chlorination.....	110
Chlorination chemistry	111
Chlorination equipment.....	112
Chlorination by-products.....	112
Alternative methods of disinfection	114
UV radiation.....	114
Ozonation	115
Membrane processes	115
Reverse osmosis.....	115
Electrodialysis.....	116
Summary	118
Chapter 9 Distribution	119
Process purpose and method.....	119
Distribution systems.....	119
Process equipment	120
Summary	125
Reference and recommended reading	125

Section III: Basics of wastewater treatment

Chapter 10 Wastewater regulations, parameters, and characteristics	129
Purpose: Wastewater parameters	129
Purpose: Wastewater treatment.....	129
Wastewater regulations.....	129
Wastewater characteristics.....	130
Physical wastewater characteristics.....	130
Solids in water	130
Turbidity.....	131
Color	132
Odor.....	132
Temperature	132
Chemical wastewater characteristics	132
Total dissolved solids (TDS).....	132
Metals	133
Organics	133
Inorganics	134
pH.....	134
Chlorides.....	135
Nutrients	135

Biological wastewater characteristics	135
Bacteria	136
Viruses.....	136
Algae.....	137
Protozoa	137
Worms (helminths).....	137
Indicator organisms	137
Coliforms	138
Summary	138
Reference and recommended reading	138
 Chapter 11 Wastewater sources and types.....	139
Wastewater.....	139
Wastewater sources and general constituents	139
Human and animal wastes.....	139
Household wastes	140
Industrial wastes	140
Storm water runoff.....	140
Groundwater infiltration.....	140
Average wastewater physical characteristics	140
Physical characteristics.....	141
Chemical characteristics.....	141
Summary	142
Reference and recommended reading	143
 Chapter 12 Wastewater treatment: Basic overview	145
Wastewater treatment.....	145
Summary	146
 Chapter 13 Collection systems.....	149
Process purpose: Collection	149
Collection system types	149
Sanitary sewers.....	149
Storm sewers	150
Combined sewerage systems.....	150
Collection system components.....	151
Construction materials.....	152
Materials	152
Selection factors	153
Maintenance	153
Line cleaning	154
Jetting	155
Flushing	155
Balling	156

Rodding	157
Bucketing.....	157
Common collection system problems	157
Aging systems	157
Roots.....	158
Grease.....	158
New technologies.....	159
Electronic technology for collection systems.....	159
Trenchless technologies.....	159
Summary	160
References and recommended reading	160
Chapter 14 Preliminary treatment	161
Preliminary treatment processes.....	161
Process purpose and equipment: Preliminary treatment.....	161
Screening	161
Shredding	163
Grit removal	163
Flow measurement.....	164
Preaeration	165
Chemical addition.....	166
Chemical feeders	166
Flow equalization.....	167
Summary	167
Chapter 15 Primary sedimentation.....	169
Process purpose and method: Sedimentation	169
Process equipment: Sedimentation tanks	169
Septic tanks	169
Two-story tanks.....	171
Plain settling tanks	171
Settling tank effluent	172
Summary	172
Chapter 16 Biological treatment	173
Process purpose	173
Process systems	174
Trickling filters	174
Trickling filter definitions	176
Trickling filter performance classifications	177
Trickling filter equipment	178
Rotating biological contactors (RBCs)	179
RBC equipment.....	180

Treatment ponds and lagoons	181
Pond types	182
Ponds by location and waste	182
Oxidation ponds	183
Polishing ponds	183
Ponds by pond biological process	183
Aerobic ponds	183
Anaerobic ponds	184
Facultative ponds	184
Aerated ponds	184
Activated sludge systems	184
Activated sludge terminology	184
Activated sludge process operation	187
Activated sludge process equipment	188
Summary	189
 Chapter 17 Secondary sedimentation	191
Process purpose: Secondary sedimentation	191
Secondary settling	191
Summary	193
 Chapter 18 Advanced treatment	195
Process purpose	195
Advanced treatment processes	196
Effluent polishing	196
Nitrogen removal	196
Phosphorus removal	197
Membrane processes for advanced treatment	197
Land application	199
Summary	200
References and recommended reading	201
 Chapter 19 Wastewater disinfection	203
Process purpose	203
Chlorination	203
Other forms of chlorination: Hypochlorite	206
Dechlorination	206
Sulfur dioxide dechlorination	207
Ultraviolet (UV) radiation	208
Ozonation	209
Bromine chloride	211
No disinfection	211
Summary	211

Chapter 20 Discharge effluent	213
Process purpose: Discharge and reuse	213
Wastewater discharge	213
Wastewater reuse	213
Nonpotable reuse	214
Potable reuse	215
Summary	216

Section IV: Basics of water and wastewater solids treatment and management

Chapter 21 Water solids management: System overview	219
Process purpose: Water treatment sludges	219
Water treatment sludge disposal regulations	220
Alum sludge treatment processes	220
Softening sludge (lime sludge) treatment processes.....	220
Summary	221
References and recommended reading	221

Chapter 22 Water solids treatment and disposal.....	223
Water sludge treatment processes	223
Alum sludge treatment.....	223
Thickening	224
Coagulant recovery.....	224
Conditioning.....	225
Dewatering.....	225
Drying.....	225
Disposal.....	225
Recoverable and nonrecoverable water	228
Summary	228
References and recommended reading	230

Chapter 23 Wastewater biosolids management: System overview	231
Process purpose: Wastewater biosolids treatment.....	231
Sewage biosolids regulations	231
Process: Wastewater biosolids treatment.....	232
Public opinion and odor control	232
Summary	233
Reference and recommended reading	233

Chapter 24 Wastewater biosolids treatment.....	235
Wastewater biosolids treatment and disposal alternatives	235

Thickening	235
Gravity thickening	236
Flotation thickening	236
Centrifugation	238
Stabilization	238
Anaerobic digestion	238
Aerobic digestion	239
Thermal stabilization	240
Chemical application	240
Chlorine stabilization	240
Lime stabilization	240
Conditioning	241
Chemical conditioning	241
Thermal conditioning	241
Dewatering	242
Natural dewatering methods	243
Mechanical dewatering methods	243
Vacuum filtration	243
Pressure filtration	243
Centrifugation	245
Summary	246
References and recommended reading	246
 Chapter 25 Wastewater biosolids disposal	247
Disposal alternatives	247
Disposal methods	247
Water	247
Land	248
Landfilling	248
Land application: Soil conditioning/fertilizing	249
Land reclamation	249
Composting	250
Aerated static pile composting	250
Curing and drying	251
Screening	252
Shaker screens	252
Trommel screens	252
Incineration	252
Incineration advantages	253
Incineration process	253
Types of incinerators	253
Multiple-hearth furnaces (MHFs)	254
Fluid bed furnace (FBF)	255
Cyclonic furnace	257

Electric furnace..... 257

Ash disposal vs. reuse..... 257

Summary 258

References and recommended reading 258

Glossary 259

Preface

An industry-wide best-seller hailed on its first publication as a masterly account written in an engaging, highly readable style, *Water and Wastewater Treatment: A Guide for the Nonengineering Professional*, 2nd edition, is ideal for municipal managers, departmental and administrative assistants, equipment sales or marketing personnel, and customer services representatives, as well as those serving on utility municipality boards and those professionals and general readers with little or no science background.

This standard synthesis has been completely revised and expanded for the second edition. For example, we begin with a comprehensive discussion of updated current issues facing the water and wastewater industries. Then, the text presents all the basic unit processes involved in drinking water and wastewater treatment, step-by-step, in jargon-free language. It describes each unit process, what function the process provides in water or wastewater treatment, and the basic equipment each process uses. It details how the processes fit together within a drinking water or wastewater treatment system, and surveys the fundamental concepts that make up water/wastewater treatment processes as a whole.

By design, this text does not include mathematics, engineering, chemistry, or biology. However, it does include numerous illustrations, as well as an extensive glossary of terms and abbreviations for easy comprehension of concepts and processes, and for quick reference.

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On the cover: Pepacton Reservoir

The New York City Watershed covers approximately 2,000 square miles in the southeastern part of New York State. The watershed encompasses 19 reservoirs that provide water to nearly 9 million people in and around New York City.

One of the 19 reservoirs is the Pepacton Reservoir. Located in southern Delaware County of New York, it is the largest, by volume, of four reservoirs in the Delaware Water Supply System of the watershed. The reservoir is more than 100 miles northwest of the city, near Catskills Park. Placed into service in 1955, the Pepacton is 15 miles long, contains 140 billion gallons of water at full capacity, and provides about 25% of the over 1 billion gallon total daily flow into New York City.

New York City Department of Environmental Protection (DEP) is tasked with managing and conserving the city's water supply. DEP implemented the Long-Term Watershed Protection Program to ensure that water in the New York City Watershed remains of a high quality. Water that is transferred to New York City is disinfected with chlorine. The treated water then enters the water distribution system and is delivered directly to the consumers. Due to DEP's efforts in land acquisition and management within the watershed, the water obtained is of such a high quality that New York City is not required to filter its drinking water.

section one

Introduction

chapter one

Current issues in water and wastewater treatment operations

The failure to provide safe drinking water and adequate sanitation services to all people is perhaps the greatest development failure of the twentieth century.

—Gleick (1998, 2000, pp. 39–64)

*Water is the new oil**

Although not often thought of as a commodity (or, for that matter, not thought about at all), water is a commodity—a very valuable, very necessary, very vital commodity. We consume water, waste it, discard it, pollute it, poison it, and relentlessly modify the hydrological cycles (natural and urban cycles), with total disregard to the consequences: “too many people, too little water, water in the wrong places and in the wrong amounts. The human population is burgeoning, but water demand is increasing twice as fast” (De Villiers, 2000). It is our position that with the passage of time, potable water will become even more valuable. Moreover, with the passage of even more time, potable water will be even more valuable than we might ever imagine—possibly (likely) comparable in pricing, gallon for gallon, to what we pay for gasoline, or even more. From urban growth to infectious disease and newly identified contaminants in water, greater demands are being placed on our planet’s water supply (and other natural resources). As the global population continues to grow, people will place greater and greater demands on our water supply (U.S. Water News Online, 2000). The fact is—simply, profoundly, without a doubt in the authors’ mind—water is the new oil.

Earth was originally allotted a finite amount of water—we have no more or no less than that original allotment today. Thus, it logically follows that, in order to sustain life as we know it, we must do everything we can to preserve and protect our water supply. Moreover, we also must purify and reuse the water we presently waste (i.e., wastewater). Further,

* Much of this section is taken from or adapted from Spellman, F.R., *Handbook of Water and Wastewater Treatment Plant Operations*, 2nd ed., Boca Raton, FL: CRC Press, 2008.

it is our belief that the day is nearing when pipe to pipe (toilet to treatment plant to drinking water tap) is quickly approaching.

Let's get to water being the new oil. You may be wondering how we can make such an audacious and all-encompassing statement. Well, consider that even though 70+% of earth is covered with water, only 3% is fit for human consumption, of which two-thirds is frozen and largely uninhabited ice caps and glaciers, leaving 1% available for consumption. The remaining 97% is saltwater, which cannot be used for agriculture or drinking. If all the earth's water fit in a quart jug, available freshwater would not equal a teaspoon. Thus, some (including us) would consider water the new oil.

Let's take a moment and make a few important points about water, the new oil.

Unless you are thirsty, in real need of refreshment, when you look upon a glass of water you might ask—well, what could be more boring? The curious might wonder: What are the physical and chemical properties of water that make it (the water in the glass) so unique and necessary for living things? Again, when you look at a glass of water, taste and smell it—well, what could be more boring? Pure water is virtually colorless and has no taste or smell. But don't be snookered or taken aback by its boring presence; the hidden qualities of water make it a most interesting subject.

When the uninitiated becomes initiated to the wonders of water, one of the first surprises is that the total quantity of water on earth is much the same now as it was more than 3 or 4 billion years ago, when the 320+ million cubic miles of it were first formed—there is no more freshwater on earth today than there was millions of years ago. The water reservoir has gone round and round, building up, breaking down, cooling, and then warming. Water is very durable, but remains difficult to explain, because it has never been isolated in a completely undefiled state.

Have you ever wondered what the nutritive value of water is? Well, the fact is water has no nutritive value. It has none; yet it is the major ingredient of all living things. Consider yourself, for example. Think of what you need to survive—just to survive. Food? Air? PS3? MTV? Water? NFL Football? Twinkies? An aspirin each day? Naturally, the focus of this text is on water. Water is of major importance to all living things; in some organisms, up to 90% of their body weight comes from water. Up to 60% of the human body is water, the brain is composed of 70% water, and the lungs are nearly 90% water. About 83% of our blood is water, which helps digest our food, transport waste, and control body temperature. Each day humans must replace 2.4 L of water, some through drinking and the rest taken by the body from the foods eaten.

There wouldn't be any you, me, or Luci Lu the dog without the existence of an ample liquid water supply on earth. The unique qualities and properties of water are what make it so important and basic to life. The

cells in our bodies are full of water. The excellent ability of water to dissolve so many substances allows our cells to use valuable nutrients, minerals, and chemicals in biological processes.

Water's "stickiness" (from surface tension) plays a part in our body's ability to transport these materials all through ourselves. The carbohydrates and proteins that our bodies use as food are metabolized and transported by water in the bloodstream. No less important is the ability of water to transport waste material out of our bodies.

Water is used to fight forest fires. Yet we use water spray on coal in a furnace to make it burn better.

Water can be esthetically pleasing—incomparable. For instance, have you ever stood on the rim of Crater Lake, Oregon, on a clear day and looked down 1,000 ft into the matchless beauty of those startling, mesmerizing blue waters?

Chemically, water is hydrogen oxide. It turns out, however, on more advanced analysis to be a mixture of more than 30 possible compounds. In addition, all of its physical constants are abnormal (strange).

At a temperature of 2,900°C some substances that contain water cannot be forced to part with it. And yet others that do not contain water will liberate it when even slightly heated.

When liquid, water is virtually incompressible; as it freezes, it expands by an 11th of its volume.

For the above stated reasons, and for many others, we can truly say that water is special, strange, and different.

Characteristics of water

To this point in this text many things have been said about water; however, it has not been said (nor will it be) that water is plain. This is the case because nowhere in nature is plain water to be found. Here on earth, with a geologic origin dating back over 3 to 5 billion years, water found in even its purest form is composed of many constituents. You probably know water's chemical description is H_2O —that is one atom of oxygen bound to

DID YOU KNOW?

All these water molecules attracting each other mean they tend to clump together. This is why water drops are, in fact, drops! If it *wasn't* for some of earth's forces, such as gravity, a drop of water would be ball shaped—a perfect sphere. Even if it doesn't form a perfect sphere on earth, we should be happy water is sticky.

Pure water has a neutral pH of 7, which is neither acidic nor basic.

DID YOU KNOW?

Water is called the universal solvent because it dissolves more substances than any other liquid. This means that wherever water goes, either through the ground or through our bodies, it takes along valuable chemicals, minerals, and nutrients.

two atoms of hydrogen. The hydrogen atoms are “attached” to one side of the oxygen atom, resulting in a water molecule having a positive charge on the side where the hydrogen atoms are and a negative charge on the other side, where the oxygen atom is. Since opposite electrical charges attract, water molecules tend to attract each other, making water kind of “sticky”—the hydrogen atoms (positive charge) attract the oxygen side (negative charge) of a different water molecule.

Along with H_2O molecules, hydrogen (H^+), hydroxyl (OH^-), sodium, potassium, and magnesium, there are other ions and elements present. Additionally, water contains dissolved compounds, including various carbonates, sulfates, silicates, and chlorides. Rainwater, often assumed to be the equivalent of distilled water, is not immune to contamination that is collected as it descends through the atmosphere. The movement of water across the face of land contributes to its contamination, taking up dissolved gases, such as carbon dioxide and oxygen, and a multitude of organic substances and minerals leached from the soil. Don’t let that crystal-clear-looking lake or pond fool you. These are not filled with water alone but are composed of a complex medium of chemical ingredients far exceeding the brief list presented here; it is a special medium in which highly specialized life can occur.

How important is water to life? To answer this question all we need do is to take a look at the common biological cell: it easily demonstrates the importance of water to life.

Living cells comprise a number of chemicals and organelles within a liquid substance, the cytoplasm, and the cell’s survival may be threatened by changes in the proportion of water in the cytoplasm. This change in proportion of water in the cytoplasm can occur through desiccation (evaporation), oversupply, or the loss of either nutrients or water to the external environment. A cell that is unable to control and maintain homeostasis (i.e., the correct equilibrium/proportion/balance of water) in its cytoplasm may be doomed—it may not survive.

Water use

In the United States, rainfall averages approximately $4,250 \times 10^9$ gal/day. About two-thirds of this returns to the atmosphere through evaporation

directly from the surface of rivers, streams, and lakes and transpiration from plant foliage. This leaves approximately $1,250 \times 10^9$ gal/day to flow across or through the earth to the sea.

USGS (2004) points out that estimates in the United States indicate that about 408 billion gal/day (Bgal/day) were withdrawn from all uses during 2000. This total has varied less than 3% since 1985 as withdrawals have stabilized for the two largest uses—thermoelectric power and irrigation. Fresh groundwater withdrawals (83.3 Bgal/day) during 2000 were 14% more than during 1985. Fresh surface water withdrawals for 2000 were 262 Bgal/day, varying less than 2% since 1985.

About 195 Bgal/day, or 8% of all freshwater and saline water withdrawals for 2000, were used for thermoelectric power. Most of this water was derived from surface water and used for once-through cooling at power plants. About 52% of fresh surface water withdrawals and about 96% of saline water withdrawals were for thermoelectric power use. Withdrawals for thermoelectric power have been relatively stable since 1985.

Irrigation remained the largest use of freshwater in the United States and totaled 137 Bgal/day for 2000. Since 1950, irrigation has accounted for about 65% of total water withdrawals, excluding those for thermoelectric power. Historically, more surface water than groundwater has been used for irrigation. However, the percentage of total irrigation withdrawals from groundwater has continued to increase, from 23% in 1950 to 42% in 2000. Total irrigation withdrawals were 2% more for 2000 than for 1995, because of a 16% increase in groundwater withdrawals and a small decrease in surface water withdrawals. Irrigated acreage more than doubled between 1950 and 1980, then remained constant before increasing nearly 7% between 1995 and 2000. The number of acres irrigated with sprinkler and microirrigation systems has continued to increase and now comprises more than one-half the total irrigated acreage.

Public supply withdrawals were more than 43 Bgal/day for 2000. Public supply withdrawals during 1950 were 14 Bgal/day. During 2000, about 85% of the population in the United States obtained drinking water from public suppliers, compared to 62% during 1950. Surface water provided 63 of the total during 2000, whereas surface water provided 74% during 1950.

Self-supplied industrial withdrawals totaled nearly 20 Bgal/day in 2000, or 12% less than in 1995, and compared to 1985, industrial self-supported withdrawals declined by 24%. Estimates of industrial water use in the United States were largest during the years from 1965 to 1980, but during 2000, estimates were at the lowest level since reporting began in 1950. Combined withdrawals for self-supplied domestic, livestock, aquaculture, and mining were less than 13 Bgal/day for 2000, and represented about 3% of total withdrawals.

California, Texas, and Florida accounted for one-fourth of all water withdrawals for 2000. States with the largest surface water withdrawals were California, which has large withdrawals for irrigation and thermo-electric power, and Texas and Nebraska, which have large withdrawals for irrigation.

All this factual information is interesting. Well, it is interesting to those of us who are admirers, purveyors, or students of water. Obviously, these are the folks that read and use a book like this one. However, the question is: What does all this information have to do with water being the new oil?

Water is the new oil because there is no more freshwater on earth today than there was millions of years ago. Yet at the present time, more than 6 billion people share it. Since the 1950s, the world population has doubled, but water use has tripled. A simple extrapolation of today's water usage compared to projected usage in the future shows that water will become a much more important commodity than it is today. Earlier it was stated that the day is coming when a gallon of water will be comparable in value to (or even more expensive than) a gallon of gasoline. There are those who will read this and shake their heads in doubt and state: "Water is everywhere; water belongs to no one; water belongs to everyone; no one owns water; water pours freely from the sky; water has no real value ... certainly water is nowhere near as valuable as gasoline ... nowhere near as valuable as gold or diamonds or silver or my iPod."

Hmmm ... interesting, to say the least. Water has no real value? Really?

In regard to water and diamonds and which of the two is more valuable, consider the following. Adam Smith, the 18th century philosopher credited with laying the foundation of modern economics, in his epic book *The Wealth of Nations*, described the paradox of diamonds and water. Smith asked: How could it be that water, so vital to life, is so cheap, while diamonds, used only for adornment, are very costly? Smith pointed out that when it comes to value, a container full of diamonds is exponentially more valuable than an equal amount of water. In today's value system (as it was in Smith's), this is true, of course. It is true unless you are dying of thirst. While on the verge of dying or thirst—when your throat is sandpaper dry and your cough so harmful and painful that your only choice is to choke to death, what value would you place on that same container of diamonds? On the container of water? If you were offered one or the other, which would you choose? Which would you give up everything you own for?

That is our point. Although Adam Smith used the paradox for his own pedagogical purposes, explaining the basic concepts of supply and demand and showing that prices reflect relative scarcity, today the paradox provides a troubling description of the way water is treated in our economy. While water may be critical to life itself, we don't have a clue

as to its true value (USEPA, 2003). No, not yet ... we have not reached that point yet. However, with the majority of the world's population being relatively thirsty and many dying of thirst or dying from drinking filthy, disgusting, pathogen-contaminated water, the dawn of new understanding is just around the corner. Moreover, as our population continues to grow and degradation of the world's supply continues and global climate change accelerates (it is our view that the convenient truth about global climate change is that it is a normal cyclical matter), it is our view that the diamond and water paradox will flip-flop. Diamonds will lose some value when compared to safe, potable, refreshing, life-sustaining drinking water. This will occur because when it comes to sustaining life and quenching our thirst, all the diamond-encrusted drinking glasses filled to the brim with diamond clear water will be just what the doctor ordered, thank you very much!

Years ago, when we first stated that water will be more valuable than an equal amount of gasoline, many folks (reviewers) asked us what part of the planet Mars, Neptune, or Venus we were from. Well, we have not been to Mars or the others and have not changed our opinion on the ever-increasing value of water—and this same realization will soon confront us all. By the way, with regard to that water we flush down our toilets and drains, the day is coming, in our opinion, when we will have direct pipe-to-pipe connection from wastewater treatment plants to our municipal potable water supply systems. Why? Water is the new oil. Furthermore, have you heard about the recent discovery of the ancient presence of water on Mars? My guess is that if we do not protect our water supplies, the Mars of today may be the earth of tomorrow. This is a thought to keep close at hand, close at heart, and very close to the brain cells as a reminder of what really matters.

If you do not accept the premise that water is the new oil, maybe you are willing to accept the possibility that we can use water as a medium to make oil. We are not talking about converting hydrogen from water into fuel; instead, consider that we can turn algae into fuel. Scientists at Old Dominion University (ODU), Norfolk, Virginia, for example, are conducting successful research on growing algae in treated sewage and extracting fatty oils from the weedy slime, then converting the oils into cleaner-burning

DID YOU KNOW?

Growing algae in wastewater will soak up nutrients in wastewater at the wastewater plant, thus helping the receiving water body, which could suffer from excessive nutrients discharged by such treatment plants.

fuel. As part of the research project, the algae is grown in tanks at a wastewater treatment plant in Norfolk, then converted to biofuel at an ODU facility. It should be pointed out that this wastewater-grown-algae-to-oil-to-fuel process has already proven itself in New Zealand (Harper, 2007).

The bottom line: The day is drawing near when water becomes new oil. This day is closer than what we may be willing to readily acknowledge.

Publicly owned treatment works: Cash cows or cash dogs?

Water and wastewater treatment facilities are usually owned, operated, and managed by the community (the municipality) where they are located. While many of these facilities are privately owned, the majority of water treatment plants (WTPs) and wastewater treatment plants (WWTPs) are publicly owned treatment works (POTW) (i.e., owned by local government agencies).

These publicly owned facilities are managed and operated on-site by professionals in the field. On-site management, however, is usually controlled by a board of elected, appointed, or hired directors/commissioners, who set policy, determine budget, plan for expansion or upgrading, hold decision-making power for large purchases, set rates for ratepayers, and in general control the overall direction of the operation.

When final decisions on matters that affect plant performance are in the hands of, for example, a board of directors comprised of elected and appointed city officials, their knowledge of the science, the engineering, and the hands-on problems that those who are on-site must solve can range from everything to nothing. Matters that are of critical importance to those in on-site management may mean little to those on the board. The board of directors may indeed also be responsible for other city services, and have an agenda that encompasses more than just the water or wastewater facility. Thus, decisions that affect on-site management can be affected by political and financial concerns that have little to do with the successful operation of a WTP or POTW.

Finances and funding are always of concern, no matter how small or large, well supported or underfunded, the municipality. Publicly owned treatment works are generally funded from a combination of sources.

DID YOU KNOW?

More than 50% of Americans drink bottled water occasionally or as their major source of drinking water—an astounding fact given the high quality and low cost of U.S. tap water.

These include local taxes, state and federal monies (including grants and matching funds for upgrades), as well as usage fees for water and wastewater customers. In smaller communities, in fact, the water/wastewater (W/WW) plants may be the only city services that actually generate income. This is especially true in water treatment and delivery, which is commonly looked upon as the cash cow of city services. As a cash cow, the water treatment works generates cash in excess of the amount of cash needed to maintain the treatment works. These treatment works are “milked” continuously with as little investment as possible. Funds generated by the facility do not always stay with the facility. Funds can be reassigned to support other city services—and when facility upgrade time comes, funding for renovations can be problematic. On the other end of the spectrum, spent water (wastewater) treated in a POTW is often looked upon as one of the cash dogs of city services. Typically, these units make only enough money to sustain operations. This is the case, of course, because managers and oversight boards or commissions are fearful, for political reasons, of charging ratepayers too much for treatment services. Some progress has been made, however, in marketing and selling treated wastewater for reuse in industrial cooling applications and some irrigation projects. Moreover, wastewater solids have been reused as soil amendments; also, ash from incinerated biosolids has been used as a major ingredient in forming cement revetment blocks used in areas susceptible to heavy erosion from river and sea inlets and outlets.

New regulations: The paradigm shift

Historically, as mentioned, the purpose of water supply systems has been to provide pleasant drinking water that is free of disease organisms and toxic substances. In addition, the purpose of wastewater treatment has been to protect the health and well-being of our communities. Water/wastewater treatment operations have accomplished this goal by (1) prevention of disease and nuisance conditions; (2) avoidance of contamination of water supplies and navigable waters; (3) maintenance of clean water for survival of fish, bathing, and recreation; and (4) and generally conservation of water quality for future use.

The purpose of water supply systems and wastewater treatment processes has not changed. However, primarily because of new regulations that include (1) protecting against protozoan and virus contamination; (2) implementation of the multiple-barrier approach to microbial control; (3) new requirements of the Ground Water Disinfection Rule (GWDR), the Total Coliform Rule (TCR) and Distribution System (DS), the Lead and Copper (Pb/Cu) rule; (4) regulations for trihalomethanes (THMs) and disinfection by-products (DBPs); and (5) new requirements to remove even more nutrients (nitrogen and phosphorus) from wastewater effluent, the

paradigm has shifted. We discuss this important shift momentarily, but first it is important to abide by Voltaire's advice; that is, "If you wish to converse with me, please define your terms."

For those not familiar with the term *paradigm*, it can be defined in the following ways. A *paradigm*, a general conversation buzzword, is the consensus of the scientific community; "concrete problem solutions that the profession has come to accept" (Holyningen-Huene, 1993, 134). Thomas Kuhn coined the term *paradigm*. He outlined it in terms of the scientific process. He felt that "one sense of paradigm, is global, embracing all the shared commitments of a scientific group; the other isolates a particularly important sort of commitment and is thus a subset of the first" (Holyningen-Huene, 1993, 134). The concept of paradigm has two general levels. The first is the encompassing whole, the summation of parts. It consists of the theories, laws, rules, models, concepts, and definitions that go into a generally accepted fundamental theory of science. Such a paradigm is global in character. The other level of paradigm is that it can also be just one of these laws, theories, models, etc., that combine to formulate a global paradigm. These have the property of being local. For instance, Galileo's theory that the earth rotated around the sun became a paradigm in itself, namely, a generally accepted law in astronomy. Yet, on the other hand, his theory combined with other local paradigms in areas such as religion and politics to transform culture. *Paradigm* can also be defined as a pattern or point of view that determines what is seen as reality.

We use the latter definition in this text.

A *paradigm shift* is defined as a major change in the way things are thought about, especially scientifically. Once a problem can no longer be solved in the existing paradigm, new laws and theories emerge and form a new paradigm, overthrowing the old if it is accepted. Paradigm shifts are the "occasional, discontinuous, revolutionary changes in tacitly shared points of view and preconceptions" (Daly, 1980). Simply, a paradigm shift represents "a profound change in the thoughts, perceptions, and values that form a particular vision of reality" (Capra, 1982, 30). For our purposes, we use the term *paradigm shift* to mean a change in the way things are understood and done.

In regard to water supply systems, the historical focus, or traditional approach, has been to control turbidity, iron and manganese, taste and odor, color, and coliforms. New regulations provided new focus, and thus a paradigm shift. Today the traditional approach is no longer sufficient. Providing acceptable water has become more sophisticated and costly. To meet the requirements of the new paradigm, a systems approach must be employed. In the systems approach, all components are interrelated. What affects one impacts others. The focus has shifted to multiple requirements (i.e., new regulations require the process to be modified or the plant upgraded).

To illustrate the paradigm shift in the operation of water supply systems, let us look back on the traditional approach of disinfection. Disinfection was used in water to destroy harmful organisms. Currently, disinfection is still used in water to destroy harmful organisms, but is now only one part of the *multiple-barrier approach*. Moreover, disinfection has traditionally been used to treat for coliforms only. Currently, because of the paradigm shift, disinfection now (and in the future) is used against coliforms, *Legionella*, *Giardia*, *Cryptosporidium*, and others. (Note: To effectively remove the protozoans *Giardia* and *Cryptosporidium* filtration is required; disinfection is not effective against the oocysts of *Cryptosporidium*.) Another example of the traditional vs. current practices is seen in the traditional approach to particulate removal in water to lessen turbidity and improve aesthetics, but now microbial removal plus disinfection is practical.

Another significant factor that contributed to the paradigm shift in water supply systems was the introduction of the Surface Water Treatment Rule (SWTR) in 1989. SWTR requires water treatment plants to achieve 99.9% (3 log) removal/activation/inactivation of *Giardia* and 99.99% (4 log) removal/inactivation of viruses. SWTR applies to all surface waters and groundwaters under direct influence (GWUDI).

As mentioned earlier, removal of excess nutrients such as nitrogen and phosphorus in wastewater effluent is now receiving more attention from regulators (U.S. Environmental Protection Agency (USEPA)) and others. One of the major concerns is over the appearance of dead zones in various water bodies (i.e., excess nutrients cause oxygen-consuming algae to grow and thus create oxygen-deficient dead zones). For example, in recent years it has not been uncommon to find several dead zone locations in the Chesapeake Bay region.

Multiple-barrier concept

On August 6, 1996, during the Safe Drinking Water Act Reauthorization signing ceremony, President Bill Clinton stated: "A fundamental promise we must make to our people is that the food they eat and the water they drink are safe."

No rational person could doubt the importance of the promise made in this statement.

The Safe Drinking Water Act (SDWA), passed in 1974 and amended in 1986 and (as stated above) reauthorized in 1996, gives the USEPA the authority to set drinking water standards. This document is important for many reasons, but is even more important because it describes how USEPA establishes these standards.

MULTIPLE-BARRIER APPROACH

Source Protection

Optimization of Treatment Process
Trained & Certified Plant Operators

Sound Distribution System Management
A Second Dose of Disinfectant

Cross-Connection Control

Continuous Monitoring & Testing

Drinking water standards are regulations that USEPA sets to control the level of contaminants in the nation's drinking water. These standards are part of the Safe Drinking Water Act's multiple-barrier approach to drinking water protection.

The multiple-barrier approach includes the following elements:

1. **Assessing and protecting drinking water sources.** Doing everything possible to prevent microbes and other contaminants from entering water supplies. Minimizing human and animal activity around our watersheds is one part of this barrier.
2. **Optimizing treatment processes.** Provides a second barrier. This usually means filtering and disinfecting the water. It also means making sure that the people who are responsible for our water are properly trained and certified and knowledgeable of the public health issues involved.
3. **Ensuring the integrity of distribution systems.** This consists of maintaining the quality of water as it moves through the system on its way to the customer's tap.
4. **Effecting correct cross-connection control procedures.** This is a critical fourth element in the barrier approach. It is critical because the greatest potential hazard in water distribution systems is associated with cross-connections to nonpotable waters. There are many connections between potable and nonpotable systems—every drain in a hospital constitutes such a connection—but cross-connections are those through which backflow can occur (Angele, 1974).
5. **Continuous monitoring and testing of the water before it reaches the tap.** Monitoring water quality is a critical element in the barrier approach. It should include having specific procedures to follow should potable water ever fail to meet quality standards.

With the involvement of USEPA, local governments, drinking water utilities, and citizens, these multiple barriers ensure that the tap water in the United States and territories is safe to drink. Simply, in the multiple-barrier concept, we employ a holistic approach to water management that begins at the source, continues with treatment, through disinfection and distribution.

Multiple-barrier approach: Wastewater operations

Not shown in the multiple-barrier approach is the fate of the used water. What happens to the wastewater produced? Wastewater is treated via the multiple-barrier treatment train, which is the combination of unit processes used in the system. The primary mission of the wastewater treatment plant (and the operator/practitioner) is to treat the waste stream to a level of purity acceptable to return it to the environment or for immediate reuse (i.e., at the present time, reuse in such applications as irrigation of golf courses, etc.).

Water and wastewater professionals maintain a continuous urban water cycle on a daily basis. B.D. Jones (1980, 2) sums this up as follows:

Delivering services is the primary function of municipal government. It occupies the vast bulk of the time and effort of most city employees, is the source of most contacts that citizens have with local governments, occasionally becomes the subject of heated controversy, and is often surrounded by myth and misinformation. Yet, service delivery remains the “hidden function” of local government.

Water is the most important (next to air) life-sustaining product on earth. There is nothing new, exaggerated, or hidden about this statement of fact. Yet, its service delivery (and all that it entails) remains a “hidden function” of local government (Jones, 1980). Shedding light on this hidden function is what this text is all about. We present our discussion in a completely new and unique dual manner—in what we consider the new

DID YOU KNOW?

Artificially generated water cycles or the urban water cycles consist of (1) source (surface or groundwater), (2) water treatment and distribution, (3) use and reuse, and (4) wastewater treatment and disposition, as well as the connection of the cycle to the surrounding hydrological basins (see Figures 1.1, 1.2, and 1.3).

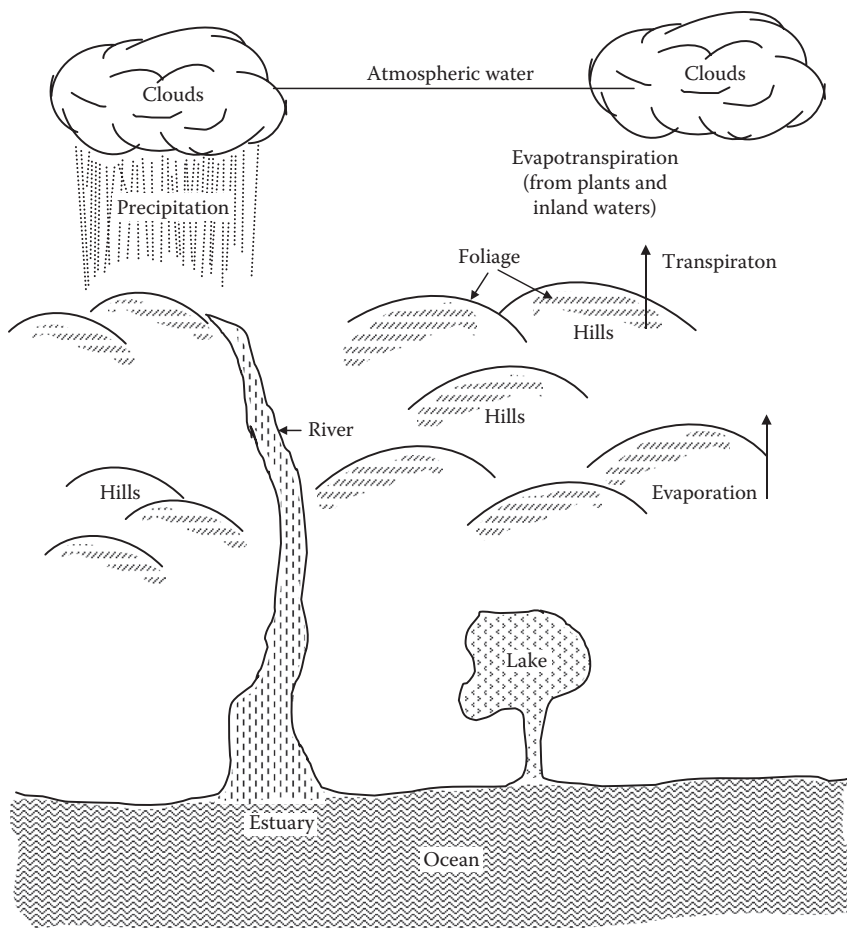


Figure 1.1 Natural water cycle.

paradigm shift in water management and in the concept of the multiple-barrier approach. Essentially, in blunt, plain English, this text exposes the hidden part of services delivered by water and wastewater professionals.

Water service professionals provide water for typical urban domestic and commercial uses, eliminate wastes, protect the public health and safety, and help control many forms of pollution. Wastewater service professionals treat the urban waste stream to remove pollutants before discharging the effluent into the environment. Water and wastewater treatment services are the urban circulatory system, the hidden circulatory system. In addition, like the human circulatory system, the urban circulatory system is less than effective if flow is not maintained. In a practical sense, we must keep both systems plaque-free and free-flowing.

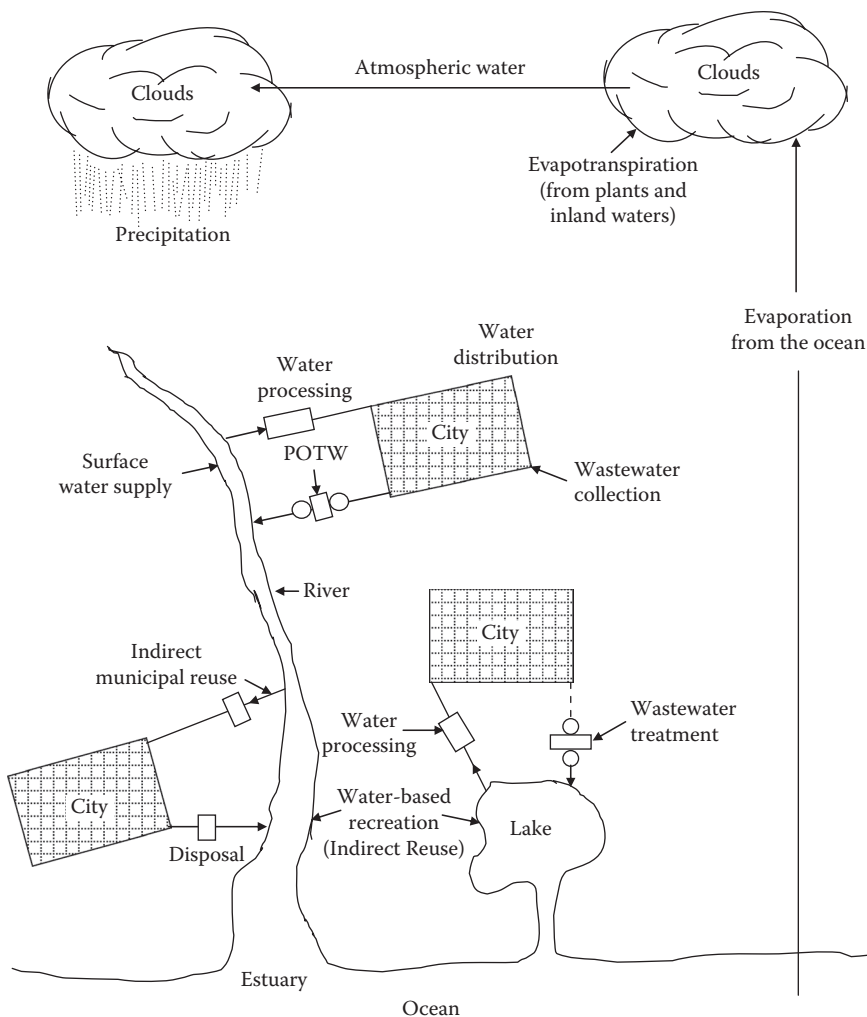


Figure 1.2 Urban water cycle.

Maintaining flow is what water and wastewater operations is all about. This seems easy enough: water has been flowing literally for eons, emerging from mud, rocks, silt. It is the very soul of moving water to carve a path, to pick up its load, to forge its way to the open arms of a waiting sea.

This is not to say that water and wastewater operations are not without problems or challenges. After surviving the Y2K (year 2000 problem or millennium bug) fiasco (were you surrounded by dysfunctional managers running about helter-skelter waiting until midnight for digital melt-down as we were?), the dawn of the 21st century brought with it, for many

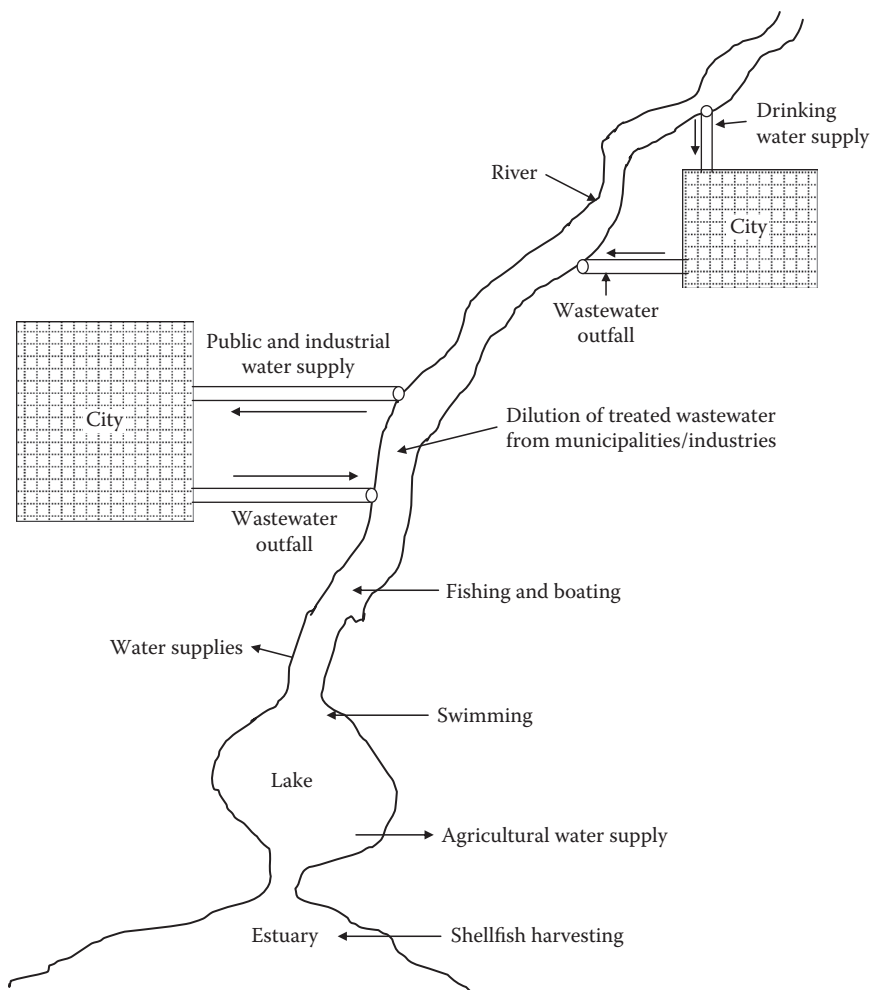


Figure 1.3 Indirect water reuse process.

of us, aspirations of good things ahead in the constant struggle to provide quality food and water for humanity. However, the only way in which we can hope to accomplish this is to stay on the cutting edge of technology and to face all challenges head on. Some of these other challenges are addressed in the following sections.

Challenges facing water and wastewater operations

Problems come and go, shifting from century to century, decade to decade, year to year, and from site to site. They range from the problems

DID YOU KNOW?

Every 15 to 20 seconds on our earth, a child dies from waterborne disease.

caused by natural forces (droughts, storms, earthquakes, fires, and floods) to those caused by social forces, currently including terrorism. In general, seven areas are of constant concern to many water and wastewater management personnel:

1. Complying with regulations, and coping with new and changing regulations
2. Sustaining infrastructure—maintaining and upgrading facilities, unit processes, and equipment
3. Sustaining energy
4. Privatization or reengineering
5. Benchmarking
6. Maintaining a viable and well-trained workforce
7. Upgrading security

Compliance with new, changing, and existing regulations

In September 2011, Fox News published an article titled “Regulation Nation: Drowning in Rules, Businesses Brace for Cost and Time for Compliance.” The article points out that even though President Obama recently acknowledged the need to minimize regulations, the number appears to be growing. The Obama administration has introduced regulations equivalent to 10 per week. Whether you believe this is good or bad practice is not the point. The point is that adapting the workforce to the challenges of meeting changing regulations and standards for both water and wastewater treatment is a major concern. As mentioned, drinking water standards are regulations that USEPA sets to control the level of contaminants in the nation’s drinking water. Again, these standards are part of the Safe Drinking Water Act’s (SDWA) multiple-barrier approach to drinking water protection. There are two categories of drinking water standards:

1. **A national primary drinking water regulation** (primary standard): This is a legally enforceable standard that applies to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water. They take the form of maximum contaminant levels (MCLs) or treatment techniques. The contaminants of concern include microorganisms,

disinfectants, disinfection by-products, inorganic chemicals, organic chemicals, and radionuclides.

2. **A national secondary drinking water regulation** (secondary standard): This is a nonenforceable guideline regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. USEPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards. Secondary contaminants include aluminum, chloride, color, copper, corrosivity, fluoride, foaming agents, iron, manganese, odor, pH, silver, sulfate, total dissolved solids, and zinc. This information focuses on national primary standards.

Drinking water standards apply to public water systems, which provide water for human consumption through at least 15 service connections, or regularly serve at least 25 individuals. Public water systems include municipal water companies, homeowner associations, schools, businesses, campgrounds, and shopping malls.

More recent requirements, for example, the Clean Water Act Amendments that went into effect in February 2001, require water treatment plants to meet tougher standards, presenting new problems for treatment facilities to deal with, and offering some possible solutions to the problems of meeting the new standards. These regulations provide for communities to upgrade existing treatment systems, replacing aging and outdated infrastructure with new process systems. Their purpose is to ensure that facilities are able to filter out higher levels of impurities from drinking water, thus reducing the health risk from bacteria, protozoa, and viruses, and that they are able to decrease levels of turbidity, and reduce concentrations of chlorine by-products in drinking water.

With regard to wastewater collection and treatment, the National Pollution Discharge Elimination System (NPDES) program established by the Clean Water Act issues permits that control wastewater treatment plant discharges. Meeting permit is always a concern for wastewater treatment managers because the effluent discharged into water bodies affects those downstream of the release point. Individual point source dischargers must use the best available technology (BAT) to control the levels of pollution in the effluent they discharge into streams. As systems age, and best available technology changes, meeting permit with existing equipment and unit processes becomes increasingly difficult.

Sustaining infrastructure

Another buzzword that has come into vogue in the last decade (used, as with all other buzzwords in this text, in a nonesoteric sense) is

sustainability. During the 1950s and 1960s, the U.S. government encouraged the prevention of pollution by providing funds for the construction of municipal wastewater treatment plants, water pollution research, and technical training and assistance. New processes were developed to treat sewage, analyze wastewater, and evaluate the effects of pollution on the environment. In spite of these efforts, however, expanding population and industrial and economic growth caused the pollution and health difficulties to increase.

In response to the need to make a coordinated effort to protect the environment, the National Environmental Policy Act (NEPA) was signed into law on January 1, 1970. In December of that year, a new independent body, the USEPA, was created to bring under one roof all of the pollution control programs related to air, water, and solid wastes. In 1972, the Water Pollution Control Act Amendments expanded the role of the federal government in water pollution control and significantly increased federal funding for construction of wastewater treatment plants.

Many of the wastewater treatment plants in operation today are the result of federal grants made over the years. For example, because of the 1977 Clean Water Act Amendment to the Federal Water Pollution Control Act of 1972 and the 1987 Clean Water Act reauthorization bill, funding for wastewater treatment plants was provided.

Many large sanitation districts, with their multiple plant operations, and even a larger number of single plant operations in smaller communities in operation today are a result of these early environmental laws. Because of these laws, the federal government provided grants of several hundred million dollars to finance construction of wastewater treatment facilities throughout the country.

Many of these locally or federally funded treatment plants are aging. Based on our experience, we rate some as dinosaurs, with some of our infrastructure over 100 years old. The point is many facilities are facing problems caused by aging equipment, facilities, and infrastructure. Complicating the problems associated with natural aging is the increasing pressure on inadequate older systems to meet demands of increased population and urban growth. Facilities built in the 1960s and 1970s are now 30 to 40 years old, and not only are they showing signs of wear and tear, but they simply were not designed to handle the level of growth that has occurred in many municipalities.

Regulations often necessitate a need to upgrade. By matching funds or providing federal money to cover some of the costs, municipalities can take advantage of a window of opportunity to improve their facility at a lower direct cost to the community. Those federal dollars, of course, do come with strings attached; they are to be spent on specific projects in specific areas. On the other hand, many times new regulatory requirements are put in place without the financial assistance needed to implement.

When this occurs, either the local community ignores the new requirements (until caught and forced to comply) or they face the situation and implement through local tax hikes to pay the cost of compliance.

An example of how a change in regulations can force the issue is demonstrated by the demands made by OSHA and USEPA in their Process Safety Management (PSM)/Risk Management Planning (RMP) regulations (29 CFR 1910.119—OSHA). These regulations put the use of elemental chlorine (and other listed hazardous materials) under scrutiny. Moreover, because of these regulations, plant managers throughout the country are forced to choose which side of a double-edged sword cuts their way the most. One edge calls for full compliance with the regulations (analogous to stuffing the regulation through the eye of a needle). The other edge calls for substitution, that is, replacing elemental chlorine with a nonlisted chemical (e.g., hypochlorite) or a physical (ultraviolet irradiation (UV)) disinfectant. Either way, it is a very costly undertaking.

Note: Many of us who have worked in water and wastewater treatment for years characterize PSM and RMP as the USEPA's way of killing the use of chlorine for disinfectant purposes. You have probably heard the old saying: "If you can't do away with something in one way, then regulate it to death." Remember, some call us the regulation nation.

Note: Changes resulting because of regulatory pressure sometimes mean replacing or changing existing equipment, increased chemical costs (e.g., substituting hypochlorite for chlorine typically increases costs threefold), and could easily involve increased energy and personnel costs. Equipment condition, new technology, and financial concerns are all considerations when upgrades or new processes are chosen. In addition, the safety of the process must be considered, of course, because of the demands made by USEPA and OSHA. The potential of harm to workers, the community, and the environment is all under study, as are the possible long-term effects of chlorination on the human population.

Case Study 1.1: Chesapeake Bay and Nutrients: A Modest Proposal

Nutrient pollution in the Chesapeake Bay and other water bodies is real and ongoing—the controversy over what is the proper mitigation procedure is intense and never ending (and very political). Nutrients are substances that all living organisms need for growth and reproduction. Two major nutrients, nitrogen and phosphorus, occur naturally in water, soil, and air. Nutrients are present in animal and human waste and chemical fertilizers. All organic material such as leaves and grass clippings contains nutrients. These nutrients cause algal growth and depletion of oxygen in the bay, which leads to the formation of dead zones lacking in oxygen and aquatic life.

The U.S. Fish and Wildlife Service (2007) points out that nutrients can find their way to the bay from anywhere within the 64,000

square mile Chesapeake Bay watershed—and that is the problem. All streams, rivers and storm drains in this huge area eventually lead to the Chesapeake. The activities of over 13.6 million people in the watershed have overwhelmed the bay with excess nutrients. Nutrients come from a wide range of sources, which include sewage treatment plants (20 to 22%), industry, agricultural fields, laws, and even the atmosphere. Nutrient inputs are divided into two general categories: point sources and nonpoint sources.

Sewage treatment plants, industries, and factories are the major point sources. These facilities discharge wastewater containing nutrients directly into a waterway. Although each facility is regulated for the amount of nutrients that can be legally discharged, at times violations still occur.

In this text, it is the wastewater treatment plant, a point source discharger, that is of concern to us. It should be pointed out that wastewater treatment plants, approximately 350 units outfalling effluent to nine major rivers and other locations, all flowing into the Chesapeake Bay region, discharge somewhere between 20 and 22% of the total nutrients into the bay. Many target these point source dischargers as principal causes of oxygen depletion and creators of dead zone regions within the bay. If this is true, one needs to ask the question: Why is wastewater outfalling into the Chesapeake Bay in the first place? If we accept that water is the new oil, we should preserve and use our treated wastewater with great care and even greater utility. Thus, it makes good sense (to us) to take the wastewater that is presently discharged into the Chesapeake Bay and reuse it. This recycling of water saves raw water supplies in reservoirs and aquifers and limits the amount of wastewater that is discharged from wastewater treatment plants into public waterways, such as the Chesapeake Bay. Properly treated wastewater could be used for many other purposes that raw water now serves. Those include irrigating lawns, parks, gardens, golf courses, and farms; fighting fires; washing cars; controlling dust; cooling industrial machinery and towers and nuclear reactors; making concrete; and cleaning streets. It is our contention, of course, that when we get thirsty enough, we will find another use for properly treated and filtered wastewater, and when this occurs, we certainly will not use this treated wastewater for any other purpose than quenching our thirst. In reality, we are doing this already.

Let's get back to the Chesapeake Bay problem.

The largest source of nutrients dumped into the bay is from nonpoint sources. These nonpoint sources pose a greater threat to the Chesapeake ecosystem, as they are much harder to control and regulate. It is our view that, because of the difficulty involved in controlling runoff from agricultural fields and the lack of political will along with the technical difficulty of preventing such flows, wastewater treatment plants and other end-of-pipe dischargers have become the targets of convenience for the regulators. The problem is that the regulators are requiring the expenditure of hundreds of millions

to billions of dollars to upgrade wastewater treatment to biological nutrient removal (BNR), tertiary treatment, or the combining of microfiltration membranes with a biological process to produce superior quality effluent—these requirements are commendable, interesting, and achievable, but not necessary.

What is the alternative, the answer to the dead zone problem—the lack of oxygen problem in various locations in the Chesapeake Bay? Putting it simply, take a portion of the hundreds of millions of dollars earmarked for upgrading wastewater treatment plants and build mobile, floating platforms containing electromechanical aerators or mixers. These platforms should be outfitted with diesel generators and accessories to provide power to the mixers. The mixer propellers will be adjustable and will be able to mix at a water depth of as little as 10 ft, or they can be extended to mix at a depth of 35 ft. Again, these platforms are mobile. When a dead zone appears in the bay, the mobile platforms with their mixers are moved to a center portion of the dead zone area and energized at the appropriate depth. These mobile platforms are anchored to the bay bottom and so arranged to accommodate shipping to ensure that maritime traffic is not disrupted. The idea is to churn the dead zone water and sediment near the benthic zone and force a geyser-like effect above the surface to aerate the bay water in the dead zone regions. Nothing adds more oxygen to water than natural or artificial aeration. Of course, while aerating and forcing oxygen back into the water, bottom sediments containing contaminants will also be stirred up and sent to the surface, and temporary air pollution problems will occur around the mobile platforms. Some will view this turning up of contaminated sediments as a bad thing, not a good thing. We, in contrast, suggest that removing contaminants from the bay by volatilizing them is a very good thing.

How many of these mobile mixer platforms will be required? It depends on the number of dead zones. Enough platforms should be constructed to handle the warm season's average number of dead zones that appear in the bay in the warm season.

Will this modest proposal—using aerators to eliminate dead zones—actually work? We do not have a clue. This proposal makes more sense to us, though, than spending billions of dollars on upgrading wastewater treatment plants and effluent quality when this only accounts for 20 to 22% of the actual problem. The regulators and others do not have the political will or the insight to go after runoff, which is the real culprit in contaminating the Chesapeake Bay with nutrient pollution.

Recall that it was that great mythical hero Hercules, the world's first environmental engineer, who said that "dilution is the solution to pollution." We agree with this; however, in this text the solution to preventing dead zones in the Chesapeake Bay is to prohibit discharge of wastewater from point sources (i.e., reuse to prevent abuse) and to aerate the dead zones.

Sustaining energy

In addition to sustaining water sector infrastructure, it is also important to recognize that an important element of water sector infrastructure is energy use and efficiency and the sustainability of energy. The fact is delivering water and wastewater services is an energy-intensive effort, as the water is treated, pumped to our homes and businesses, then pumped to wastewater facilities to be treated again. The USEPA estimates 3 to 4% of national electricity consumption, equivalent to approximately 56 billion kW, or \$4 billion, is used in providing drinking water and wastewater services each year. Water and wastewater utilities are typically the largest consumers of energy in municipalities, often accounting for 30 to 40% of total energy consumed. Pursuing energy efficiency at water sector systems can significantly reduce operating costs.

In regard to actual water sector facility energy use, the major energy user in wastewater treatment occurs in secondary treatment (activated sludge processes), partially because of its need for continuous operation. Based on our personal observations and calculations conducted at a typical (well-managed and -maintained) 30 million gallons per day (MGD) secondary treatment plant with belt press solids handling, we found that the electricity requirements for lighting, building, and each unit process were as follows:

- Aeration—54%
- Wastewater pumping—14%
- Anaerobic digestion—14%
- Lighting and buildings—8%
- Belt press—4%
- Clarifiers—3%
- Grit removal—2%
- Return sludge pumping—0.5%
- Disinfection—0.4%
- Gravity thickening—0.1%
- Screening—0.0%

Note: It should be pointed out that at other treatment plants of 15 to 55 MGD we found approximately the same percentages of electrical power usage.

In a typical waterworks and distribution operation we found approximately 12% of the plant's budget was spent on energy. In 2005 we found that the waterworks we surveyed (serving more than 5,000 customers) had an energy use rate of 1.52 kWh/1,000 gal. Further, our findings showed that most of the electrical power (~90%) was used for pumping operations.

Contributing to the high cost of energy use in water and wastewater treatment operations is the aging of infrastructure. Many of the facilities we inspected, surveyed, or studied were using pumps, motors, and motor controllers that were almost 60 years old. We also found that treatment plants that disinfected using ultraviolet irradiation, ozonation, and membrane filtration used increased amounts of energy compared to conventional treatment processes (i.e., those using chlorine or sodium hypochlorite systems).

Because fewer sources of conventional fuels and increasingly expensive extraction processes (fracking for oil and natural gas comes to mind) are driving up oil prices, destabilizing the economy, and causing global shortages and uncertainty for water and wastewater utility operating budgets, consideration of energy conservation practices has come to the forefront of managerial challenges. Experience has demonstrated that energy conservation can improve a utility's bottom line. Cost savings from reduced energy use and increased operation efficiency can save time and money. There are many different types of processes and fuel sources—like upgrading to energy-efficient motors, installing clean energy sources, or capturing biogas for combined heat and power generation—that make your facility more efficient. In addition to energy conservation measures, utilities are giving serious consideration to employing alternative/renewable energy* sources for plant operations. Let's take a closer look at alternative/renewable energy sources and how they can be applied in water or wastewater treatment operations.

As mentioned, the worldwide use of liquid fossil fuels and their decreasing availability along with the politics involved and other economic forces are pushing for substitute, alternate, or renewable fuel sources. This is the case, of course, because of the current and future economic problems that \$4+/gal gasoline has generated (especially in the United States) and because of the perceived crisis developing with high carbon dioxide emissions, the major contributing factor of global climate change.

Before proceeding with our discussion of alternative/renewable energy sources, it is important to make a clear distinction between the two terms, the current buzzwords, *alternative* and *renewable energy*. *Alternative energy* is an umbrella term that refers to any source of usable energy intended to replace fuel sources without the undesired consequences of the replaced fuels. The use of the term *alternative* presupposes an undesirable connotation (for many people *fossil fuel* has joined that endless list of four-letter words); that is, alternative energy is fueled

* Much of the information and data in this section are from EIA, "Renewable Energy Trends," 2004, <http://www.eia.doe.gov/cneaf/solar/renewables/page/trends/rentrends04.html> (accessed June 12, 2009), and EIA, "How Much Renewable Energy Do We Use?" 2007, http://tonto.eia.doe.gov/energy_in_brief/renewable_energy.cfm (accessed June 12, 2009).

Table 1.1 U.S. Energy Consumption by Energy Source, 2008
(Quadrillion Btu)

Energy source	2008
Total	99.438
Renewable	7.367
Biomass (biofuels, waste, wood, and wood derived)	3.852
Biofuels	1.372
Waste	0.436
Wood-derived fuels	2.044
Geothermal	0.360
Hydroelectric conventional	2.512
Solar/PV	0.097
Wind	0.546

Source: EIA, *U.S. Energy Consumption by Energy Source*, 2008, <http://www.eia.gov/cneaf/solar.renewables/page/trends/table1.html> (accessed June 12, 2011).

energy that does not use up natural resources or harm the environment. Examples of alternative fuels include petroleum as an alternative to whale oil, coal as an alternative to wood, alcohol as an alternative to fossil fuels, and coal gasification as an alternative to petroleum. The key point in understanding the term *alternative energy* is that these fuels need not be renewable.

Renewable energy is energy generated from natural resources—such as sunlight, wind, water (hydro), ocean thermal, wave and tide action, biomass and geothermal heat—which are naturally replenished (and thus renewable). Renewable energy resources are virtually inexhaustible—they are replenished at the same rate as they are used—but limited in the amount of energy that is available per unit time. If we have not come full circle in our cycling from renewable to nonrenewable back to renewable we are getting close to that. Consider, for example, that in 1850, about 90% of the energy consumed in the United States was from renewable energy resources (hydro power, wind, burning wood, etc.). Now, however, the United States is heavily reliant on the nonrenewable fossil fuels, natural gas, oil, and coal. In 2009, about 7% of all energy consumed (see Table 1.1) and about 8.5% of total electricity production was from renewable energy resources.

At the present time, most renewable energy generated in water and wastewater treatment operations is used for electricity generation, heating and cooling buildings, and transportation fuels. Electricity producers (utilities, independent produces, and combined heat and power plants) consumed 51% of total U.S. renewable energy in 2007 for producing electricity. Most of the rest of the remaining 49% was biomass consumed for industrial applications (principally paper making) by plants producing

only heat and steam. Biomass is also used for transportation fuels (ethanol) and to provide residential and commercial space heating. The largest share of the renewable-generated electricity comes from hydroelectric energy (71%), followed by biomass (16%), wind (9%), geothermal (4%), and solar (0.2%). Wind-generated electricity increased by almost 21% in 2007 over 2006, more than any other energy source. Its growth rate was followed closely by solar, which increased by over 19% in 2007 over 2006.

From Table 1.1 it is obvious that there are (currently) five primary forms of renewable energy: solar, wind, biomass, geothermal, and hydroelectric energy sources. Each of these holds promise and poses challenges regarding future development.

The United States imports more than 50% of its oil. Replacing some of our petroleum with fuels provided from solar power or made from plant matter, for example, could save money and strengthen our energy security.

Renewable energy is plentiful, and the technologies are improving all the time. There are many ways to use renewable energy. Our main focus should be to find and develop a renewable source of liquid fuels (e.g., developed from biomass), because our economy runs on liquid fuels. Most of the nonliquid renewable energies will not (at the present time) provide power for airplanes and heavy trucks; that is, solar, wind, hydro, geothermal, wave and tidal, and fuel cells can't power the main transportation vehicles we use today. Note that we did not list trains. Remember that today many trains are powered by diesel power or diesel electric systems. If necessary, that is, if diesel type fuels become scarce, trains could be retrofitted to steam power developed by burning coal and wood products (a step back into the past); however, we can't do this to power heavy trucks and airplanes. Most Americans still do not understand that we are running short of the fuels that we use every day, the fuels that made us what we are today. We built the world's greatest economy on oil that sold for \$3 to 4 per barrel. That is no longer the case. To maintain our present level of living, the so-called good life, we must find and develop renewable energy sources to power and secure our future.

Specifically, with regard to water and wastewater utilities and their utilization of alternative or renewable energy, at the present time most in-plant applications are auxiliary or supplemental. That is, alternative or renewable energy sources are primarily used in backup roles to conventional sources of electricity and heating.

Privatization or reengineering

As mentioned, water and wastewater treatment operations are undergoing a new paradigm shift. We explained that this paradigm shift focused on the holistic approach to treating water, but more inclusive. It also

includes thinking outside the box. In order to remain efficient and therefore competitive in the real world of operations, water and wastewater facilities have either bought into the new paradigm shift or been forcibly “shifted” to doing other things (often these other things have little to do with water/wastewater operations) (Johnson and Moore, 2001).

Experience has shown that few words conjure up more fear among public service plant managers than *privatization* or *reengineering*. *Privatization* means allowing private enterprise to compete with government in providing public services, such as water and wastewater operations. Privatization is often proposed as one solution to the numerous woes facing water and wastewater utilities, including corruption, inefficiencies, poor management, and the lack of capital for needed service improvements and infrastructure upgrades and maintenance. Existing management, on the other hand, can accomplish reengineering, internally, or it can be used (and usually is) during the privatization process. *Reengineering* is the systematic transformation of an existing system into a new form to realize quality improvements in operation, system capability, functionality, performance, or evolvability at a lower cost, schedule, or risk to the customer.

Many on-site managers consider privatization or reengineering schemes threatening. In the worst-case scenario, a private contractor could bid the entire staff out of their jobs. In the best case, privatization and reengineering are often a very real threat that forces on-site managers into workforce cuts (privatization anxiety is explained in Case Study 1.2), improving efficiency and cutting costs. At the same time, on-site managers work to ensure the community receives safe drinking water and the facility meets standards and permits, with fewer workers—and without injury to workers, the facility, or the environment.

Local officials need to take a hard look at privatization and reengineering for a number of reasons:

1. **Decaying infrastructures.** Many water and wastewater operations include water and wastewater infrastructures that date back to the early 1900s. The most recent systems were built with federal funds during the 1970s, and even these now need upgrading or replacing. The USEPA recently estimated that the nation’s 75,000+ drinking water systems alone would require more than \$100 billion in investments over the next 20 years. Wastewater systems will require a similar level of investment.
2. **Mandates.** The federal government has reduced its contributions to local water and wastewater systems over the past 30 years, while at the same time imposing stricter water quality and effluent standards under the Clean Water Act and Safe Drinking Water Act. Moreover, as previously mentioned, new unfunded mandated safety regulations, such as OSHA’s Process Safety Management and USEPA’s

Risk Management Planning, are expensive to implement using local sources of revenues or state revolving loan funds.

3. **Hidden function.** Earlier we stated that much of the work of water/wastewater treatment is a hidden function. Because of this lack of visibility, it is often difficult for local officials to commit to making the necessary investments in community water and wastewater systems. Simply, the local politicians lack the political will—water pipes and interceptors are not visible and not perceived as immediately critical for adequate funding. Thus, it is easier for elected officials to ignore them in favor of expenditures of more visible services, such as police and fire. Additionally, raising water and sewage rates to cover operations and maintenance is not always effective because it is an unpopular move for elected officials to make. This means that water and sewer rates do not adequately cover the actual cost of providing services in many municipalities.

In many locations throughout the United States, expenditures on water and wastewater services are the largest facing local governments today. (This is certainly the case for those municipalities struggling to implement the latest storm water and nutrient reduction requirements.) Thus, this area presents a great opportunity for cost savings. Through privatization, water/wastewater companies can take advantage of advanced technology, more flexible management practices, and streamlined procurement and construction practices to lower costs and make the critical improvements more quickly.

In regards to privatization, the view taken in this text is that ownership of water resources, treatment plants, and wastewater operations should be maintained by the public (local government entities) to prevent a tragedy of the commons type of event (i.e., free access and unrestricted demand for water or other natural resource ultimately structurally dooms the resource through overexploitation by private interests). However, because management is also a hidden function of many public service operations (e.g., water and wastewater operations), privatization may be a better alternative to prevent creating a home for poor managers (see Case Study 1.2).

The bottom line: Water and wastewater are commodities, the quantity and quality of which are much too important to leave at the whims of public authorities.

Case Study 1.2: Privatization Anxiety

In 1995, at a large sanitation district, the commission that governed operations was bandying about the idea of privatizing the organization. The commission reasoned that public ratepayers would be better

served by a private, efficient operation. In their view, private operation would not only save money but also bring in talented top managers. The commissioners felt that public service entities do not have a stellar history of attracting quality managers; for example, they felt their own operation was a repository for a bunch of good old boys and no-loads. Unfortunately for the commissioners (and anyone else for that matter), once entrenched, it is almost impossible, excepting for criminal behavior bordering on murder, to get rid of these no-loads.

The treatment manager understood that one of the first moves any privatizer would likely make would be to replace many in top management with proven private, nonpublic service professionals. Many of the manager's friends' and coworkers' jobs could possibly be on the chopping block if this were to occur. However, the treatment manager knew that the commission, before making the decision to privatize or not, had decided to conduct a pilot study (engineers just love the words *pilot study*) to determine if privatization actually made sense in their operation.

Knowing that the metrics involved with the pilot study would focus on staffing, value-added operation, and total costs, he decided to nip the situation in the bud. He knew each of the wastewater treatment plants he was responsible for was overmanned. Each of the 11 plants had a workforce of approximately 44 personnel. He reasoned that by reducing plant staff levels to less than 40 personnel would save a large portion of annual funds. Each plant had four to six plant operator assistants. Many of these plant operator assistants were licensed operators at the lowest professional certification levels (i.e., class 3 or 4 wastewater operator, with 4 being the lowest certification level at that time). Annual salaries for each assistant plant operator averaged around \$32,000, depending on longevity. Then he figured in benefits (company paid life insurance, retirement, and medical insurance) along with personnel expenses (uniforms, safety shoes, training, etc.) at 1.4 times the annual salary. He determined that on average the plant operator assistants cost his operation \$44,800 per annum. He then did the math: $56 \times \$44,800 = \$2,508,800$. Being surprised at this total cost figure, he could not fathom how a bunch of assistant operators could cost so much!

Before the upcoming budget submission deadline of July 1, 1996, the treatment manager subtracted the cost of operator assistants (\$2,508,800), generated and distributed a memo giving all assistant treatment plant operators notice that their services were no longer required after June 30, 1996 (last day of the fiscal year), sat back in his chair, actually quite pleased with himself.

Feeling good about his actions was short-term, however. As it turned out, after the new fiscal year began on July 1, 1996, the governor replaced the commission chairperson with a professional public administrator who had no intention (no personal motivation) for privatizing the district. So, the privatization effort evaporated before it ever got started.

The results of downsizing the treatment plant assistant operators did not sit well with the 11 plant managers who had lost their assistants. The treatment manager had not bothered to discuss his downsizing plans with anyone, let alone with the plant managers—the ones most affected by the downsizing. If he had taken the time to explain his downsizing plan with them, the plant managers could have forcefully argued against such a short-sighted move. For example, the assistant operators formed a pool of fully trained personnel to instantly draw from whenever it became necessary to replace full-time treatment plant operators (the average turnover rate of full-time operators was approximately three per year per plant).

In addition to losing their pool of trained assistant operators to draw upon to fill vacant positions, the lack of fully qualified assistant operators caused another glaring problem. Since district employees earned annual leave (which the employees did like to use on occasion), when the assistants were removed from the payroll, fill-in personnel for those operators wanting to use their annual leave were no longer available. Thus, it became increasingly difficult for plant management to allow key operators to use their annual leave each year.

Another unforeseen problem with doing away with the assistant operators was that when an operator became ill or injured, or encountered personal family problems, it placed a huge burden on those plant personnel who had to fill the shoes of those who could no longer work. Unexpected absences did not cause major problems when the plant had a cadre of assistant plant operators to draw upon to fill in for those employees.

In summarizing Case Study 1.2, it can be said that it adds meaning to Albert Einstein's thought in the following: "You cannot solve a problem within the mind-set that created it."

Benchmarking

As shown in Case Study 1.2, it is primarily out of self-preservation (to retain their lucrative positions) that many utility directors work against the trend to privatize water, wastewater, and other public operations. Usually the real work to prevent privatization is delegated to the individual managers in charge of each specific operation because they also have a stake in making sure that their relatively secure careers are not affected by privatization. It can be easily seen that working against privatization by these local managers is in their own self-interest and in the interest of their workers because their jobs may be at stake.

The question is, of course, how do these managers go about preventing their water and wastewater operation from being privatized? The answer is rather straightforward and clear: efficiency must be improved at reduced cost of operations. In the real world, this is easier said than done but is not impossible; for example, for those facilities under properly

Start → Plan → Research → Observe → Analysis → Adapt

Figure 1.4 Five steps of the benchmarking process.

implemented and managed total quality management (TQM), the process can be much easier. The advantage TQM offers the plant manager is the variety of tools provided to help plan, develop, and implement water and wastewater efficiency measures. These tools include self-assessments, statistical process control, International Organization for Standardization (ISO) 9000 and 14000, process analysis, quality circle, and benchmarking (see Figure 1.4).

In this text, the focus is on use of the benchmarking tool to improve water and wastewater operation's efficiency. Benchmarking is a process for rigorously measuring your performance vs. best-in-class operations, and using the analysis to meet and exceed the best in class.

What benchmarking is:

1. Benchmarking vs. best practices gives water and wastewater operations a way to evaluate their operations overall.
 - a. How effective
 - b. How cost-effective
2. Benchmarking shows plants both how well their operations stack up and how well those operations are implemented.
3. Benchmarking is an objective-setting process.
4. Benchmarking is a new way of doing business.
5. Benchmarking forces an external view to ensure correctness of objective setting.
6. Benchmarking forces internal alignment to achieve plant goals.
7. Benchmarking promotes teamwork by directing attention to those practices necessary to remain competitive.

Potential results of benchmarking:

1. Benchmarking may indicate direction of required change rather than specific metrics.
 - a. Costs must be reduced
 - b. Customer satisfaction must be increased
 - c. Return on assets must be increased
 - d. Improved maintenance
 - e. Improved operational practices
2. Best practices are translated into operational units of measure.

Targets:

1. Consideration of available resources converts benchmark findings to targets.
2. A target represents what can realistically be accomplished in a given time frame.
3. A target can show progress toward benchmark practices and metrics.
4. Quantification of precise targets should be based on achieving the benchmark.

Note: Benchmarking can be performance based, process based, or strategic based and can compare financial or operational performance measures, methods or practices, or strategic choices.

Benchmarking: The process

When forming a benchmarking team, the goal should be to provide a benchmark that evaluates and compares privatized and reengineered water and wastewater treatment operations to your operation in order to be more efficient and remain competitive and make continual improvements. It is important to point out that benchmarking is more than simply setting a performance reference or comparison; it is a way to facilitate learning for continual improvements. The key to the learning process is looking outside one's own plant to other plants that have discovered better ways of achieving improved performance.

Benchmarking Steps. As shown in Figure 1.4, the benchmarking process consists of five steps.

1. Planning. Managers must select a process (or processes) to be benchmarked. A benchmarking team should be formed. The process of benchmarking must be thoroughly understood and documented. The performance measure for the process should be established (i.e., cost, time, and quality).
2. Research. Information on the best-in-class performer must be determined through research. The information can be derived from the industry's network, industry experts, industry and trade associations, publications, public information, and other award-winning operations.
3. Observation. The observation step is a study of the benchmarking subject's performance level, processes, and practices that have achieved those levels, and other enabling factors.
4. Analysis. In this phase, comparisons in performance levels among facilities are determined. The root causes for the performance gaps

- are studied. To make accurate and appropriate comparisons, the comparison data must be sorted, controlled for quality, and normalized.
5. Adaptation. This phase is putting what is learned throughout the benchmarking process into action. The findings of the benchmarking study must be communicated to gain acceptance, functional goals must be established, and a plan must be developed. Progress should be monitored and, as required, corrections in the process made.

Note: Benchmarking should be interactive. It should also recalibrate performance measures and improve the process itself.

Case Study 1.3: Benchmarking: An Example

To gain better understanding of the benchmarking process, the following limited example (it is in outline and summary form only; discussion of a full-blown study is beyond the scope of this text) is provided.

RACHEL'S CREEK SANITATION DISTRICT

Introduction

In January 1997, Rachel's Creek Sanitation District formed a benchmarking team with the goal of providing a benchmark that evaluates and compares privatized and reengineered wastewater treatment operations to Rachel's Creek operations in order to be more efficient and remain competitive. After 3 months of evaluating wastewater facilities using the benchmarking tool, our benchmarking is complete. This report summarizes our findings and should serve as a benchmark by which to compare and evaluate Rachel's Creek Sanitation District operations.

Facilities

Forty-one wastewater treatment plants throughout the United States.

The benchmarking team focused on the following target areas for comparison:

1. Reengineering
2. Organization
3. Operations and maintenance
 - a. Contractual services
 - b. Materials and supplies
 - c. Sampling and data collection
 - d. Maintenance
4. Operational directives
5. Utilities
6. Chemicals
7. Technology

8. Permits
 - a. Water quality
 - b. Solids quality
 - c. Air quality
 - d. Odor quality
9. Safety
10. Training and development
11. Process
12. Communication
13. Public relations
14. Reuse
15. Support services
 - a. Pretreatment
 - b. Collection systems
 - c. Procurement
 - d. Finance and administration
 - e. Laboratory
 - f. Human resources

Summary of Findings

Our overall evaluation of Rachel's Creek Sanitation District compared to our benchmarking targets is a good one; that is, we are in good standing compared to the 41 target facilities we benchmarked with. In the area of safety, we compare quite favorably. Only plant 34, with its own full-time safety manager, appeared to be better than we are. We were very competitive with the privatized plants in our usage of chemicals and far ahead of many public plants. We were also competitive in the use of power. Our survey of what other plants are doing to cut power costs showed that we clearly identified those areas of improvement, and our current effort to further reduce power costs is on track. We were far ahead in the optimization of our unit processes, and we were leaders in the area of odor control.

There were also areas that we need to improve. To the Rachel's Creek employee, reengineering applies to only the treatment department and has been limited to cutting staff while plant practices and organizational practices are outdated and inefficient. Under the reengineering section of this report, we have provided a summary of reengineering efforts at the reengineered plants visited. The experiences of these plants can be used to improve our own reengineering effort. Next is our organization and staffing levels. A private company could reduce the entire treatment department staff by about 18 to 24%. The 18 to 24% is based on number of employees and not costs. In the organization section of this report, organizational models and their staffing levels are provided as guidelines to improving our organization and determining optimum staffing levels. The last big area that we need to improve is in the way we accomplish the work we perform. Our people are not used efficiently because of outdated and inefficient policies and work practices. Methods to improve the

way we do work are found throughout this report. We noted that efficient work practices used by private companies allow plants to operate with small staffs.

Overall, Rachel's Creek Sanitation District's treatment plants are much better than other public service plants. Although some plants may have better equipment, better technology, and cleaner effluents, the costs in labor and materials are much higher than ours. Several of the public plants were in bad condition. Contrary to popular belief, the privately operated plants had good to excellent operations. These plants met permit, complied with safety regulations, maintained plant equipment, and kept the plant clean. Due to their efficiency and low staff, we felt that most of the privately operated plants were better than us. We agreed that this needs to be changed. Using what we learned during our benchmarking effort, we can be just as efficient as a privately operated plant and still maintain our standards of quality.

THE BOTTOM LINE ON PRIVATIZATION

Privatization is becoming of greater and greater concern. Governance boards such as state commissions see privatization as a potential way to shift liability and responsibility from the municipality's shoulders, with the attractive bonus of cutting costs. Both water and wastewater facilities face constant pressure to work more efficiently, more cost-effectively, with fewer workers, to produce a higher-quality product; that is, all functions must be value-added. Privatization is increasing, and many municipalities are seriously considering outsourcing parts or all of their operations to contractors (Drinan, 2001).

Maintaining a viable workforce

Maintaining a viable, well-trained workforce becomes ever more difficult as new regulations require higher levels of training and certification for workers. Low unemployment rates also increase an employee's opportunities to move from job to job, seeking higher pay. Municipalities are often tied to state or city worker payment levels, and can offer little flexibility for pay increases. Workers who received solid training financed by the municipality can sometimes simply take their certification and walk into a higher-paid position elsewhere, because of standard contract or employment policy limitations and an inflexible pay structure. When new regulations mandating worker certification for water treatment are imminent, an already trained, skillful, knowledgeable worker is an attractive target.

Upgrading security

World-wide conflicts are on-going ... seem never ending. One of the most important conflicts of our

DID YOU KNOW?

Community water systems serve by far the largest proportion of the U.S. population—273 million out of a total population of 290 million (as of 2003).

Source: USEPA (2004).

time, such as the on-going Israeli-Palestinian conflict, is in fact conflict over scarce but vital water resources. This conflict over water, unfortunately, may be a harbinger of things to come.

According to USEPA (2004), there are approximately 160,000 public water systems (PWS) in the United States, each of which regularly supplies drinking water to at least 25 persons or 15 service connections. Eighty-four percent of the total U.S. population is served by PWS, while the remainder is served primarily by private wells. PWS are divided into community water systems (CWS) and noncommunity water systems (NCWS). Examples of CWS include municipal water systems that serve mobile home parks of residential developments. Examples of NCWS include schools, factories, churches, commercial campgrounds, hotels, and restaurants.

Because drinking water is consumed directly, health effects associated with contamination have long been major concerns. In addition, interruption or cessation of the drinking water supply can disrupt society, impacting human health and critical activities such as fire protection. Although they have no clue as to its true economic value and to its future worth, the general public correctly perceives drinking water as central to the life of an individual and of society. However, the general public knows even less about the importance of wastewater treatment and the fate of its end product.

Wastewater treatment is important for preventing disease and protecting the environment. Wastewater is treated by publicly owned treatment works (POTW) and by private facilities such as industrial plants. There are approximately 2.3 million miles of distribution system pipes and approximately 16,255 POTW in the United States. Seventy-five percent of the total U.S. population is served by POTW, with existing flows of less than 1 MGD considered small; they number approximately 13,057 systems. For the purpose of determining population served, 1 MGD equals approximately 10,000 persons served.

Disruption of a wastewater treatment system or service can cause loss of life, economic impacts, and severe public health incidents. If structural

damage occurs, wastewater systems can become vulnerable to inadequate treatment. The public is much less sensitive to wastewater as an area of vulnerability than it is to drinking water; however, wastewater systems do provide opportunities for terrorist threats.

Federal and state agencies have long been active in addressing these risks and threats to water and wastewater utilities through regulations, technical assistance, research, and outreach programs. As a result, an extensive system of regulations governing maximum contaminant levels of 90 conventional contaminants (most established by the USEPA), construction and operating standards (implemented mostly by the states), monitoring, emergency response planning, training, research, and education has been developed to better protect the nation's drinking water supply and receiving waters.

Since the events of 9/11, the USEPA has been designated as the sector-specific agency responsible for infrastructure protection activities for the nation's drinking water and wastewater system. The USEPA is utilizing its position within the water sector and working with its stakeholders to provide information to help protect the nation's drinking water supply from terrorism or other intentional acts.

Consequences of 9/11

One consequence of the events of September 11 was USEPA's directive to establish a water protection task force to ensure that activities to protect and secure water supply and wastewater treatment infrastructure are comprehensive and carried out expeditiously. Another consequence is a heightened concern among citizens in the United States over the security of their critical water and wastewater infrastructure. The nation's water and wastewater infrastructure, consisting of several thousand publicly owned water/wastewater treatment plants, more than 100,000 pumping stations, hundreds of thousands of miles of water distribution and sanitary sewers, and another 200,000 miles of storm sewers, is one of America's most valuable resources, with treatment and distribution/collection systems valued at more than \$2.5 trillion. Wastewater treatment operations taken alone include the sanitary and storm sewers forming an extensive network that runs near or beneath key buildings and roads, and is contiguous to many communication and transportation networks. Significant damage to the nation's wastewater facilities or collection systems would result in loss of life, catastrophic environmental damage to rivers, lakes, and wetlands, contamination of drinking water supplies, long-term public health impacts, destruction of fish and shellfish production, and disruption to commerce, the economy, and our normal way of life.

Governor Tom Ridge points out the security role for the public professional (I interpret this to include water and wastewater professionals):

Americans should find comfort in knowing that millions of their fellow citizens are working every day to ensure our security at every level—federal, state, county, municipal. These are dedicated professionals who are good at what they do. I’ve seen it up close, as Governor of Pennsylvania.... But there may be gaps in the system. The job of the Office of Homeland Security will be to identify those gaps and work to close them. (Henry, 2002, 30–31)

It is to shore up the “gaps in the system” that has driven many water and wastewater facilities to increase security. Moreover, USEPA, in its *Water Protection Task Force Alert #IV: What Wastewater Utilities Can Do Now to Guard against Terrorist and Security Threats* (October 24, 2001), made several recommendations to increase security and reduce threats from terrorism. The recommendations include:

1. Guarding against unplanned physical intrusion (water/wastewater)
 - a. Lock all doors and set alarms at your office, pumping stations, treatment plants, and vaults, and make it a rule that doors are locked and alarms are set.
 - b. Limit access to facilities and control access to pumping stations, and chemical and fuel storage areas, giving close scrutiny to visitors and contractors.
 - c. Post guards at treatment plants, and post “Employee Only” signs in restricted areas.
 - d. Control access to storm sewers.
 - e. Secure hatches, metering vaults, manholes, and other access points to the sanitary collection system.
 - f. Increase lighting in parking lots, treatment bays, and other areas with limited staffing.
 - g. Control access to computer networks and control systems, and change the passwords frequently.
 - h. Do not leave keys in equipment or vehicles at any time.
2. Making security a priority for employees
 - a. Conduct background security checks on employees at hiring and periodically thereafter.
 - b. Develop a security program with written plans and train employees frequently.
 - c. Ensure all employees are aware of communications protocols with relevant law enforcement, public health, environmental protection, and emergency response organizations.
 - d. Ensure that employees are fully aware of the importance of vigilance and the seriousness of breaches in security, and make note

- of unaccompanied strangers on the site and immediately notify designated security officers or local law enforcement agencies.
 - e. Consider varying the timing of operational procedures if possible, in case someone is watching the pattern changes.
 - f. Upon the dismissal of an employee, change pass codes and make sure keys and access cards are returned.
 - g. Provide customer service staff with training and checklists of how to handle a threat if it is called in.
3. Coordinating actions for effective emergency response
- a. Review existing emergency response plans, and ensure they are current and relevant.
 - b. Make sure employees have necessary training in emergency operating procedures.
 - c. Develop clear protocols and chains of command for reporting and responding to threats along with relevant emergency, law enforcement, environmental, public health officials, consumers, and the media. Practice the emergency protocols regularly.
 - d. Ensure key utility personnel (both on- and off-duty) have access to crucial telephone numbers and contact information at all times. Keep the call list up to date.
 - e. Develop close relationships with local law enforcement agencies, and make sure they know where critical assets are located. Request they add your facilities to their routine rounds.
 - f. Work with local industries to ensure that their pretreatment facilities are secure.
 - g. Report to county or state health officials any illness among the employees that might be associated with wastewater contamination.
 - h. Report criminal threats, suspicious behavior, or attacks on wastewater utilities immediately to law enforcement officials and the relevant field office of the Federal Bureau of Investigation.
4. Investing in security and infrastructure improvements
- a. Assess the vulnerability of collection/distribution systems, major pumping stations, water and wastewater treatment plants, chemical and fuel storage areas, outfall pipes, and other key infrastructure elements.
 - b. Assess the vulnerability of the storm water collection system. Determine where large pipes run near or beneath government buildings, banks, commercial districts, industrial facilities, or are contiguous with major communication and transportation networks.
 - c. Move as quickly as possible with the most obvious and cost-effective physical improvements, such as perimeter fences, security lighting, tamper-proofing manhole covers and valve boxes, etc.
 - d. Improve computer system and remote operational security.

- e. Use local citizen watches.
- f. Seek financing for more expensive and comprehensive system improvements.

Ideally, in a perfect world, water and wastewater infrastructure would be secured in a layered fashion (aka the barrier approach). Layered security systems are vital. Using the protection in depth principle, requiring that an adversary defeat several protective barriers or security layers to accomplish its goal, water and wastewater infrastructure can be made more secure. *Protection in depth* is a term commonly used by the military to describe security measures that reinforce one another, masking the defense mechanisms from view of intruders, and allowing the defender time to respond to intrusion or attack.

A prime example of the use of the multibarrier approach to ensure security and safety is demonstrated by the practices of the bottled water industry. In the aftermath of 9/11 and the increased emphasis on homeland security, a shifted paradigm of national security and vulnerability awareness has emerged. Recall that in the immediate aftermath of the 9/11 tragedies, emergency responders and others responded quickly and worked to exhaustion. In addition to the emergency responders, bottled water companies responded immediately by donating several million bottles of water to the crews at the crash sites in New York, at the Pentagon, and in Pennsylvania. International Bottled Water Association (IBWA, 2004) reports that “within hours of the first attack, bottled water was delivered where it mattered most; to emergency personnel on the scene who required ample water to stay hydrated as they worked to rescue victims and clean up debris” (p. 2).

Bottled water companies continued to provide bottled water to responders and rescuers at the 9/11 sites throughout the postevent processes. These patriotic actions by the bottled water companies, however, beg the question: How do we ensure the safety and security of the bottled water provided to anyone? IBWA (2004) has the answer: using a multibarrier approach, along with other principles, will enhance the safety and security of bottled water. IBWA (2004) describes its multibarrier approach as follows:

A multi-barrier approach—Bottled water products are produced utilizing a multi-barrier approach, from source to finished product, that helps prevent possible harmful contaminants (physical, chemical, or microbiological) from adulterating the finished product as well as storage, production, and transportation equipment. Measures in a multi-barrier approach may include source protection, source

monitoring, reverse osmosis, distillation, filtration, ozonation or ultraviolet (UV) light. Many of the steps in a multi-barrier system may be effective in safeguarding bottled water from microbiological and other contamination. Piping in and out of plants, as well as storage silos and water tankers are also protected and maintained through sanitation procedures. In addition, bottled water products are bottled in a controlled, sanitary environment to prevent contamination during the filling operation. (p. 3)

In water and wastewater infrastructure security, protection in depth is used to describe a layered security approach. A protection in depth strategy uses several forms of security techniques or devices against an intruder and does not rely on one single defensive mechanism to protect infrastructure. By implementing multiple layers of security, a hole or flaw in one layer is covered by the other layers. An intruder will have to intrude through each layer without being detected in the process—the layered approach implies that no matter how an intruder attempts to accomplish his goal, he will encounter effective elements of the physical protection system.

Summary

Many problems face those who operate treatment facilities, but their most critical concern, of course, is the basic one they face every day: providing the best level of treatment possible, ensuring the safe condition of water supplies.

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section two

Basics of water treatment

chapter two

Water regulations, parameters, and characteristics

Purpose: Quality parameters for water

The unit processes used to prepare raw or untreated water for public use and consumption are controlled and determined by water quality parameters. These parameters are set by federal regulations and are supported and strengthened by state law. Individual facilities must prove they meet regulatory standards through regulated programs of testing and reporting (see Figure 1.1).

Purpose: Water treatment

Treatment for drinking water removes from raw water those contaminants (Table 2.1) harmful or unpleasant to humans by a confirmed series of treatment steps or unit processes that produce safe potable water. In raw water treatment, the goals are to remove pollutants that affect water quality and to ensure that water safe for consumption is delivered to the consumer.

Water quality: Federal regulations

Water quality standards are controlled by federal regulation, applied on all levels. After water quality standards came into law in the 1970s, the condition of our drinking water supplies improved drastically. These improvements were the result of two critically important regulations: the Safe Drinking Water Act (SDWA), passed by Congress in 1974, and the Water Pollution Control Act Amendments of 1972 (Clean Water Act (CWA)).

Drinking water regulations

The Safe Drinking Water Act (SDWA) was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and groundwater wells. SWDA requires the USEPA to establish mandatory



Figure 2.1 City of Oneonta, New York, water treatment plant.

Table 2.1 Common Chemical Pollutants

Source	Common associated chemical pollutants
Cropland	Turbidity, phosphorus, nitrates, temperature, total solids
Forestry harvest	Turbidity, temperature, total solids
Grazing land	Fecal bacteria, turbidity, phosphorus
Industrial discharge	Temperature, conductivity, total solids, toxics, pH
Mining	pH, alkalinity, total dissolved solids
Septic systems	Fecal bacteria, (i.e., <i>Escherichia coli</i> , <i>Enterococcus</i>), nitrates, phosphorus, dissolved oxygen/BOD, conductivity, temperature
Sewage treatment plants	Dissolved oxygen and BOD, turbidity, conductivity, phosphorus, nitrates, fecal bacteria, temperature, total solids, pH
Construction	Turbidity, temperature, dissolved oxygen and BOD, total solids, and toxics
Urban runoff	Turbidity, phosphorus, nitrates, temperature, conductivity, dissolved oxygen, and BOD

drinking water standards for all public water systems serving 25 or more people, or having 15 or more connections. Under SDWA, the USEPA established maximum contaminant levels for drinking water delivered through public water distribution systems. If water analysis indicates a water system is exceeding a maximum contamination level (MCL) for a contaminant, the system must either stop providing the water to the public or treat the water to reduce the contaminant concentration to below the MCL.

Secondary drinking water standards (Table 2.2) are USEPA-issued guidelines (and thus, unlike MCLs, are not mandatory) that apply to drinking water contaminants known to adversely affect odor and appearance—water's aesthetic qualities. While these qualities present no known health risks to the public, most drinking water systems comply, if for no other reason than consumer relations. It would be difficult to convince us that the water from our taps is safe if it has an unpleasant smell or is an odd color.

The Comprehensive Disinfectant/Disinfection By-Product Rules (D/DBP—Stage 1 and Stage 2) are aimed at filtering out higher levels of impurities from drinking water and helping communities to upgrade their treatment systems. Meant to simultaneously reduce health threats from bacteria, protozoa, and viruses, as well as from disinfectants, these rules toughen standards for allowable concentrations of chlorine by-products in drinking water, regulate *Cryptosporidium*, and tighten standards for turbidity from 5 μm to 1 μm . Estimates suggest that compliance with these standards will reduce individual exposure to disinfection by-products (including trihalomethanes (THMs)) by 25%.

Water quality characteristics

Water quality parameters provide a yardstick by which to measure water's physical, chemical, and biological characteristics. These parameters include a range of characteristics that make water appealing and useful to consumers, and that ensure the water presents no harm or disruption to the environment or to humans within a wide range of possible water uses.

Physical water quality characteristics

Water's physical characteristics (those detectable by sight, touch, taste, or smell) include suspended solids, turbidity, color, temperature, taste, and odor (see Figure 2.2).

DID YOU KNOW?

Water is the only substance found on earth in three forms: solid, liquid, and gas.

Table 2.2 National Secondary Drinking Water Standards

Contaminants	Suggested levels	Contaminant effects
Aluminum	0.05–0.2 mg/L	Discoloration of water
Chloride	250 mg/L	Salty taste, corrosion of pipes
Color	15 color units	Visible tint
Copper	1.0 mg/L	Metallic taste, blue-green staining of porcelain
Corrosivity	Noncorrosive	Metallic taste, fixture staining corroded pipes (corrosive water can leach pipe materials, such as lead, into drinking water)
Fluoride	2.0 mg/L	Dental fluorosis (a brownish discoloration of the teeth)
Foaming agents	0.5 mg/L	Aesthetic: frothy, cloudy, bitter taste, odor
Iron	0.3 mg/L	Bitter metallic taste; staining of laundry, rusty color, sediment
Manganese	0.05 mg/L	Taste; staining of laundry, black to brown color, black staining
Odor	3 threshold odor	Rotten egg, musty, or chemical smell
pH	6.5–8.5	Low pH: bitter metallic taste, corrosion High pH: slippery feel, soda taste, deposits
Silver	0.10 mg/L	Argyria (discoloration of skin), graying of eyes
Sulfate	250 mg/L	Salty taste, laxative effects
Total dissolved solids (TDS)	500 mg/L	Taste and possible relation between low hardness and cardiovascular disease, also an indicator of corrosivity (related to lead levels in water), can damage plumbing and limit effectiveness of soaps and detergents
Zinc	5 mg/L	Metallic taste

Source: USEPA, *Drinking Water Contaminants*, 2011, retrieved from <http://water.epa.gov/drink/contaminants/#SecondaryList>.

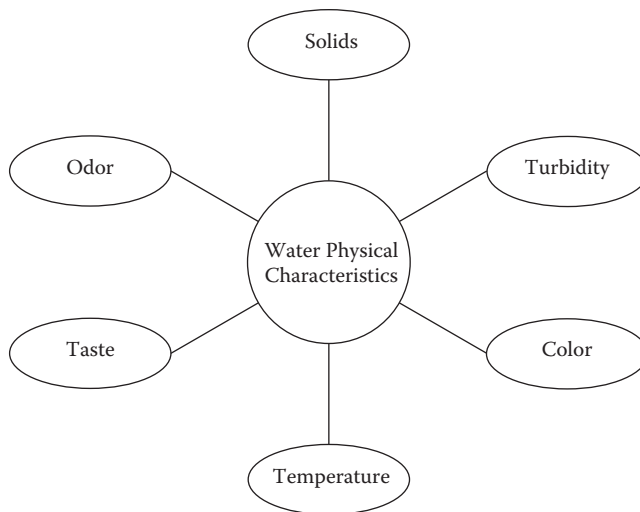


Figure 2.2 Water's physical characteristics.

Solids in water

Solids removal is of great concern in drinking water treatment. Suspended materials provide adsorption sites for biological and chemical agents, and give microorganisms protection against chlorine disinfectants. As suspended solids degrade biologically, they can create objectionable by-products.

Solids can be either suspended or dissolved in water, and are classified by their size and state, by their chemical characteristics, and by their size distribution. These solids consist of inorganic or organic particles, or of immiscible liquids such as oils and greases. Surface waters often contain inorganic solids such as clay, silt, and other soil constituents as the result of erosion. Organic materials (including plant fibers and biological solids such as bacteria) are also common in surface waters. Groundwater seldom contains suspended solids because of soil's filtering properties.

Filtration provides the most effective means of removing solids in water treatment, although colloids and some other dissolved solids cannot be removed by filtration (see Figure 2.3).

Turbidity

Water's clarity is usually measured against a turbidity index. Insoluble particulates scatter and absorb light rays, impeding the passage of light through water. Turbidity indices measure light passage interference (see Figure 2.4). The index starts with 1, showing little or no turbidity, and goes to 5, allowing no passage of light.

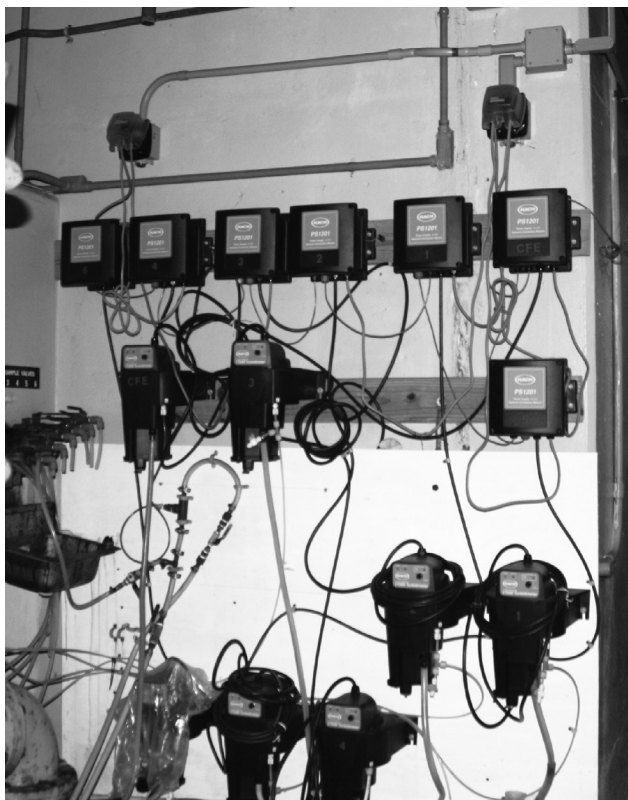


Figure 2.3 Turbidity meters.

DID YOU KNOW?

A person can live more than a month without food, but only about a week, depending on conditions, without water.

Surface water turbidity can result from very small particulate colloidal material (rock fragments, silt, clay, and metal oxides from soil) contributed by erosion or by microorganisms and vegetable materials.

Color

Pure water has no color, but foreign substances can often tint water. These include organic matter from soils, vegetation, minerals and aquatic organisms, or municipal and industrial wastes. Color can be a treatment problem that exerts chlorine demand, reducing chlorine's disinfectant effectiveness.

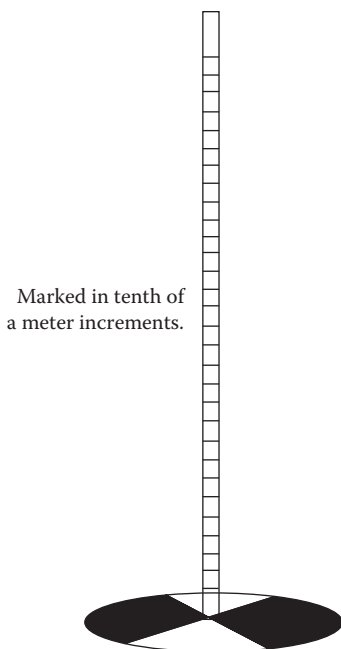


Figure 2.4 Secchi disk measures turbidity.

Water's color is classified as true color (from dissolved solids that remain after suspended matter is removed) or apparent color (from suspended matter). True color is the most difficult to remove. Measured by comparing a water sample with standard color solutions or colored glass disks, one color unit is equal to the color produced by a 1 mg/L solution of platinum.

Water's color affects its marketability for domestic and industrial use. While colored water does not present a safety issue, most people object to obviously colored water. Colored water can affect laundering, food processing, papermaking, manufacturing, and textiles.

Taste and odor

Water's taste and odor (the terms are used jointly when used to describe drinking water) is another aesthetically important issue with little safety impact. Taste and odor problems can be caused by minerals, metals and salts from the soil, wastewater constituents, and biological reaction end products.

A common method to remove taste and odor from drinking water is to oxidize the problem materials with potassium permanganate, chlorine, or other oxidant. Powdered activated carbon is also used for taste and odor control.

DID YOU KNOW?

Sixty-six percent of the human body is water; 75% of the human brain is water.

Temperature

Surface water and groundwater temperature is affected both naturally and artificially. Heat or temperature change in surface waters affects the solubility of oxygen in water, the rate of bacterial activity, and the rate at which gases are transferred to and from water, as well as the health of the fish population.

Temperature is one of the most important parameters in natural surface water systems because such systems are subject to great temperature variations; other than this, temperature is not commonly used for water quality evaluation.

Water temperature does, however, affect in part the efficiency of some water treatment processes. Temperature affects chemical dissolve and reaction rates. Cold water requires more chemicals for efficient coagulation and flocculation. High water temperatures can increase chlorine demand because of increased reactivity, as well as increased levels of algae and other organic matter in the raw water.

Chemical water quality characteristics

The major chemical parameters of concern in water treatment are total dissolved solids (TDS): alkalinity, hardness, fluorides, metals, organics and nutrients, pH, and chlorides. The solvent capabilities of water are directly related to its chemical parameters (see Figure 2.5).

Total dissolved solids (TDS)

Solids in water occur either in solution or in suspension. The solids in the water that remain after filtration and evaporation as residue are called total dissolved solids (TDS). Dissolved solids can be removed from water by filtration and evaporation, and also by electrodialysis, reverse osmosis, or ion exchange.

Dissolved solids may be organic or inorganic and come from water's contact with substances in soil, on surfaces, and in the atmosphere. Organic dissolved constituents come from decayed vegetation, and from organic chemicals and gases. These dissolved minerals, gases, and organic constituents may cause physiological effects, as well as color, taste, and odor problems.

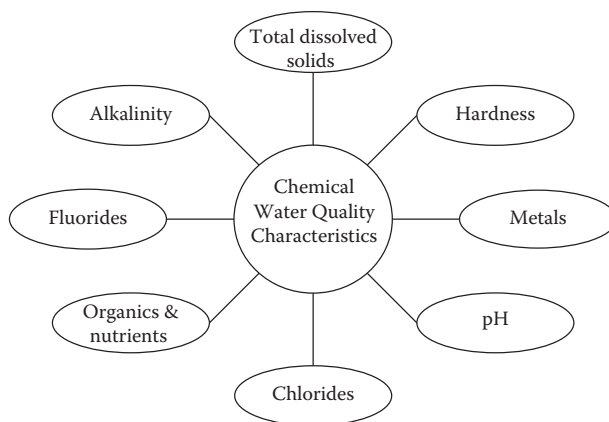


Figure 2.5 Chemical water quality characteristics.

Alkalinity

Alkalinity is an important water quality parameter, because it measures the water's ability to neutralize acids. Alkalinity constituents in natural water supplies are bicarbonate, carbonate, and hydroxyl ions—mostly the carbonates and bicarbonates of sodium, potassium, magnesium, and calcium. Alkalinity also occurs naturally from carbon dioxide (from the atmosphere and as a by-product of microbial decomposition of organic material) and from mineral origins (primarily from chemical compounds dissolved from rocks and soil).

While highly alkaline waters do not seriously affect human health, elevated alkalinity can cause an objectionable bitter taste. In treatment, alkaline water can cause problems with the reactions that occur between alkalinity and certain substances in the water, which can foul water system appurtenances.

Hardness

Hardness in water usually indicates the presence of such minerals as calcium and magnesium. These dissolved minerals cause scale deposits in hot water pipes and affect soap efficiency. These problems make hard water generally unacceptable to the public, though advantages to hard water do exist. Hard water helps tooth and bone growth and hard water scaling reduces toxicity of lead oxide in pipelines made of lead.

Fluorides

Fluoride is toxic to humans in large quantities, and to some animals, though moderate amounts of fluoride ions (F^-) in drinking water contribute to

good dental health. Fluoride appears in groundwater in only a few geographical regions, and in a few types of igneous or sedimentary rocks. It is seldom found in appreciable quantities of surface waters. Fluoride is a common addition to drinking water in many communities.

Metals

Metals in water that are harmful in relatively small amounts are classified as toxic; other metals are classified as nontoxic. In natural waters other than groundwater, metal sources include dissolution from natural deposits and discharges of domestic, agricultural, or industrial wastes. Leachate from improperly designed, constructed, or managed landfills is another common source.

Some metals (iron (Fe) and manganese (Mn), for example) impart a bitter taste to drinking water even at low concentrations, though they do not cause health problems. These metals usually occur in groundwater in solution. They (and other metals) in solution may cause brown or black stains on laundry and on plumbing fixtures.

Organics

Organic matter in water can cause color problems as well as taste and odor problems. Organic matter can contribute to the formation of halogenated compounds in water undergoing chlorine disinfection. Organic matter can also create problems with oxygen depletion in streams, because as microbes metabolize organic material, they consume oxygen. Oxygen depletion from organic matter interferes with water treatment processes.

The oxygen microbes consume is dissolved oxygen (DO). This demand for oxygen is called the biochemical oxygen demand (BOD): the amount of dissolved oxygen aerobic decomposers require to decay organic materials in a given volume of water over a 5-day incubation period at 68°F (20°C). If the oxygen is not continually replaced, the DO level decreases as the microbes decompose the organics, until the cycle fails from lack of available oxygen.

Generally, organic matter in water comes from natural sources—decaying leaves, weeds, and trees. Man-made sources include pesticides and other synthetic organic compounds (see Table 2.3) (see Figure 2.6).

Many organic compounds are soluble in water, and surface waters are more prone to contamination by natural organic compounds than are groundwaters. Dissolved organics are usually divided into biodegradable and nonbiodegradable.

Nonbiodegradable organics resist biological degradation. For example, the refractory (resistant to biodegradation) constituents of woody plants (tannin and lignic acids, phenols, and cellulose) are found in natural water systems. Other essentially nonbiodegradable constituents include some

Table 2.3 Primary Standard MCLs and MCLGs for Organic Chemicals

Contaminant	Health effects	MCL—MCLG (mg/L)	Sources
Aldicarb	Nervous system effects	0.003—0.001	Insecticide
Benzene	Possible cancer risk	0.005—0	Industrial chemicals, paints, plastics, pesticides
Carbon tetrachloride	Possible cancer risk	0.005—0	Cleaning agents, industrial wastes
Chlordane	Possible cancer	0.002—0	Insecticide
Endrin	Nervous system, liver, kidney effects	0.002—0.002	Insecticide
Heptachlor	Possible cancer	0.0004—0	Insecticide
Lindane	Nervous system, liver, kidney effects	0.0002—0.0002	Insecticide
Pentachlorophenol	Possible cancer risk, liver, kidney effects	0.001—0	Wood preservative
Styrene	Liver, nervous system effects	0.1—0.1	Plastics, rubber, drug industry
Toluene	Kidney, nervous system, liver, circulatory effects	1—1	Industrial solvent, gasoline additive chemical manufacturing
Total trihalomethanes (TTHMs)	Possible cancer risk	0.1—0	Chloroform, drinking water chlorination by-product
Trichloroethylene (TCE)	Possible cancer risk	0.005—0	Waste from disposal of dry cleaning material and manufacture of pesticides, paints, waxes; metal degreaser
Vinyl chloride	Possible cancer	0.002—0	May leach from PVC pipe
Xylene	Liver, kidney, nervous system effects	10—10	Gasoline refining by-product, paint ink, detergent

Source: USEPA, *Selected Primary MCLs and MCLGs for Organic Chemicals*, 810-F-94-002, May 1994, 2010, 2011.



Figure 2.6 Small stream in Treadwell, New York, carrying organic debris to the Susquehanna River.

polysaccharides with exceptionally strong bonds, and benzene with its ringed structure (associated with the refining of petroleum).

Inorganics

Natural water can possess several common inorganic constituents (pH, chlorides, alkalinity, nitrogen, phosphorous, sulfur, toxic inorganic compounds, and heavy metals) that are important to treatment processes. Water's inorganic load is affected by wastewater discharges, geologic conditions and formations, and inorganics that remain in water after evaporation (Snoeyink and Jenkins, 1988). Natural waters dissolve rocks and minerals, adding inorganics to water, and these constituents can also enter water through human use (see Table 2.4).

Inorganic contaminants are often removed by corrosion control methods or by removal techniques. Corrosion controls reduce corrosion by-products (lead, for example) in potable water. Removal technologies, which include coagulation/filtration, reverse osmosis (RO), and ion exchange, are used to treat source water contaminated with metals or radioactive substances.

Nutrients

The nutrients of greatest concern in water supplies are nitrogen and phosphorous. Other nutrients include carbon, nitrogen, phosphorous, sulfur,

Table 2.4 Primary Standard MCLs for Inorganic Chemicals

Contaminant	Health effects	MCL (mg/L)	Sources
Arsenic	Nervous system effects	0.01	Geological, pesticide residues, industrial waste, smelter operations
Asbestos	Possible cancer	7 MFL ^a	Natural mineral deposits, A/C pipe
Barium	Circulatory system effects	2	Natural mineral deposits, paint
Cadmium	Kidney effects	0.005	Natural mineral deposits, metal finishing
Chromium	Liver, kidney, digestive system effects	0.1	Natural mineral deposits, metal finishing, textile and leather industries
Copper	Digestive system effects	TT ^b	Corrosion of household plumbing, natural deposits, wood preservatives
Cyanide	Nervous system effects	0.2	Electroplating, steel, plastics, fertilizer
Fluoride	Dental fluorosis, skeletal effects	4	Geological deposits, drinking water additive, aluminum industries
Lead	Nervous system and kidney effects, toxic to infants	TT	Corrosion of lead service lines and fixtures
Mercury	Kidney, nervous system effects	0.002	Industrial manufacturing, fungicide, natural mineral deposits
Nickel	Heart, liver effects	0.1	Electroplating, batteries, metal alloys
Nitrate	Blue-baby effect	10	Fertilizers, sewage, soil and mineral deposits
Selenium	Liver effects	0.05	Natural deposits, mining, smelting

Source: USEPA, *Selected Primary MCLs and MCLGs for Organic Chemicals*, 810-F-94-002, May 1994, 2010, 2011.

^a Million fibers per liter.

^b Treatment techniques have been set for lead and copper because the occurrence of these chemicals in drinking water usually results from corrosion of plumbing materials. All systems that do not meet the *action level* at the tap are required to improve corrosion control treatment to reduce the levels. The action level for lead is 0.015 mg/L, and for copper it is 1.3 mg/L.

calcium, iron, potassium, manganese, cobalt, and boron—all essential to the growth and reproduction of plants and animals.

Nitrogen (N_2) is an extremely stable gas. As the primary component of the earth's atmosphere, it occurs in many forms in the environment and takes part in many biochemical reactions. Nitrogen enters water from runoff from animal feedlots, fertilizer runoff, municipal wastewater discharges, and certain bacteria and blue-green algae that directly obtain atmospheric nitrogen. Some types of acid rain also add nitrogen to surface waters.

In water, nitrogen in the form of nitrate (NO_3) indicates contamination with sewage. An immediate health threat to both human and animal infants, excessive nitrate concentrations in drinking water can even cause death.

Though the presence of phosphorous (P) in drinking water has little effect on health, too much phosphorus in water supplies causes problems. While essential for growth, excess amounts of this nutrient contribute to algae bloom and lake eutrophication. Phosphorous sources include phosphates from detergents, fertilizer, and feedlot runoff, as well as municipal wastewater discharges.

pH

pH (hydrogen ion concentration) indicates the intensity of acidity or alkalinity in water and affects biological and chemical reactions. Water's chemical balance (equilibrium relationships) is strongly influenced by pH. For example, water's pH levels directly affect certain unit processes, including disinfection with chlorine. Increased pH increases the contact time needed for chlorine disinfection.

Chlorides

Chloride (a major inorganic constituent in water) generally does not cause any harmful effects on public health, though a high enough concentration can cause an objectionable salty taste. Chlorides occur naturally in groundwater, streams, and lakes, but concentrations in freshwater of 500 mg/L or more may indicate sewage contamination.

Biological water quality characteristics

Whether or not living organisms are present in water is a very useful indicator of water quality. Thousands of biological species spend part, if not all, of their life cycles in water. All members of the biological community can provide water quality parameters (see Figure 2.7).

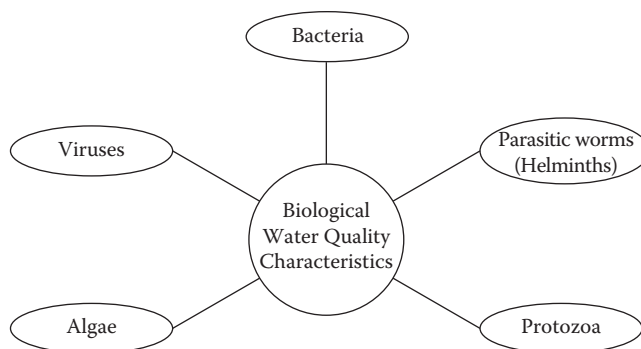


Figure 2.7 Biological water quality characteristics.

Most waterborne microbes are beneficial, particularly as food chain decomposers. Only a few microorganism species cause disease in humans or damage to the environment: the pathogens—organisms capable of infecting or transmitting diseases to humans and animals (Table 2.5).

The presence or absence of pathogens in water is of primary importance. Pathogens include species of bacteria, viruses, algae, protozoa, and parasitic worms (helminths). Although they do not naturally occur in aquatic environments, pathogens can be transmitted by natural water systems.

Bacteria

Air, water, soil, rotting vegetation, and human and animal intestines all contain bacteria. While most bacteria we encounter are harmless, waterborne pathogenic bacteria transmit diseases that cause common symptoms of gastrointestinal disorder. Eliminating pathogenic organisms through chemical treatment ensures safe drinking water to the consumer (see Figure 2.8).

Viruses

Viruses are tiny entities that require a host to live and reproduce. They carry the information they need for replication, but not the required machinery. The host provides that machinery. Waterborne viral infections generally cause nervous system disorders, not gastrointestinal ones.

Because the many varieties of viruses are small in size, unstable in behavior and appearance, and occur in low concentrations in natural waters, testing for viruses in water is difficult (see Figure 2.9). This difficulty is compounded by limited identification methods. Add to this concern of disinfection effectiveness, and the reasons that viruses are of special concern in water treatment become apparent.

Table 2.5 Waterborne Disease-Causing Organisms

Microorganism	Disease
Bacterial	
<i>Escherichia coli</i>	—
<i>Salmonella typhi</i>	Typhoid fever
<i>Salmonella</i> sp.	Salmonellosis
<i>Shigella</i> sp.	Shigellosis
<i>Yersinia enterocolitica</i>	Yersiniosis
<i>Vibrio cholerae</i>	Cholera
<i>Campylobacter jejuni</i>	Campylobacter enteritis
<i>Legionella</i>	Legionellosis
Intestinal Parasites	
<i>Entamoeba histolytica</i>	Amebic dysentery
<i>Giardia lamblia</i>	Giardiasis
<i>Cryptosporidium</i>	Cryptosporidiosis
Viral	
Norwalk agent	—
Rotavirus	—
Enterovirus	Polio
	Aseptic meningitis
	Herpangina
Hepatitis A	Infectious hepatitis
Adenoviruses	Respiratory disease
	Conjunctivitis

Source: Spellman, F.R., *Handbook of Water and Wastewater Treatment Plant Operations*, 2nd ed., Boca Raton, FL, CRC Press, 2008.

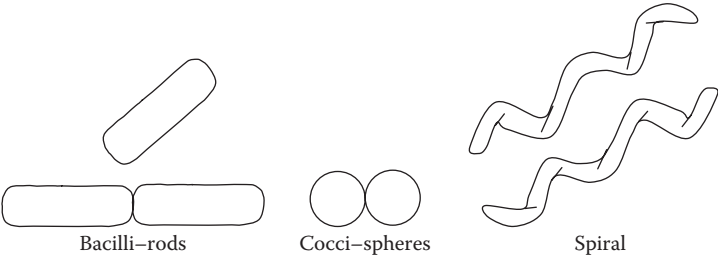


Figure 2.8 Bacterial shapes.

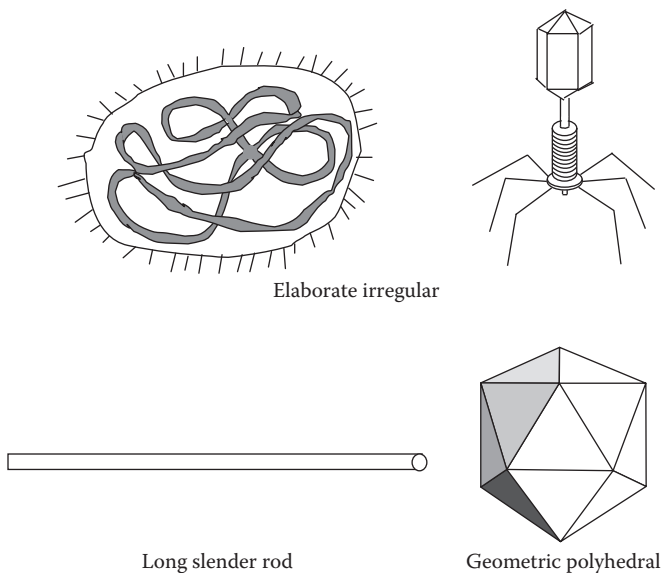


Figure 2.9 Virus shapes.

Algae

Algae are microscopic plants that occur in freshwater, saltwater, polluted water, and wastewater. Since most need sunlight to live, they only grow where they can be exposed to light—near the water surface (see Figure 2.10).

Algae play an important role in lake eutrophication (aging). In general, algae are considered nuisance organisms because they create taste and odor problems in public water supplies, and because removing them from the water causes extra expense.

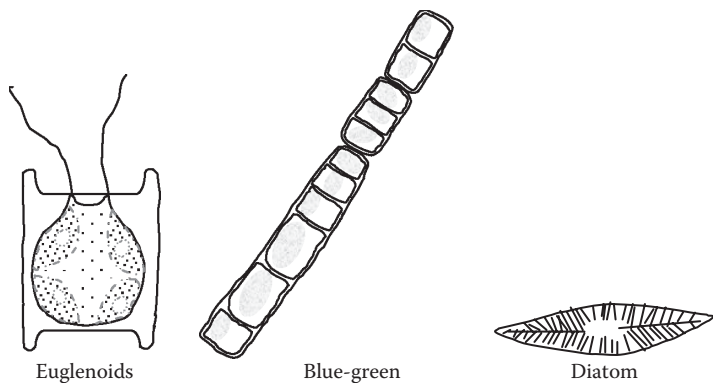


Figure 2.10 Algae.

Protozoa

Protozoa, the simplest of animal species, are mobile, single-celled, completely self-contained organisms (see Figure 2.11). Some protozoa are free-living, and others (only a few) are parasitic. They can be pathogenic or nonpathogenic, microscopic or macroscopic. Highly adaptable, protozoa are widely distributed in natural waters. Most protozoa are harmless; only a few

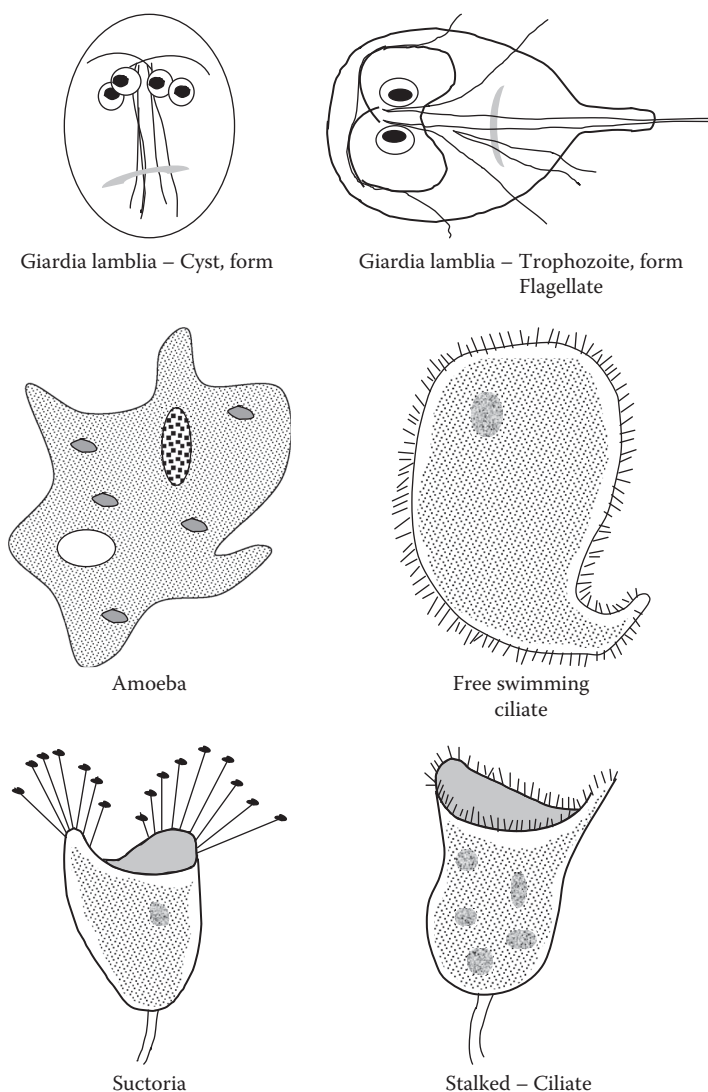


Figure 2.11 Protozoa.

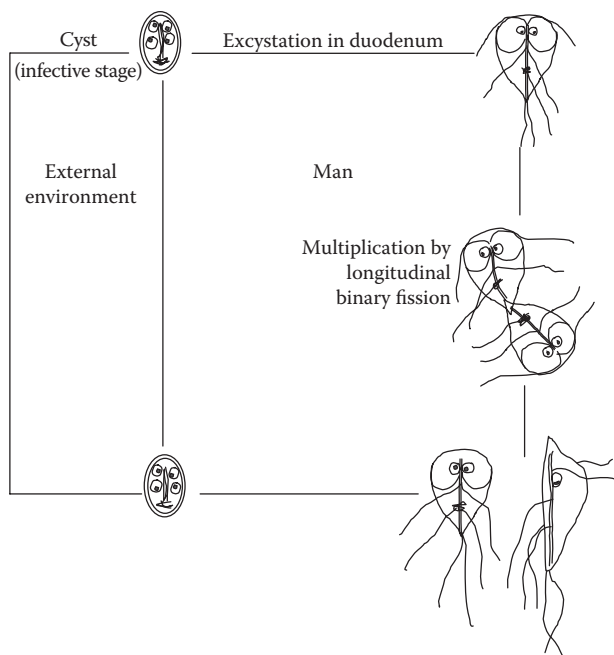


Figure 2.12 Life cycle of *Giardia lamblia*.

cause illness in humans—*Entamoeba histolytica* (amebiasis), *Cryptosporidium parvum*, and *Giardia lamblia* (giardiasis) are the important exceptions (see Figures 2.12 and 2.13). The cysts aquatic protozoans form during adverse environmental conditions make them difficult to deactivate by disinfection. Filtration is usually the most effective means to remove them from water.

Worms (helminths)

Worms inhabit organic mud and slime. They have aerobic requirements and can metabolize solid organic matter that other microbes cannot degrade. Human and animal wastes containing worms usually seed supply waters with worms. Worms are a hazard primarily to those who directly contact untreated water. *Tubifex* worms are common indicator organisms for pollution in streams.

Indicator organisms

Because of the difficulties inherent in microbial testing and identification, a method for obtaining a clear indication of a source water's condition (the presence or absence of pollution) is essential. Water treatment common practice does not test for individual pathogens (which may be present in

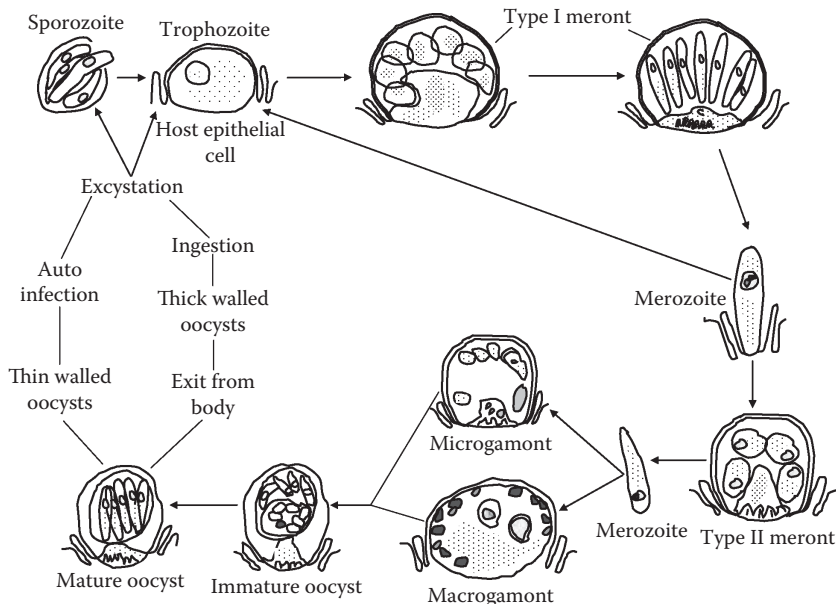


Figure 2.13 Life cycle of *Cryptosporidium parvum*.

such small quantities that they are undetectable), which would mean testing and retesting for each pathogenic organism—an enormously time-consuming (and thus costly) process. Instead, common practice requires testing for a single species of indicator organisms. A positive test for the indicator organism alerts us to the possible presence of sewage contamination. The indicator organisms used are the coliforms. When coliforms are present in a water sample, they indicate sewage contamination. A water source contaminated with sewage may also contain pathogenic microorganisms and presents a threat to public health.

Coliforms

Coliform group testing indicates a proportion of contamination relative to an easily defined quantity of water. It involves estimating the number of fecal coliform bacteria present in a measured water sample. Not only are fecal coliforms always present in fecal wastes, but water recently contaminated with sewage will always contain coliforms, which will outnumber disease-producing organisms.

Fecal coliform bacteria do not themselves cause disease. These organisms are present in the intestinal tract of all mammals. Human bodily wastes contain literally millions of coliforms. While the correlation between coliforms and human pathogens in natural waters is not

absolute, the number of fecal coliform bacteria present effectively indicates the water source's pollution levels.

Summary

A water source's normal condition is compared to the standards, and taking the raw water influent to accepted standards is the foundational task of water treatment. The parameters and testing methods lay the groundwork for the processes used in effective, efficient water treatment.

References and recommended reading

- Snoeyink, V.L., and Jenkins, D. 1988. *Water chemistry*. 2nd ed. New York: John Wiley & Sons.
- USEPA. May 1994, 2010, 2011. *Selected primary MCLs and MCLGs for organic chemicals*. 810-F-94-002. Washington, DC: USEPA.

chapter three

Water purification

System overview

Process purpose: Water purification

Water treatment brings raw water up to drinking water quality. The processes this entails depend on the quality of the water source. Surface water sources (lakes, rivers, reservoirs, and impoundments) generally require higher levels of treatment than groundwater sources. Groundwater sources may incur higher operating costs from machinery, but may require only simple disinfection (see Figure 3.1).

Water treatment unit processes

Treatment for raw water taken from groundwater and surface water supplies differs somewhat, but one commonly employed treatment technology illustrates many of the unit processes involved. Primary treatment processes for surface water supplies include the basic water treatment processes shown in Table 3.1 and hardness removal (not mandatory), as well as:

- *Intake* to bring in treatment water of the best possible quality the source can provide
- *Screening* to remove floating and suspended debris of a certain size
- *Chemical mixing* with the water to allow suspended solids to coagulate into larger particles that settle more easily
- *Coagulation*—a chemical water treatment method that causes small particles to stick together to form larger particles
- *Flocculation* to gently mix the coagulant and water, encouraging large floc particle formation

DID YOU KNOW?

Seventy-five percent of a chicken, 80% of a pineapple, and 95% of a tomato are water.

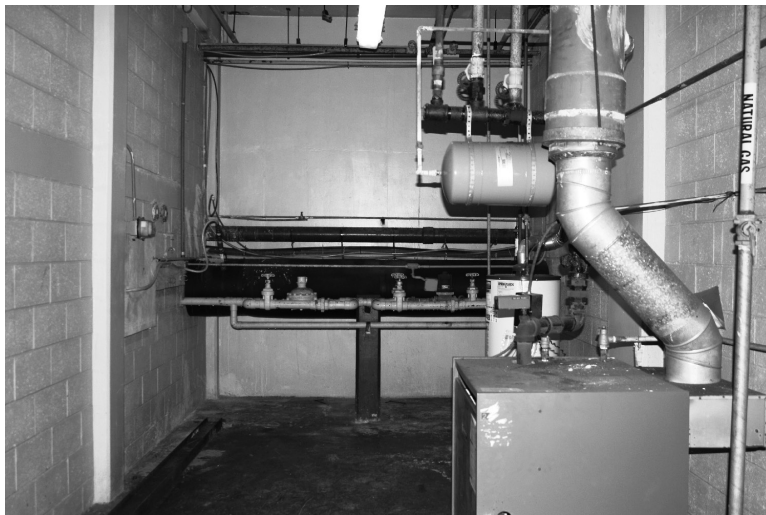


Figure 3.1 Raw water pipes into water treatment plant.

- *Sedimentation* to slow the flow so that gravity settles the floc
- *Sludge processing* to remove the solids and liquids collected in the settling tank, and to dewater and dispose of them
- *Disinfection* to ensure the water contains no harmful pathogens

Once water from the source has entered the plant as influent, water treatment processes break down into two parts. The first part, *clarification*, consists of screening, coagulation, flocculation, sedimentation, and filtration. Clarification processes go far in potable water production, but while they do remove many microorganisms from the raw water, they cannot produce water free of microbial pathogens. The final step, *disinfection*, destroys or inactivates disease-causing infection agents.

Summary

The major unit processes that make up the standard water treatment process are presented in the model in Figure 3.2. It shows the water source (in this case a river, since surface water treatment requires more process steps than does groundwater), screening, coagulation, flocculation, sedimentation, filtration, disinfection, and distribution. The remaining chapters in Section II cover these processes step-by-step.

Table 3.1 Basic Water Treatment Processes

Process/step	Purpose
Intake	Conveys water from source to treatment plant
Screening	Removes large debris (leaves, sticks, fish) that could foul or damage plant equipment
Chemical pretreatment	Conditions the water for removing algae and other aquatic nuisances
Presedimentation	Removes gravel, sand, silt, and other gritty materials
Microstraining	Removes algae, aquatic plants, and remaining debris
Chemical feed and rapid mix	Adds chemicals—coagulants, pH adjusters, etc.
Coagulation/flocculation	Converts nonsettleable or settleable particles
Sedimentation	Removes settleable particles
Softening	Removes hardness-causing chemicals
Filtration	Removes particles of solid matter—includes biological contamination and turbidity
Disinfection	Kills disease-causing organisms
Adsorption using granular activated carbon (GAC)	Removes radon and many organic chemicals, including pesticides, solvents and trihalomethanes (THMs)
Aeration	Removes volatile organic chemicals (VOCs), radon, H ₂ S, and other dissolved gases; oxidizes iron and manganese
Corrosion control	Prevents scaling and corrosion
Reverse osmosis, electrodialysis	Removes nearly all inorganic contaminants
Ion exchange	Removes some inorganic contaminants, including hardness-causing chemicals
Activated alumina	Removes some inorganic contamination
Oxidation filtration	Removes some inorganic contaminants—iron, manganese, radium, etc.

Source: Adapted from AWWA, *Introduction to Water Treatment*, Vol. 2, Denver, CO, American Water Works Association, 1984.

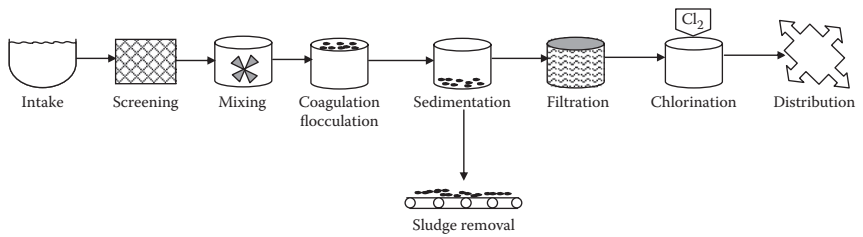


Figure 3.2 Unit processes: Water treatment.

Reference and recommended reading

AWWA. 1984. *Introduction to water treatment*. Vol. 2. Denver: American Water Works Association.

chapter four

Sources, intake, and screening

Introduction: Water sources

While all communities are different, one element they all have in common is the need for water for industries, commercial enterprises, and residents to use. In fact, a regular supply of potable water is the most important factor affecting whether or not any living creature chooses an area to live. Stable and plentiful freshwater sources are not always readily available where they could be put to most practical use, however. We readily recognize that water is not uniformly distributed. The heaviest populations of any life-forms, including humans, are found in regions of the world where potable water is present, because lands barren of water simply won't support large populations. The hydrologic cycle constantly renews our freshwater supplies, but population pressure is constantly increasing. As our population grows and we move into lands without ready freshwater supplies, we place ecological strain upon those areas, and on their ability to support life (see Figure 4.1).

Communities must have a constant adequate water supply to survive. Populations that choose to build in areas without adequate local water supply are at risk when emergencies occur. While attention to water source remediation, pollution control, water reclamation, and reuse can help to ease the strain increasing populations place on water supply, technology can't create local freshwater supplies, whether from surface or groundwater sources; it can only stretch the supplies already on hand.

Water sources

Water treatment brings raw water up to drinking water quality. The processes this entails depend on the quality of the water source—either surface water or groundwater. Common surface water sources include lakes and rivers, and precipitation or spring water that has been channeled into surface water storage in reservoirs. Most drinking water used by larger communities (especially in cities) is taken from surface sources. Surface water sources generally need both filtration and disinfection to be potable.



Figure 4.1 Lake Chargoggagoggmanchauggagoggchaubunagungmaugg (or Webster Lake), Webster, Massachusetts. This spring-fed 1,442-acre lake is the second largest natural lake in Massachusetts. The lake is primarily used for recreation.

Surface water supplies

In general, surface water is the result of precipitation—either rainfall or snow. An average of about 4,250 billion gal per day falls on the U.S. mainland, of which about 66% returns to the atmosphere directly from lake and river surface evaporation and plant transpiration. About 1,250 billion gal per day remains, flowing over or through the earth on its constant travel through the hydrogeologic cycle to return to the sea.

Surface water sources include:

- Rivers and streams
- Lakes
- Impoundments (manmade lakes created by damming)
- Shallow wells affected directly by precipitation
- Springs whose flow or quantity directly depends upon precipitation
- Rain catchments (drainage basins)
- Tundra ponds or muskegs (peat bogs)

As a source for potable water, surface water has some advantages over groundwater. Surface water is comparatively easy to locate without the aid of a geologist or hydrologist. Surface water is usually not tainted with minerals leached out during contact with the earth.

However, surface water sources are easily contaminated with microorganisms that can cause waterborne diseases, and from chemicals that enter

from surrounding runoff and upstream discharges. Especially in areas where surface waters are in short supply, water rights can present problems.

Human interferences (influences) and natural conditions affect surface water runoff flow rates. When surface water runs quickly off land surfaces, the water does not have enough time to infiltrate the ground and recharge groundwater aquifers, and can cause erosion and flooding problems. Surface water that runs off quickly usually does not have enough contact time to increase in mineral content—about the only positive to be said for this generally damaging condition.

Surface water collects in drainage basins, which direct the water through gravity-driven paths to the ocean. Surface water runoff follows the path of least resistance, normally flowing toward a primary watercourse unless some man-made distribution system diverts the flow. Drainage basins are generally measured in square miles, acres, or sections. A community drawing water from a surface water source must consider drainage basin size.

Several factors affect runoff over land surfaces. These include:

- **Rainfall duration:** Any rain, if it lasts long enough, will eventually saturate soil and allow runoff to take place.
- **Rainfall intensity:** Hard-driving rain saturates the soil more quickly than gentle rain. Saturated soil holds no more water; excess water builds up on the surface, creating surface runoff.
- **Soil moisture:** Already saturated soil causes surface runoff to occur sooner than dry soil. Frozen soil is basically impervious; snowmelt or rain runoff can be 100% off frozen ground.
- **Soil composition:** Surface soil composition directly affects runoff amounts. For example, hard rock surfaces result in 100% runoff. Clay soils have small void spaces that close when wet and do not allow infiltration. Large void spaces in coarse sand allow water to pass easily, even in a torrential downpour.
- **Vegetation cover:** Groundcover limits runoff, creating a porous layer (a sheet of decaying natural organic substances) above the soil. This porous organic sheet passes water easily into the soil, while acting as a protective cover for the soil against hard, driving rains. Downpours can compact bare soils, close off void spaces, and increase runoff. Vegetation and groundcover maintain the soil's infiltration and water holding capacity and work to reduce soil moisture evaporation.
- **Ground slope:** Up to 80% of rainfall that lands on steeply sloping ground will become surface runoff. Gravity carries the water down the surface more quickly than it can infiltrate. A higher percentage of water flow on flat lands infiltrates the ground; water's movement

DID YOU KNOW?

A person must consume 2.5 quarts of water per day from all sources (drinking, eating) to maintain health.

over the surface is usually slow enough to provide opportunity for higher amounts of infiltration.

- **Human influences:** Many human activities impact surface water runoff, most of which tend to increase the rate of water flow. Though man-made dams generally contain the flow of runoff, practices that include channeling water through canals and ditches carry water along rather than encouraging infiltration. Agricultural activities generally remove groundcover that normally retards runoff. Communities provide ample examples of human impact on runoff. Impervious surfaces (including streets, parking lots, and buildings) greatly increase the amount of runoff from precipitation. These man-made surfaces work to hasten the flow of surface water, and can cause devastating flooding. Bad planning can create areas where even light precipitation can cause local flooding. Besides dictating increased need for storm water management systems, these surfaces also do not allow water to percolate into the soil to recharge groundwater supplies—often a serious problem for a location's water supply.

Groundwater supply

A gigantic water source forms a reservoir that feeds all the natural fountains and springs that flow on the surface of the earth—groundwater that lies contained in aquifers beneath earth's crust. But how does water travel into the aquifers that lie under earth's surface?

Groundwater is replenished through part of the 3 ft of water that (on average) falls to earth each year on every square foot of land. When water falls to earth, it follows three courses. Some runs off directly to rivers and streams (roughly 6 in. of that 3 ft), eventually traveling to the sea. Evaporation and transpiration account for another approximately 2 ft. That last 6 in. seeps into the ground, entering and filling each hollow and cavity, and trickling down into the water table that lies below the surface.

The water table is usually not level. It often follows the shape of the ground surface. Groundwater flows downhill in the direction of the water table slope. Where the water table intersects low points of the ground, it seeps out into springs, lakes, or streams. Almost all groundwater is in constant motion through the pores and crevices of the aquifer in which it occurs.

When compared to surface water as a source, groundwater does present some advantages. Groundwater is not as easily contaminated as surface

water, and is usually lower in bacteriological contamination than surface waters. Groundwater quality and quantity usually remain stable throughout the year, and are less affected by short-term droughts than surface water. Groundwater is available in most locations in the United States.

Disadvantages include higher operating costs, because groundwater supplies must be pumped to the surface. Once contaminated, groundwater is very difficult to restore, and contamination can be difficult to detect. High mineral levels and increased levels of hardness are common to groundwater supplies, because the water is in contact longer with minerals. Groundwater sources near coastal areas may be subject to saltwater intrusion.

Watershed management programs

Surface runoff water, exposed and open to the atmosphere, is water flow that has not yet reached a definite stream channel. When the rate of precipitation exceeds either the rate of interception and evapotranspiration, or the amount of rainfall readily absorbed by the earth's surface, the remainder flows over or just underneath the surface as surface water runoff or overland flow. The total land area that contributes runoff to a stream or river is called a *watershed*, *drainage basin*, or *catchment area*.

Groundwater (usually pumped from wells) often requires only simple disinfection, or at the most softening (removing calcium and magnesium), before disinfection. In rural areas, the most usual source water is subsurface (usually wells). Both groundwater and surface water supplies depend upon levels of precipitation and runoff, and surface water sources especially can vary seasonally—reservoirs for water supply storage help to regulate uneven supply conditions. While groundwater is available throughout most of the United States, the amount available at particular locations may be limited. Both surface and groundwater sources must consider watershed or catchment area conditions and protection (see Figure 4.2).

Watershed and wellhead management practices and formal programs are increasing public awareness of the need for individuals to act responsibly to protect local water supplies. Programs that provide information on nonpoint source pollutants and how they enter surface and groundwaters, that identify watershed, wellhead, or catchment areas, or that identify points where chemical dumping will cause damage to water supplies, all bring valuable consumer attention to environmental concerns.

Process purpose: Intake and screening

Water intake involves bringing the water from the source to the treatment facility (see Figure 4.3). Surface water from rivers, lakes, or reservoirs flows into the transmission system through an intake structure. Groundwater

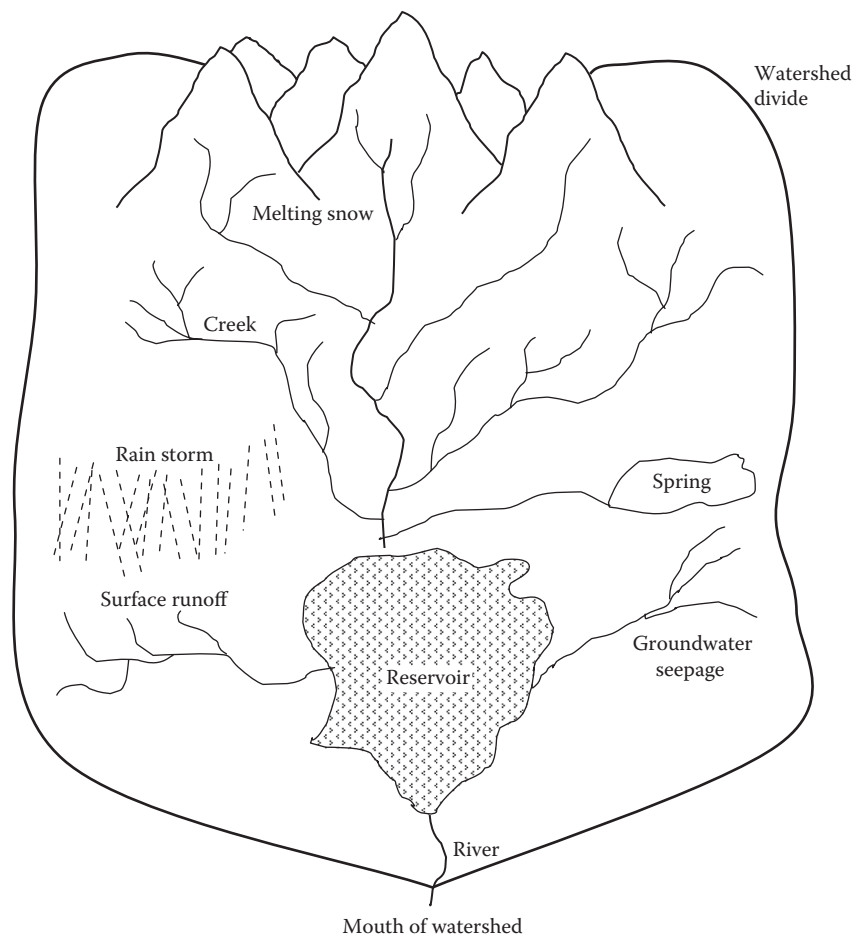


Figure 4.2 Watershed.

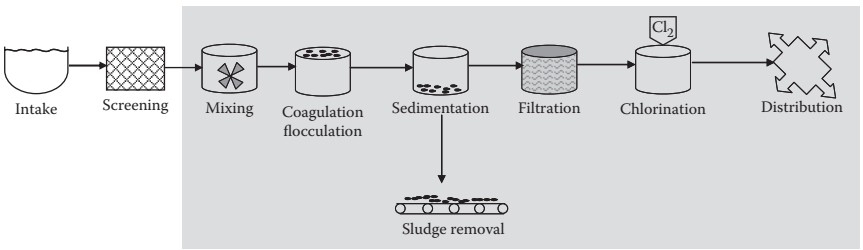


Figure 4.3 Basic water treatment unit processes: water intake and screening.

flow moves through an intake pipe from the groundwater source, then is pumped through a transmission conduit to a distribution system. Once the influent enters the plant, surface waters demand more treatment processes than groundwater sources need.

Surface water bodies (whether we use them as a drinking water source or not) unfortunately often contain large quantities of trash, as well as other pollutants. These range from natural pollutants, including brush, branches, logs, rocks, and grit, to plastic bottles, old paper and cardboard, cigarette butts and packs, lost shoes, and the beer cans people casually toss into the river, to more dangerous and persistent industrial pollutants. In short, the water that a treatment plant may take in for eventual distribution often carries with it a wide range of bulky, long-lasting solids. These solids are physically removed before the water actually enters the plant by screening, the initial treatment step.

Large debris carried along to other treatment processes could damage or foul plant equipment, increase chemical usage, block water flow in pipes or channels, or otherwise slow water treatment.

Process equipment: Intake

Sources from waters drawn directly from lakes, reservoirs, or rivers mean a need for selection of the best water possible from the source. Intake structures provide that control over the water supply quality (see Figure 4.4).



Figure 4.4 City of Oneonta lower reservoir (intake out of service).

Surface and groundwater intake

Intake structures for lakes, reservoirs, or rivers are in place to accomplish two purposes: to supply water of the best possible quality from the source, and to protect downstream equipment and piping from damage or clogging from debris, flooding, or wave action. Intakes typically consist of screened openings and conduit to carry flow to a sump, where the water is pumped to the treatment facility. Intake structure must take into account broad differences in water depth, flow, quality, and temperature. Sources of pollution and the direction that current flow will carry them are also of importance, as are navigation, wind and current patterns, scour, and sedimentation deposits, and the amount of floating debris.

Considerations for lake and reservoir intakes are different than for river intakes. Intake types include towers, submerged ports, and shoreline structures (see Figure 4.5). Changes in water level and quality variations with depth are common in lakes and reservoirs, and tower intakes (which

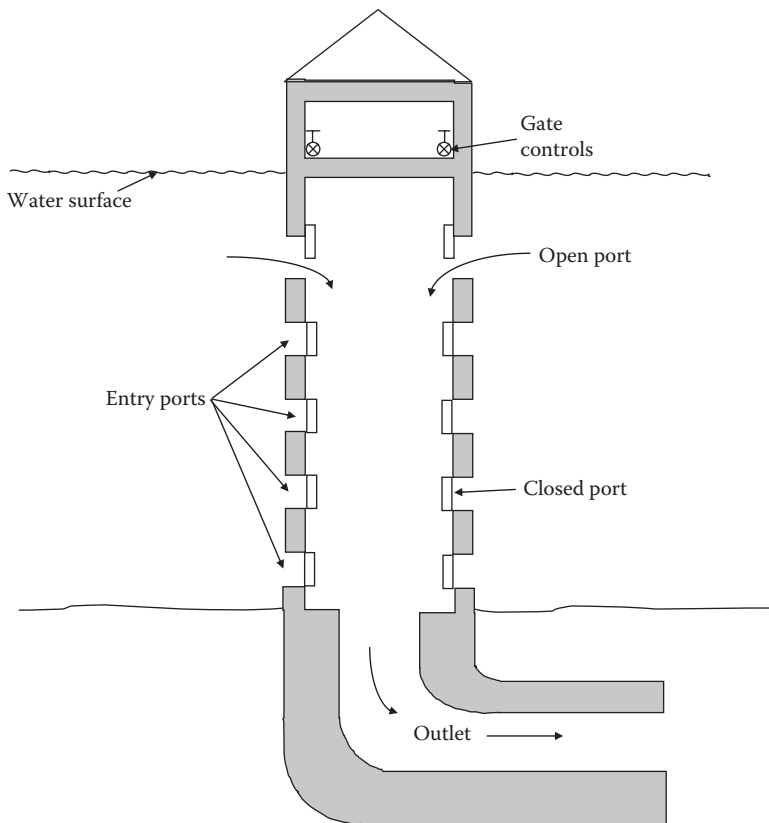


Figure 4.5 Tower water intake for a reservoir lake water supply (larger than scale).

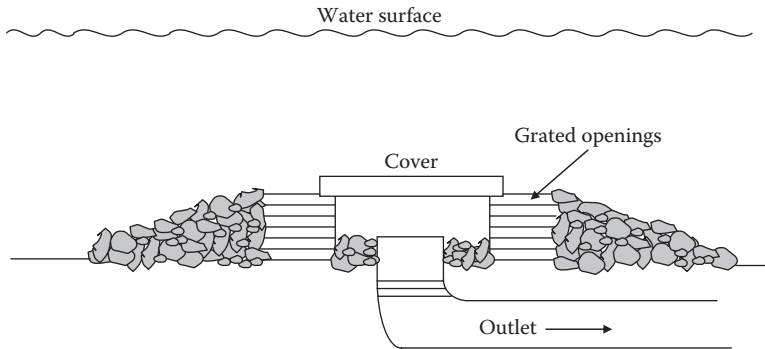


Figure 4.6 Submerged intake used for both lake and river sources.

provide ports at several depths) are designed for these conditions. In lakes, for most of the year, water quality is best near the surface, but with the changes that occur with spring and fall turnover, and with the possibility of icing in winter, the option of several ports means control over intake selection.

Generally, river intakes are submerged or screened shore intakes, in part because of low costs (see Figure 4.6). River intakes are designed to withdraw water from slightly below the surface. This generally provides the best possible river water quality, by avoiding sediment in suspension in the depths as well as floating debris.

Groundwater is pumped to an intake pipe from the groundwater source. Pumps carry the water through a transmission conduit to the distribution system.

Process equipment: Screening

Removing the floating debris is an important consideration for surface water treatment. Treatment plants use a variety of screening devices to remove the trash and natural debris surface waters carry. Once influent is past the intake, trash screens or rakes, traveling water screens, drum screens, bar screens, or passive screens are employed to remove debris from influent. Screen opening size and flow rate determine the minimum size of debris the screening equipment can halt. Considerations for equipment selection include costs related to operation and equipment, plant hydraulics, debris handling requirements, operator qualifications, and availability.

Trash screens (rakes)

Rough and large debris is caught and retained on trash racks by *trash screens* or *trash rakes*. Trash screens or rakes are commonly used as a

preliminary screening device to remove the largest debris before the influent enters finer screening systems—drum screens or traveling water screens.

Commonly, trash screens are constructed of steel, though high-density polymers are now attracting attention. Trash rack bar spacing ranges from 1.5 to 4 in., and one or more stationary racks may be used on a trash screen, along with a screen raking system. Raking mechanisms can be installed on dam walls, on the sides of buildings, depending on intake configuration requirements. Typically mounted on fixed structures designed to clean a single trash rack, rakes can also be suspended from overhead gantries, or wheel mounted to cover the complete intake structure width and clean individual sections of a wide trash rack.

Traveling water screens

Traveling water screens consist of a continuous series of wire mesh panels. These are bolted to basket frames or trays, and attached to two aligned strands of roller chain. Placed in a channel of flowing water to remove floating or suspended debris (see Figure 4.7), traveling water screens run on a sprocket assembly to cover a vertical path through the flow. The raw water passes through the revolving baskets, while the debris load is carried out of the stream flow and above the screen operating level, where high-pressure water sprays remove it. Some traveling water screens operate continuously, others intermittently. Intermittent water screens are activated by set time intervals or by metered specific head loss levels.

In river installations in particular, debris load, water depth, and water flow conditions can widely fluctuate. An individual water screen installation should consider wire mesh size, influent velocity through the mesh, basket, or channel width, the number of screens, the maximum average

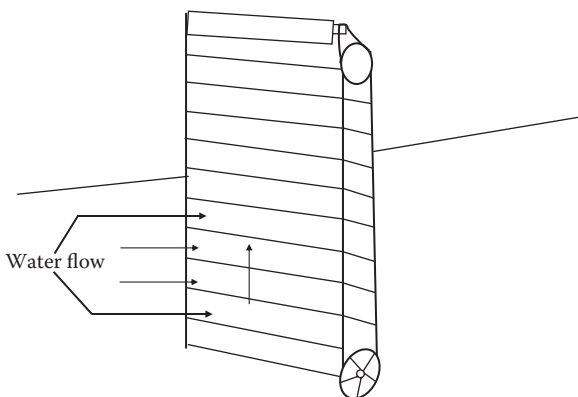


Figure 4.7 Traveling water screen.

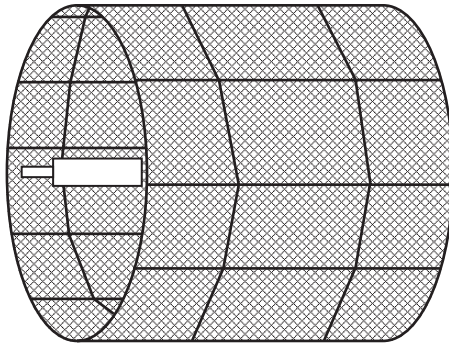


Figure 4.8 Drum screen.

flow, maximum-minimum average water levels, and the type of service, as well as the starting/operating head loss requirements.

Drum screens

Drum screens have very few moving parts. Simplicity of design and construction keep installation, operation, and maintenance costs relatively low. The screen itself (a series of wire mesh panels attached to the periphery of a cylinder) is mounted on a horizontal axis (see Figure 4.8). The screen turns slowly on its axis, picking up debris as the water flows through it.

Bar screens

Bar screens are used at some water treatment facilities, though they are more common at wastewater facilities. Designed to handle relatively large debris, a bar screen consists of a rack of straight steel bars welded at both ends to horizontal steel members. Powered rakes move up and down the bar rack face (see Figure 4.9) removing debris, and elevating in and out of flow. The debris is removed at the top of the operating cycle by a wiper mechanism. Bar screen assemblies are normally installed at a 60 to 80° angle from the horizontal.

Passive screens

The most mechanically simple screening devices are *passive intake screens* or stationary screening cylinders (see Figure 4.10). They have no moving parts, and careful placement ensures they use no debris moving or handling equipment. Usually, passive intake screens are mounted on a horizontal axis, and are oriented parallel to the current in a surface water

body to take advantage of natural ambient currents. The current action works positively to clean the screen. Controlled through-screen velocities (a maximum intake velocity of 0.5 fps is typical) minimize debris buildup and screen surface impingement.

Summary

Screening is a preliminary step that removes only relatively large visible pollution from the influent. The accumulation of trash that screening removes is less important in terms of sanitation of the water than the less apparent pollutants that remain. The downstream processes used to eliminate these problems are more complex, and eliminate far more dangerous problems from the raw water.

Coagulation and flocculation

Process purpose: Coagulation and flocculation

Coagulation is a chemical process that physically makes sedimentation more efficient (see Figure 5.1). Flocculation is a physical process used to enhance the effectiveness of coagulation's chemical addition. The screened influent is pumped into large *settling basins* (also called clarifiers or sedimentation tanks), where it is allowed to sit for a prescribed time. The settling basin allows gravity to handle many of the suspended impurities that remain in the influent. Under quiescent basin conditions, when flow and turbulence are at the minimum, *sedimentation* makes particles that are denser than water sink and settle to the tank bottom. Larger and heavier particles settle faster than smaller, lighter particles. The accumulation on the bottom of the tank is called sludge or water solids.

Not all suspended particles will be removed in this process, even under very long detention times. Buoyancy and drag (friction) affect the settling rate, as do water temperature and viscosity. Very small particles (including colloids, bacteria, color particles, and turbidity) will not settle out of suspension without some help. The coagulation process provides that help. By rapidly mixing coagulant chemicals with the water, then slowly and gently stirring the mixture before sedimentation, these particles form floc in the *flocculation* process. The larger, heavier floc particles settle, and can then be removed by subsequent settling and filtration. In fact, colloidal particles must be chemically coagulated to be removed (see Figure 5.2).

Coagulation and flocculation neutralize or reduce the natural repellent negative electrical charge that particles in water carry. This electrical

DID YOU KNOW?

Coagulant chemicals come in two main types—primary coagulant and coagulant aids. Primary coagulants (Table 5.1) neutralize the electrical charges of particles in the water, which causes the particles to clump together. Coagulant aids add density to slow-settling flocs and add toughness to the flocs so they will not break up during settling.

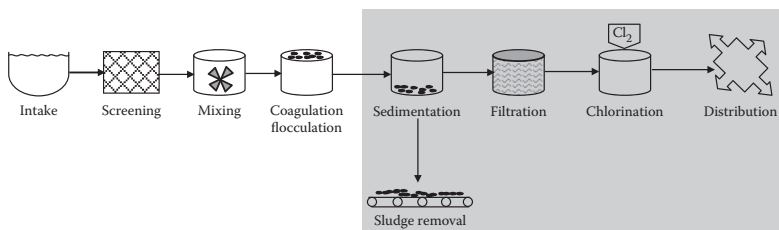


Figure 5.1 Basic water treatment unit processes: mixing and coagulation/flocculation.

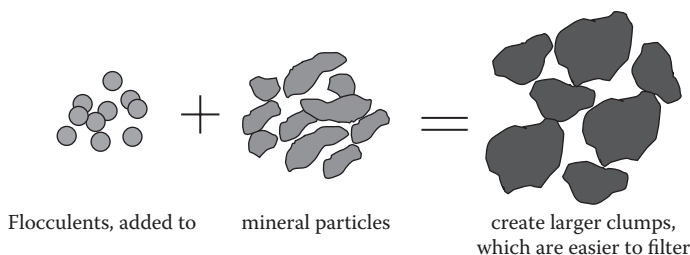


Figure 5.2 Clumping of particles.

charge keeps particles separate and in suspension. By chemically removing the charge, then ensuring the particles contact, coagulation and flocculation alter the colloids so that they adhere to form large floc particles.

Coagulant chemicals

Coagulation processes use coagulants or coagulant aids. The types appropriate for use are dependent on individual plant process schemes.

Coagulant types

Commonly used metal coagulants are based on aluminum (aluminum sulfate—alum—the most frequently used) or iron (ferric sulfate). Table 5.1 lists other common coagulants.

Chemically, when alum is added to water, it ionizes, producing Al^{3+} ions, some of which neutralize the negative charges on the colloids. However, most of the aluminum ions react with alkalinity in water (bicarbonate) to form insoluble aluminum hydroxide. The aluminum hydroxide absorbs ions from solution, forms a precipitate, and adsorbs sulfates.

AWWA's *Water Treatment: Principles and Practices of Water Supply Operations* (1995, 56) describes the process step-by-step.

Table 5.1 Common Coagulant Chemicals

Common name	Comments
Aluminum sulfate	Most common coagulant in the United States; often used with cationic polymers
Ferric chloride	May be more effective than alum in some applications
Ferric sulfate	Often used with lime softening
Ferrous sulfate	Less pH dependent than alum
Aluminum polymers	Synthetic polyelectrolytes; large molecules
Sodium aluminate	Used with alum to improve coagulation
Sodium silicate	Ingredient of activated silica coagulant aids

Source: Adapted from Larsen, T.J., *Water Treatment Plant Design*, Cox Publishing, New York, 1990, p. 77.

1. Alum added to raw water reacts with the alkalinity naturally present to form jellylike floc particles of aluminum hydroxide, $\text{Al}(\text{OH})_3$. A certain level of alkalinity is necessary for the reaction to occur. If not enough is naturally present, the alkalinity of the water must be increased.
2. The positively charged trivalent aluminum ion neutralizes the negatively charged particles of color or turbidity. This occurs within 1 or 2 s after the chemical is added to the water, which is why rapid, thorough mixing is critical to good coagulation.
3. Within a few seconds, the particles begin to attach to each other to form larger particles.
4. The floc that is first formed consists of microfloc that still has a positive charge from the coagulant; the floc particles continue to neutralize negatively charged particles until they become neutral particles themselves.
5. Finally, the microfloc particles begin to collide and stick together (agglomerate) to form larger, settleable floc particles.

Coagulant aids

Coagulation and flocculation are somewhat delicate processes. When floc settles too slowly, or breaks apart too easily under the basin water movement, coagulant aids improve settling and floc toughness. AWWA (1995) describes a coagulant aid as a chemical added during coagulation to improve coagulation; to build stronger, more settleable floc; to overcome the effect of temperature drops that slow coagulation; to reduce the amount of coagulant needed; and to reduce the amount of sludge produced.

Polymers (water-soluble, high molecular weight organic compounds that carry multiple electrical charges along a chain of carbon atoms) are widely used coagulant aids that help build large floc prior to sedimentation



Figure 5.3 Rapid mix basin.

and filtration. Activated silica, adsorbent-weighting agents, and oxidants are also used.

Process operation: Coagulation

Coagulation chemicals are added in the rapid-mix tank, generally in a matter of minutes. Coagulant aids are added and blended into the electrically destabilized water during flocculation.

Water characteristics affecting this process include pH, temperature, and ionic strength. Chemical treatment is based on empirical data derived from jar testing or other laboratory tests and field studies (Viessman and Hammer, 1998) (see Figure 5.3).

Process operation: Flocculation

Flocculation (the clumping of particles as the result of coagulation) is the most critical factor that affects particle removal efficiency. It speeds slow-settling particles and chemical precipitants.

This is accomplished by a slow mixing process, designed to bring particles into contact so that they collide, stick, and agglomerate (grow) to a size that readily settles. How fast and well the particles agglomerate depends on *velocity gradient*. Too much mixing shears the floc particles, breaking them down into smaller units. The velocity gradient (the speed

DID YOU KNOW?

Water high in color and low in turbidity and mineral content would not form floc large enough to settle out the water. The coagulant aid bentonite is used to join with the small floc, making the floc heavier and thus making it settle more quickly.

the water is moved in the mixing process) must be strictly controlled. Enough mixing to bring the floc into contact must occur (the heavier the floc and the higher the suspended solids concentration, the more mixing is needed), without breaking apart the forming floc, until maximum floc formation occurs and sedimentation can begin. Gentle agitation for about 30 min, using redwood paddles mounted horizontally on motor-driven shafts, is common. The paddles rotate slowly (about one revolution per minute), providing gentle agitation that encourages floc growth.

Floc formation depends on how much particulate matter is present, how much volume it occupies, and the basin velocity gradient. Experimentation with new techniques in coagulation and flocculation is ongoing. A relatively new practice involves coagulation dispersion (flash mixing), flocculation and sedimentation in a single unit called a *contact clarifier*.

Summary

Coagulation and flocculation work together to remove much of the hidden debris that enters the plant in the influent. The smaller the impurities that remain, however, the more complex are the processes used to remove them.

References and recommended reading

- AWWA. 1995. *Water treatment: Principles and practices of water supply operations*. 2nd ed. Denver: American Water Works Association.
- Larsen, T.J. (1990). *Water treatment plant design*. New York: Cox Publishing.
- Viessman, W., and Hammer, M.J. 1998. *Water supply and pollution control*. 6th ed. Menlo Park, CA: Addison-Wesley.

chapter six

Sedimentation

Process purpose: Sedimentation

Sedimentation (or clarification) is a physical process that separates settleable solids from influent by gravitational action. These solids include particulate matter, chemical floc, precipitates in suspension, and other solids (see Figure 6.1).

Process equipment

Sedimentation takes place in settling or sedimentation tanks or basins, where water rises vertically for discharge through effluent channels in specific flow patterns suited to tank size and shape. In rectangular tanks, water flow will be rectilinear; center-fed and square settling tanks will operate with radial flow, and peripheral-feed basins use spiral flow. Design criteria include overflow rate, weir loading and detention time (1 to 10 h is typical), and horizontal velocity for rectangular tanks. Equipment choice is determined using empirical data from full-size tank use performance. No matter what the equipment size and shape, settling tanks are designed for slow and steady water movement (see Figure 6.2).

Process operation

Ideally, water flows horizontally through the sedimentation basin, then rises vertically to overflow the discharge channel weir at the tank surface (see Figure 6.3). While the water slowly rises, the floc settles in the opposite direction and is expelled mechanically by continuous action sludge removal machinery. The process does not remove all of the floc. Particles lighter than the overflow rate flow out with the effluent, and are removed by filtration.

DID YOU KNOW?

Water regulates the earth's temperature. It also regulates the temperature of the human body, carries nutrients and oxygen to cells, cushions joints, protects organs and tissues, and removes wastes.

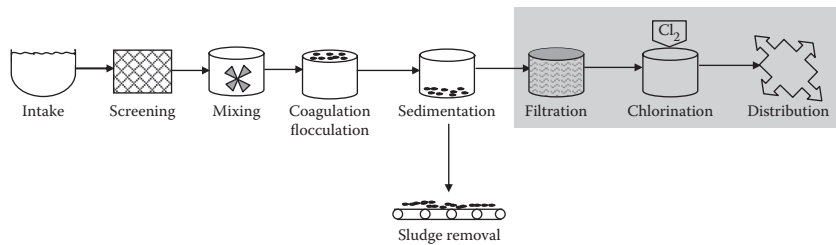


Figure 6.1 Basic water treatment unit processes: sedimentation added.



Figure 6.2 Sedimentation basin.

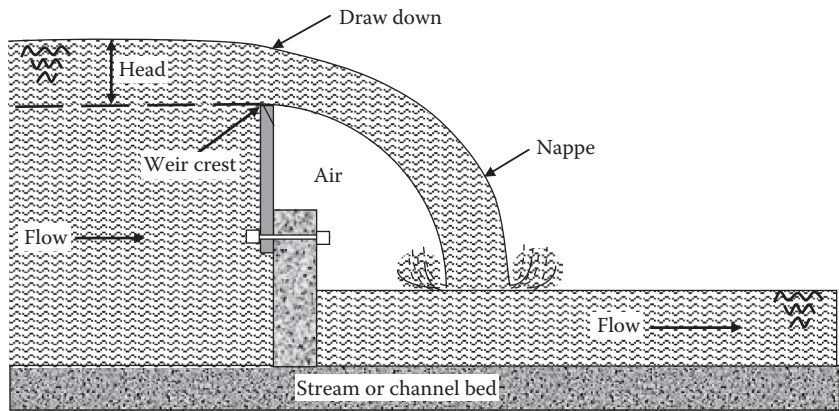


Figure 6.3 Side view of a weir.

Sedimentation basin sludge is disposed of by passing it to a lagoon, thickening and holding, or directing it to the sanitary sewer.

Summary

Sedimentation balances time efficiency against removal rate efficiency. While the physical laws of gravity work in sedimentation, allowing the removal of materials too small for the initial screening to halt (through the combined efforts of coagulation and flocculation), the lighter materials are more efficiently removed by filtration in the next water treatment process stage.

chapter seven

Filtration

Process purpose: Filtration

Filtration is also a physical process, one that occurs naturally for ground-water sources. Surface waters percolate through porous layers of soil where they eventually recharge groundwater, reducing suspended matter and microorganisms to a level that ensures groundwater usually needs no treatment other than disinfection. Filtration of surface water is the last physical step in the process of producing potable water that meets the Safe Drinking Water Act turbidity requirement of 0.5 NTU (see Figure 7.1).

Generally, about 5% of the suspended solids and other impurities remain after sedimentation. This small percentage of remaining nonsettleable floc particulate matter causes noticeable turbidity, and may shield microorganisms from disinfection. Filtration is a polishing process, and it involves passing the water through a layer (or bed) of porous granular material. This removes suspended particles by trapping them in the pore spaces of the filter media as the water flows through the filter bed (see Figure 7.2).

Process equipment

Filtration systems come in a variety of types and configurations, and system choice criteria include space considerations, speed considerations, and cost considerations for both installation and operation. Common filter types include rapid sand and slow sand filtration, diatomaceous earth filtration, and package filtration systems. Filters are also classified by the granular media (sand, anthracite coal, coal-sand, multilayered, mixed bed, or diatomaceous earth) and by directional flow (downflow, upflow, fine to coarse, or coarse to fine). Filtration action can work by either gravity or pressure.

Individual filter media present advantages and disadvantages. Ideally, the perfect filtration media qualities are that the media would have pore openings large enough to retain large quantities of floc to process large volumes of water without clogging, but small enough to prevent pass-through of suspended solids. The ideal filter media would also be lightweight enough to allow enough depth for long filter runs, and graded to allow effective backwash cleaning.

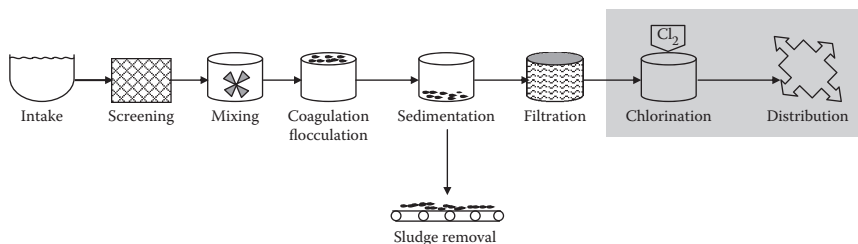


Figure 7.1 Basic water treatment and processes: filtration added.

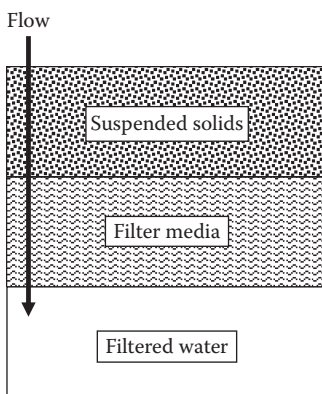


Figure 7.2 Water flow through a filter.

In gravity filtration, gravity forces the water down through the media, and forced upflow (backwashing) periodically removes collected impurities from the filter to clean it. Slow and rapid (refers to flow rate per surface area unit) sand filter systems are gravity filtration systems, and are commonly used for municipal applications.

In pressure filtration systems, the filters are completely enclosed to use line water pressure to push the influent through the filter (see Figure 7.3).

Slow sand filtration systems

While slow sand filtration systems are reliable and use proven technology, modern plants generally don't employ them, because of the variety of

DID YOU KNOW?

It is possible for people today to drink water that was part of the dinosaur era.

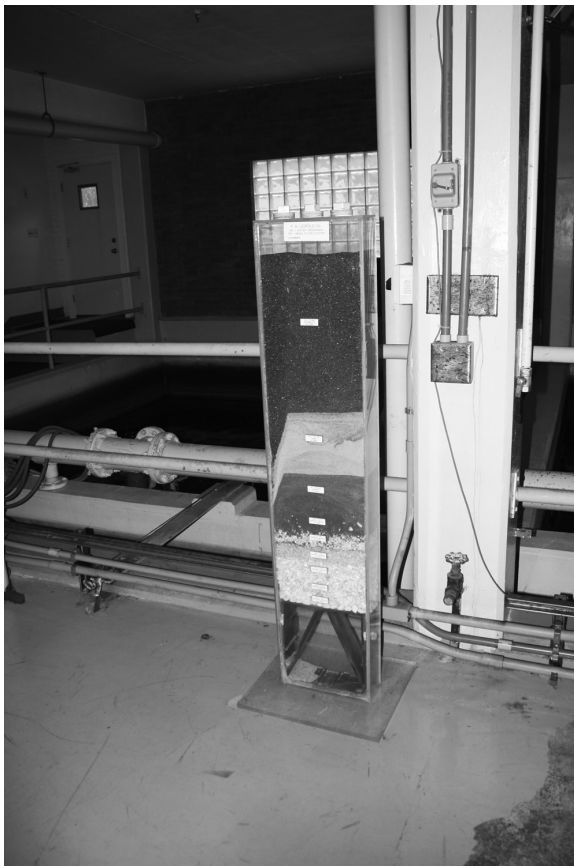


Figure 7.3 Filter media.

problems associated with the systems. These problems are mostly related to small pore spaces in fine sand. While the small pores filter effectively, they also slow down the passage of water. Slow filtration time means increased filtration area needs to process adequate amounts of water. This also means increased land usage to house the units. The fine pore spaces clog easily as well, requiring manual scraping to clean the filter (see Figure 7.4, Figure 7.5, and Figure 7.6).

Rapid sand filtration systems

Rapid sand filters are the most commonly used systems for water supply treatment because of their reliability, and have replaced slow sand filters in most modern treatment plants. Rapid filters contain a layer of carefully sieved silica sand over a bed of graded gravels. The pore openings are

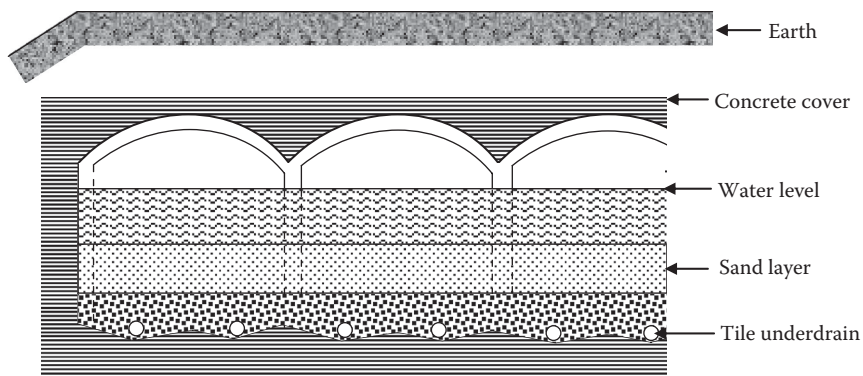


Figure 7.4 Slow sand filter.



Figure 7.5 Backwash.



Figure 7.6 Filter backwash and effluent pipes and valves.

often larger than the floc particles to be removed, so rapid system filters use a combination of techniques to remove suspended solids and particulate matter from influent, including simple straining, adsorption, continued flocculation, and sedimentation. Filter cleaning is accomplished by daily backwashing (see Figure 7.7).

Other common filtration systems

In pressure filters, as in rapid sand filters, water flows through granular media in a filter bed. However, pressure systems enclose the bed in a cylindrical steel tank and pump the water through the media under pressure. This can cause problems with reliability; occasionally solids are forced through the filter along with the effluent (see Figure 7.8).

The *diatomaceous earth* (DE) filter contains a thin layer of a powder-like material formed from the shells of diatoms. These filtration systems also present reliability problems as well as expense considerations.

DID YOU KNOW?

The earliest municipal DE filter installation was a 75,000 gallons per day (gpd) system in Campbell Hills, Illinois, that began operation in 1948. By 1977, municipalities had constructed more than 145 plants. Today (2011), nearly 200 DE plants are successfully operating.

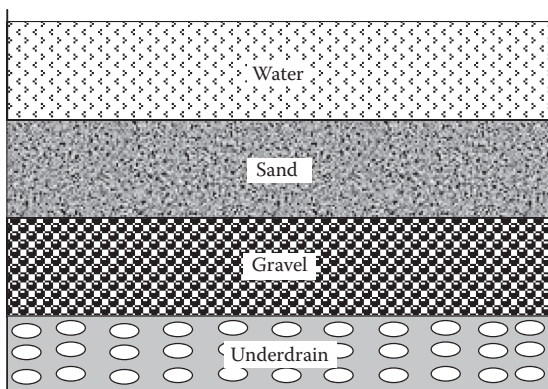


Figure 7.7 Rapid sand filter.

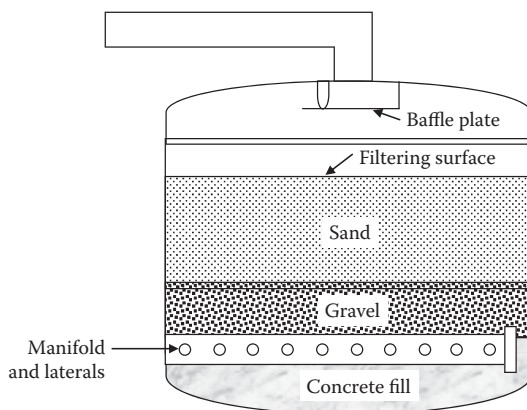


Figure 7.8 Pressure filter.

Diatomaceous earth media is replaced rather than cleaned and reused by backwashing, raising operating costs.

Both pressure and DE filtration systems are more commonly used in industrial and swimming pool applications than they are in municipal installations.

Summary

While filtration is an essential step in preparing the influent for final disinfection, it does not remove the most dangerous elements present in raw water. Bacteria and viruses are too minute to screen out. They will not coagulate, aggregate, settle out, or filter out without special processing. These pathogens must be deactivated by disinfection.

chapter eight

Disinfection

*A Sherlock Holmes at the pump**

In 1854, on the filthy streets of London, a ruthless killer was being hunted. No, not by Sherlock Holmes, but by someone absolutely as brilliant—and definitely as driven. His name: Dr. John Snow. The identity of Snow’s brutal killer: Cholera. To stop this killer, Dr. Snow took a lifesaving action for thousands; he removed the handle from a water pump.

Let’s take a closer look at Dr. Snow’s actions to contain the spread of cholera and his subsequent impact on water treatment (disinfection) of raw water used for potable and other purposes.

Dr. John Snow

An unassuming London obstetrician, Dr. John Snow (1813–1858) achieved prominence in the mid-nineteenth century for proving his theory (in his *On the Mode of Communication of Cholera*) that cholera is a contagious disease caused by a “poison” that reproduces in the human body and is found in the vomitus and stools of cholera patients. He theorized that the main (though not the only) means of transmission was water contaminated with this poison. His theory was not held in high regard at first, because a commonly held and popular countertheory stated that diseases are transmitted by inhalation of vapors. In the beginning, Snow’s argument did not cause a great stir; it was only one of many hopeful theories proposed during a time when cholera was causing great distress. Eventually, Snow was able to prove his theory. We describe how Snow accomplished this later, but for now, let’s take a look at Snow’s target: Cholera.

Cholera

According to the U.S. Centers for Disease Control (CDC), cholera is an acute, diarrheal illness caused by infection of the intestine with the bacterium *Vibrio cholera*. The infection is often mild or without symptoms, but sometimes can be severe. Approximately 1 in 20 infected persons have severe disease symptoms characterized by profuse watery diarrhea, vomiting, and leg cramps. In these persons, rapid loss of body fluids leads to dehydration and shock. Without treatment, death can occur within hours.

* From Spellman, F.R., *The Science of Water*, 2nd ed., Boca Raton, FL: CRC Press, 2007.

Note: You don't need to be a rocket scientist to figure out just how deadly cholera was during the London cholera outbreak of 1854. Comparing the state of "medicine" at that time to ours is like comparing the speed potential of a horse and buggy to a state-of-the-art NASCAR race car today. Simply stated: Cholera was the classic epidemic disease of the nineteenth century, just as the plague had been for the fourteenth. Its defeat was a reflection of both common sense and of progress in medical knowledge—and of the enduring changes in European and American social thought.

How does a person contract cholera? Good question. Again, we refer to the CDC for our answer. A person may contract cholera (even today) by drinking water or eating food contaminated with the cholera bacterium. In an epidemic, the source of the contamination is usually feces of an infected person. The disease can spread rapidly in areas with inadequate treatment of sewage and drinking water. Disaster areas often pose special risks. The aftermath of Hurricane Katrina in New Orleans caused, for example, concern for a potential cholera problem.

Cholera bacterium also lives in brackish river and coastal waters. Shellfish eaten raw have been a source of cholera, and a few people in the United States have contracted cholera after eating raw shellfish from the Gulf of Mexico. The disease is not likely to spread directly from one person to another; therefore, casual contact with an infected person is not a risk for transmission of the disease.

Flashback to London, 1854

The information provided in the preceding section was updated and provided by CDC in 1996. Basically, for our purposes, CDC confirms the fact that cholera is a waterborne disease. Today, we know quite a lot about cholera and its transmission, how to prevent infection and how to treat it. But what did they know about cholera in the 1850s? Not much, however, one thing is certain: They knew cholera was deadly. That was just about all they knew until Dr. John Snow proved his theory. Recall that Snow theorized that cholera is a contagious disease caused by a poison that reproduces in the human body and is found in the vomitus and stools of cholera victims. He also believed that the main means of transmission was water contaminated with this poison.

Dr. Snow's theory was correct, of course, as we know today. But how did he prove his theory correct? The answer provides us with an account of one of the all-time legendary quests for answers in epidemiological research ... and an interesting story.

Dr. Snow proved his theory in 1854, during yet another severe cholera epidemic in London. Though ignorant of the concept of bacteria carried in water, Snow traced an outbreak of cholera to a water pump located at an intersection of Cambridge and Broad Street (London).

How did he isolate this source to this particular pump? He accomplished this by mapping the location of deaths from cholera. His map indicated that the majority of the deaths occurred within 250 yards of that water pump. The water pump was used regularly by most of the area residents. Those who did not use the pump remained healthy. Suspecting the Broad Street pump as the plague's source, Snow had the water pump handle removed and ended the cholera epidemic.

Sounds like a rather simple solution, doesn't it? For us it is simple, but remember, in that era, aspirin had not yet been formulated, to say nothing of other medical miracles we take for granted—antibiotics, for example. Dr. John Snow, by the methodical process of elimination and linkage (Sherlock Holmes would have been impressed—and he was), proved his point, his theory. Specifically, through painstaking documentation of cholera cases and correlation of the comparative incidence of cholera among subscribers to the city's two water companies, Snow showed that cholera occurred much more frequently in customers of the water company that drew its water from the lower Thames, where the river had become contaminated with London sewage. The other company obtained water from the upper Thames. Snow tracked and pinpointed the Broad Street pump's water source. You guessed it: the contaminated lower Thames, of course.

Dr. Snow the obstetrician became the first effective practitioner of scientific epidemiology. His creative use of logic, common sense, and scientific information enabled him to solve a major medical mystery—to discern the means by which cholera was transmitted.

Pump handle removal—to water treatment (disinfection)

Dr. John Snow's major contribution to the medical profession, to society, and to humanity in general can be summarized rather succinctly: He determined and proved that the deadly disease cholera is a waterborne disease.

What does all of this have to do with water treatment (disinfection)? Actually, Dr. Snow's discovery has quite a lot to do with water treatment. Combating any disease is rather difficult without a determination on how the disease is transmitted—how it travels from vector or carrier to receiver. Dr. Snow established this connection, and from his work, and the work of others, progress was made in understanding and combating many different waterborne diseases.

Today, sanitation problems in developed countries (those with the luxury of adequate financial and technical resources) deal more with the consequences that arise from inadequate commercial food preparation, and the results of bacteria becoming resistant to disinfection techniques and antibiotics. We simply flush our toilets to rid ourselves of unwanted wastes, and turn on our taps to take in high-quality drinking water supplies, from which we've all but eliminated cholera and epidemic diarrheal

diseases. This is generally the case in most developed countries today—but it certainly wasn't true in Dr. Snow's time.

The progress in water treatment from that notable day in 1854 (when Snow made the connection [actually the disconnection of handle from pump] between deadly cholera and its means of transmission) to the present reads like a chronology of discovery leading to our modern water treatment practices. This makes sense, of course, because with the passage of time, pivotal events and discoveries occur—events that have a profound effect on how we live today. Let's take a look at a few elements of the important chronological progression that evolved from the simple removal of a pump handle to the advanced water treatment (disinfection) methods we employ today to treat our water supplies.

After Snow's discovery (that cholera is a waterborne disease emanating primarily from human waste), events began to drive the water/wastewater treatment process. In 1859, 4 years after Snow's discovery, the British Parliament was suspended during the summer because the stench coming from the Thames was unbearable. According to one account, the river began to "seethe and ferment under a burning sun." As was the case in many cities at this time, storm sewers carried a combination of storm water, sewage, street debris, and other wastes to the nearest body of water. In the 1890s, Hamburg, Germany, suffered a cholera epidemic. Detailed studies by Koch tied the outbreak to the contaminated water supply. In response to the epidemic, Hamburg was among the first cities to use chlorine as part of a wastewater treatment regimen. About the same time, the town of Brewster, New York, became the first U.S. city to disinfect its treated wastewater. Chlorination of drinking water was used on a temporary basis in 1896, and its first known continuous use for water supply disinfection occurred in Lincoln, England, and Chicago in 1905. Jersey City, New Jersey, became one of the first routine users of chlorine in 1908.

Time marched on, and with it came an increased realization of the need to treat and disinfect both water supplies and wastewater. Between 1910 and 1915, technological improvements in gaseous and then solution feed of chlorine made the process more practical and efficient. Disinfection of water supplies and chlorination of treated wastewater for odor control increased over the next several decades. In the U.S., disinfection, in one form or another, is now being used by more than 15,000 out of approximately 16,000 publicly owned treatment works (POTW). The significance

DID YOU KNOW?

Americans drink more than 1 billion glasses of tap water per day.

of this number becomes apparent when you consider that fewer than 25 of the 600+ POTW in the U.S. in 1910 were using disinfectants.

Process purpose: Disinfection

Disinfection is a process (usually chemical) that inactivates virtually all recognized pathogenic microorganisms, but not necessarily all microbial life. The disinfection process accomplishes two things. *Primary disinfection* initially kills *Giardia* cysts, bacteria, and viruses. *Secondary disinfection* maintains a disinfectant residual, which prevents regrowth of microorganisms in the water distribution system (see Figure 8.1).

Disinfection does not involve sterilization, which is the destruction of all microbial life. The level of disinfection needed for sterilization would be prohibitively expensive, and the end product would contain high levels of *disinfection by-products* (compounds formed by the reaction of a disinfectant such as chlorine with organic material in the water supply) and a strong chemical taste. Present treatment practices disinfect to the point that enough known disease-causing agents are eliminated to protect public health.

While chlorine disinfection is the best-known and most commonly used disinfection method, other methods are available. The three general types of disinfection include heat treatment (boiling water, commonly used in emergency situations), radiation treatment (UV radiation treatment), and chemical treatment (oxidizing agents including chlorine, ozone, bromine, iodine, and potassium permanganate, as well as metal ions such as silver, copper, mercury, or acids and alkalis).

Whatever disinfection method is used, the disinfectant chosen must possess certain characteristics. Obviously, it must work to kill off or deactivate pathogenic microorganisms. The disinfectant also must:

- Act in a reasonable time
- Act as temperature or pH changes
- Be nontoxic

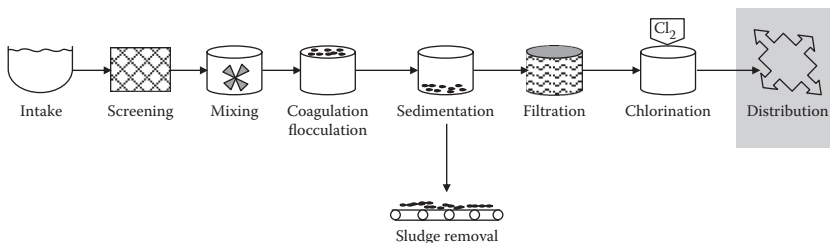


Figure 8.1 Basic water treatment unit processes: chlorination added.

- Not add unpleasant taste or odor
- Be readily available
- Be safe and easy to handle and apply
- Be easy to determine the concentration of
- Provide residual protection
- Affect pathogenic organisms more than nonpathogens
- Be capable of continual application
- Disinfect with reasonable dosage levels to produce safe water

Disinfectants typically kill pathogens in one of five ways:

1. The disinfectant damages the cell wall.
2. The disinfectant alters the pathogen's ability to pass food and waste through the cell membrane.
3. The disinfectant alters the cell protoplasm.
4. The disinfectant inhibits cellular conversion of food to energy.
5. The disinfectant inhibits reproduction.

Chlorination

In the United States, the disinfectant of choice has been chlorine. In general, chlorination is effective, relatively inexpensive, and provides effective levels of disinfectant residual for safe distribution. Applied as a gas (elemental chlorine, Cl_2), liquid (sodium hypochlorite), or solid (calcium hypochlorite), each of these forms has advantages and disadvantages.

The most cost-effective and efficient (in terms of available chlorine) is *gaseous chlorine*. One volume of liquid chlorine under pressure will yield roughly 450 volumes of gas. Large treatment works commonly use this method, creating gas from liquid chlorine stored on-site in high-pressure, high-strength steel cylinders. Gaseous chlorination is also the most inherently dangerous method—chlorine gas is lethal at concentrations as low as 0.1% air by volume. In nonlethal concentrations, it irritates the eyes, nasal membranes, and respiratory tract. Safety requirements for gaseous chlorine are extensive.

Because of the stiff safety requirements, and because it is easier to use and less toxic than gaseous chlorine, *sodium hypochlorite* (the form of chlorine in laundry bleach) is the most common disinfectant in smaller systems. Usually diluted with water before being applied as a disinfectant, sodium hypochlorite provides 5 to 15% available chlorine. Sodium hypochlorite must be handled and stored with care, and its corrosiveness means it must be kept isolated from vulnerable machinery. Sodium hypochlorite solution costs more per pound of available chlorine, and provides lower levels of protection against pathogens than chlorine gas. Because of

regulatory pressures, some large water treatment facilities are converting to sodium hypochlorite disinfection.

Calcium hypochlorite (a white solid available as tablets, powder, or in granular form) contains 65% available chlorine. Packaged calcium hypochlorite is stable, though it readily absorbs moisture from the air, reacting with it to form chlorine gas. It is also corrosive, strong smelling, and requires proper handling. When in contact with organic materials (including wood, cloth, and petroleum products), chemical reactions can cause fire or explosion.

Though some forms of chlorine are safer to handle than others, using any form of chlorine for disinfection requires special care and skill from the operator.

Chlorine, whether elemental chlorine, sodium hypochlorite, or calcium hypochlorite, may be added to the incoming flow (prechlorination) or, instead, added right before filtration. When used in prechlorination, chlorine works to help oxidize inorganics, and halts the biological action that occurs in the accumulations on the bottoms of clarifiers, preventing dangerous gaseous buildups. Chlorination prior to filtration keeps algae from growing and bacterial populations from developing in and on the filter itself.

Chlorination chemistry

In water, chlorine reacts with various substances or impurities present (organic materials, sulfides, ferrous iron, and nitrites, for example). The presence of these materials creates a *chlorine demand*, a measure of the amount of chlorine needed to eliminate these impurities by combining with them. That amount of chlorine cannot disinfect; it is already chemically depleted.

Chlorine also combines readily with ammonia or other nitrogen compounds, forming chlorine compounds. These chlorine compounds have some disinfectant properties, and are called the combined *available chlorine residual*. Chlorine in this form acts as a disinfectant. The chemically unchanged chlorine remaining in the water after combined residual is formed is *free available chlorine residual*. Free chlorine is much more effective than combined chlorine in disinfection.

For successful chlorination, several factors must be addressed: concentration of free chlorine, contact time, temperature, pH, and turbidity. How effectively chlorine disinfects is directly related to contact time with the water, as well as the free available chlorine concentration. Lower chlorine concentrations require increased contact times. Lower pH levels also aid disinfection effectiveness. Chlorine disinfects more quickly at higher temperatures. Turbidity affects chlorine's effectiveness as well, as

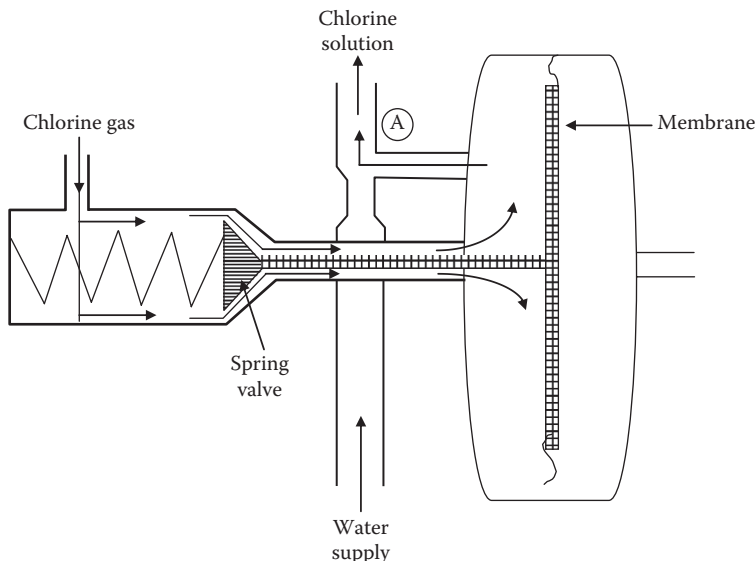


Figure 8.2 Chlorinator.

it does any disinfectant. Chlorine must contact organisms to kill them. High turbidity levels provide shelter for microorganisms, preventing efficient contact.

Chlorination equipment

Chlorine is usually fed continuously to the influent. Probably the safest and most commonly used chlorine feed devices are *all-vacuum chlorinators* (see Figure 8.2). They are installed directly on the chlorine cylinder. The chlorinator ensures that gaseous chlorine under a partial vacuum in the line is carried to the point of application. Typically, the vacuum is formed by water flowing through the ejector unit at high velocity.

Usual application methods for hypochlorites involve adding the chemical in liquid form using positive displacement pumps. These deliver a specific amount of liquid on each stroke of a piston or flexible diaphragm.

Chlorination by-products

Although using chlorine for disinfection is common (an estimated 90% of U.S. water utilities use this method), efficient, effective, and relatively inexpensive, recent studies show risks related to the potential formation of chlorine by-products. Organic compounds (including decaying

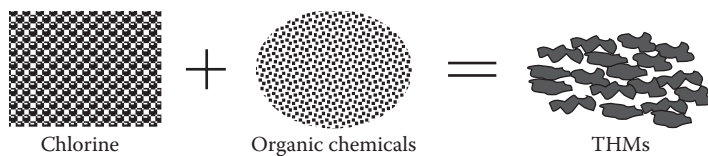


Figure 8.3 When chlorine combines with organic compounds it forms trihalomethanes.

vegetation) combine with chlorine chemically, forming trihalomethanes (THMs) (see Figure 8.3). Chloroform (one of the THMs) is a suspected carcinogen, and other common trihalomethanes are chemically similar to chloroform, and raise concerns.

While many public utilities are exploring alternative methods of disinfection, others use approaches to reduce the possibility of chlorine by-product formation. Removing more of the organics before adding chlorine is a productive approach, as is simply changing the point in the treatment process where chlorine is added. These two approaches are generally accomplished by not chlorinating the raw water before filtration. Sometimes aeration or activated carbon adsorption is used to remove more organic materials. Reducing chlorine use to achieve a safe degree of disinfection with less chemical addition is also a possibility (see Figure 8.4 and Figure 8.5).



Figure 8.4 Mixed-oxidant generator.



Figure 8.5 Brine for use with mixed-oxidant generator.

Alternative methods of disinfection

The two most common alternative disinfection methods for water treatment are *UV radiation* and *ozonation*. Neither of these methods is an ideal solution for chlorine replacement, because of uncertainties and disadvantages with their use, including that they are not adequate for disinfection by themselves. While they do prevent the formation of THMs, both methods require secondary disinfection (usually chlorine) to maintain a residual during distribution.

UV radiation

Ultraviolet (UV) radiation (electromagnetic radiation beyond blue at the end of the light spectrum, outside the visible light range) is a physical process, not a chemical process—a big advantage over both chlorine and ozone as disinfectants. It disinfects by inactivating bacteria and viruses. The genetic material in microorganisms absorbs UV energy (UV light has a higher energy level than visible light), interfering with reproduction and survival. Turbidity severely affects UV radiation's ability to inactivate microorganisms, however, providing shelter for microorganisms from contact with the light.

Commonly, UV germicidal equipment consists of a series of submerged, low-pressure mercury lamps. Technological advances are making UV radiation a more viable disinfection alternative, in terms of both effectiveness and economics (see Figure 8.6).

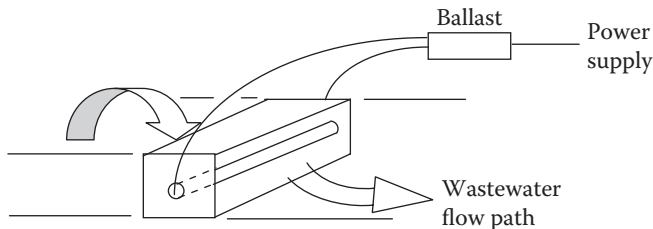


Figure 8.6 UV schematic.

Ozonation

Ozone (O_3) used as disinfectant leaves no taste and odor in the treated water, is actually more effective than chlorine against some viruses and cysts, and is unaffected by pH or ammonia levels in the water. Ozone is a gas at normal temperatures and pressures, and disinfects by breaking up molecules in water. When ozone reacts with organic materials and inorganic compounds in water, an oxygen (instead of a chlorine) atom is added, resulting in an environmentally acceptable compound. Ozone's instability, however, means that it cannot be stored and must be produced on-site, generating higher costs than chlorine disinfection. Since ozonation also provides no disinfection residual, those equipment, labor, and chemical costs must also be factored in (see Figure 8.7).

Membrane processes

In water treatment, membrane processes are generally used for demineralization. The two most common processes, reverse osmosis and electrodialysis, use microporous membranes to concentrate and separate the unwanted minerals from the influent.

Reverse osmosis and electrodialysis are related in concept to osmosis. In osmosis, a semipermeable membrane separates solutions of different mineral concentrations. Water will migrate through the membrane from the more dilute solution to the more concentrated solution until the hydrostatic pressure in the more concentrated solution is strong enough to stop the flow.

Reverse osmosis

In reverse osmosis (often abbreviated R/O, and also called ultrafiltration), external pressure applied to the semipermeable membrane offsets the hydrostatic pressure, resulting in pure water on one side of the membrane and the unwanted mineral content concentrated on the other. While perhaps the most common use for reverse osmosis is to reduce

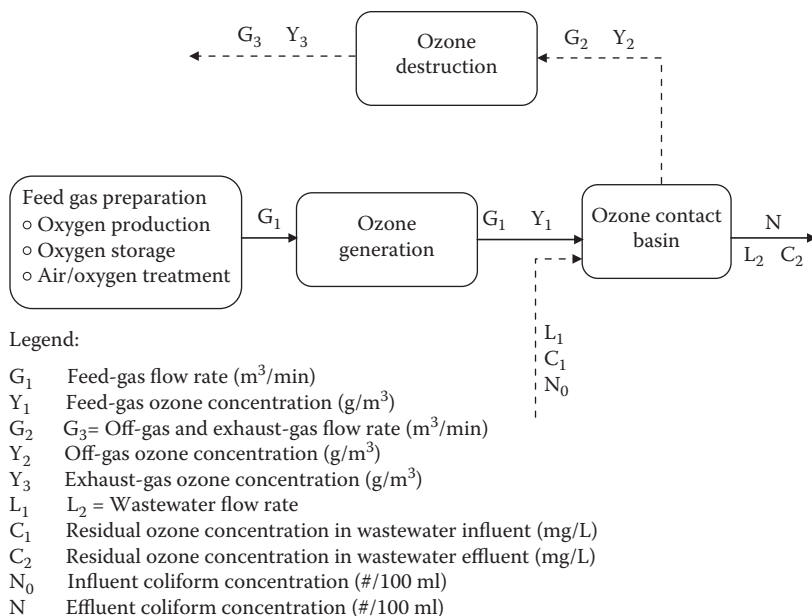


Figure 8.7 Simplified ozone process schematic diagram. (From USEPA, *Design Manual: Municipal Wastewater Disinfection*, Washington, DC, Environmental Protection Agency, 1986, p. 103.)

salinity in brackish groundwaters, reverse osmosis is used to remove aesthetic contaminants that cause taste, odor, and color problems. It can also remove unwanted off-tastes caused by chlorides or sulfates, and is also used to treat for arsenic, asbestos, atrazine, fluoride, lead, mercury, nitrate, and radium. When paired with carbon prefiltering, reverse osmosis processes are used to remove volatile contaminants that include benzene, trichloroethylene, trihalomethanes, and radon.

Reverse osmosis equipment performance is affected by water quality parameters. Membranes are damaged by water constituents that include suspended solids, dissolved organics, hydrogen sulfide, iron, and strong oxidizing agents (chlorine, ozone, and permanganate) (see Figure 8.8).

Electrodialysis

Electrodialysis demineralizes water using the principles of osmosis, separating anions and cations in solution by using ion-selective membranes and an electric field.

Both electrodialysis and reverse osmosis can be used to effectively treat water with high total dissolved solids concentrations, with appropriate pretreatment processes in place (see Figure 8.9).

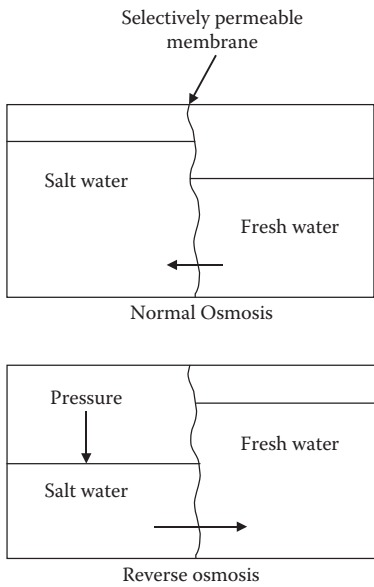


Figure 8.8 Normal osmosis and reverse osmosis.

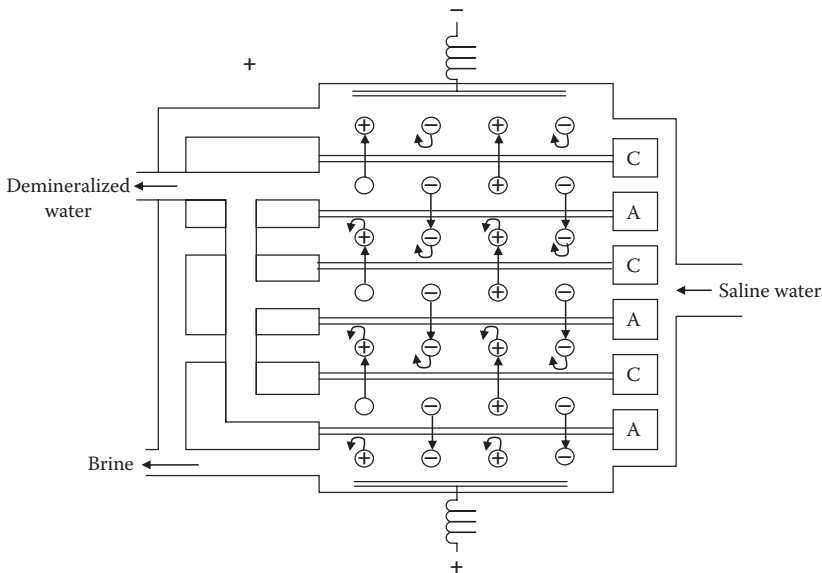


Figure 8.9 Schematic flow diagram of an electro dialysis system. (Adapted from Qasim, S.R., *Water Treatment Plant, Planning, Design, and Operation*, 2nd ed., CRC Press, Boca Raton, 1999, p. 939.)

Summary

Once the water has been disinfected, it is ready for the consumer to use. Water travels from the treatment facility to the consumer's tap via the distribution system.

chapter nine

Distribution

Process purpose and method

A municipality's water distribution and conveyance system serves two purposes: it carries raw water from a source to the plant, and it carries the finished water to the consumer (see Figure 9.1). Distribution systems consist of seven basic elements:

- Sources (wells or surface water)
- Storage facilities (reservoirs)
- Transmission facilities for influent
- Treatment facilities
- Transmission facilities for effluent
- Intermediate points (standpipes or water towers)
- Distribution facilities

Distribution systems

Gravity distribution, pumping without storage, or pumping with storage are the three common distribution methods in use. When the water supply source is well above the community's elevation, *gravity distribution* is possible. The least desirable method, *pumping without storage* provides no reserve flow and pressures fluctuate substantially. With this method, facilities must use sophisticated control systems to meet unpredictable demand. *Pumping with storage* is the most common method of distribution (McGhee, 1991).

In pumping with storage, water in typical community water supply systems is carried under pressure (pumping water up into tanks that store water at higher elevations than the households they serve provides water pressure) through a network of buried pipes. Street mains carry the water from standpipes or water towers to service individual business, industrial, commercial, or residential needs. Mains usually have a minimum diameter of 6 to 8 in. for adequate flows to supply buildings and for firefighting. Pipes connected to buildings can be as small as 1 in. for small residences. House service lines (smaller pipes) from the main water lines transport water from the distribution network to households, where gravity's force moves the water into homes when household taps open. A primary goal

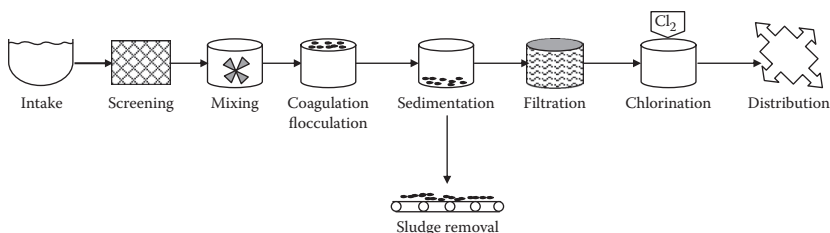


Figure 9.1 Basic water treatment unit processes: distribution added.

DID YOU KNOW?

It costs over \$3.5 billion to operate water systems throughout the United States each year.

for any water treatment facility is to provide enough water to meet system demands consistently, and at adequate pressures.

Distribution systems generally follow street patterns. The location of treatment facilities and storage works affects distribution, as do the types of residential, commercial, and industrial development present, and topography. Distribution systems commonly set up zones related to different ground elevations and service pressures. Water mains are generally designed in enclosed loops, to supply water to any point from at least two directions.

Distribution systems are categorized as grid systems, branching systems, or dead-end systems (see Figure 9.2a–d). Grid systems are generally considered the best distribution system. The looped and interconnected arterials and secondary mains eliminate dead ends, and allow free water circulation so that a heavy discharge from one main allows drawing water from other pipes. Branching systems do not furnish supply to any point from at least two directions, and include several terminals or dead ends. In new distribution systems, antiquated dead-end systems are completely avoided. Older systems with terminals often incorporate proper looping during retrofitting.

Process equipment

Surface and groundwater supply systems both generally involve canals, pipes, or other conveyances; pumping plants; distribution reservoirs or tanks to help balance water supply and demand and to control pressures; other appurtenances; and treatment works (see Figure 9.3).

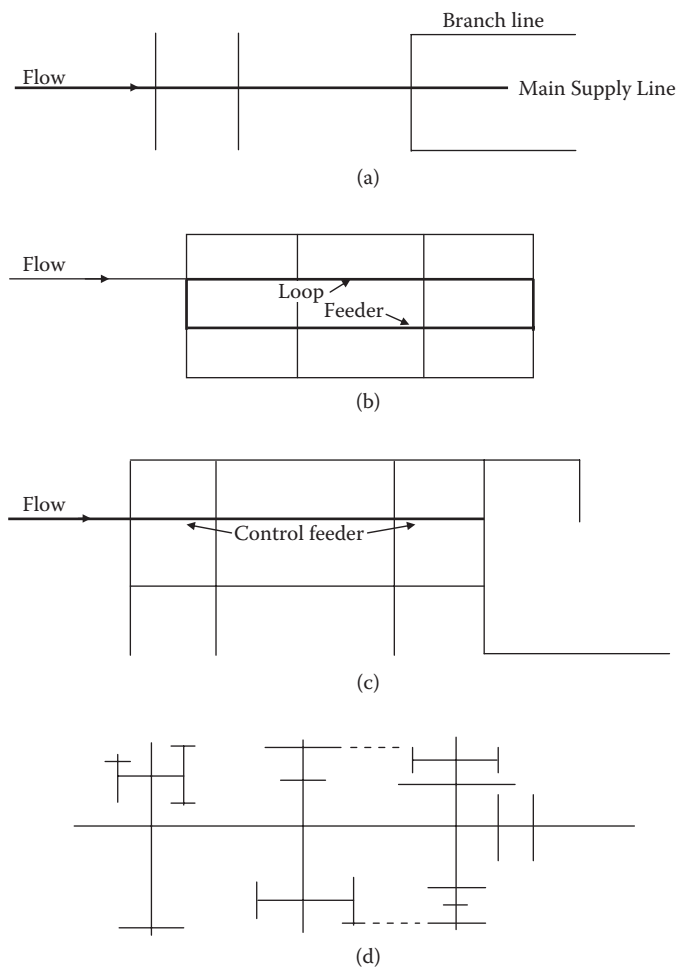


Figure 9.2 Distribution line networks: (a) branched, (b) grid, (c) combination branched-grid, (d) dead end.



Figure 9.3 City of Oneonta water storage tanks.

Storage tanks for potable water distribution come in a variety of types. Whatever the type, however, the tank interior must be properly protected and preserved from corrosion. Poor physical and material tank condition degrades the stored water. Any tank coating or preservative that will be in contact with potable water must meet National Sanitation Foundation (NSF) Standard 61.

Tank types include:

Clear wells: For storing filtered water from a treatment works. Also used as chlorine contact tanks (see Figure 9.4a).

Elevated tanks: Primarily for maintaining an adequate and fairly uniform pressure to the service zone, elevated tanks are located above the service zone (see Figure 9.4b).

Standpipes: Tanks that stand on the ground, with a height greater than their diameter (see Figure 9.4c).

Ground-level reservoirs: Maintain the required pressures when located above service area (see Figure 9.4d).

Hydropneumatic or pressure tanks: Often used in small water systems (with a well or booster pump) to maintain water pressures in the system and to control well pump or booster pump operation (see Figure 9.4e).

Surge tanks: Used mainly to control water hammer, or to regulate water flow (see Figure 9.4f), not necessarily as storage facilities.

Water stored in potable water storage facilities must be routinely properly monitored to detect problems in taste and odor, turbidity, color, and

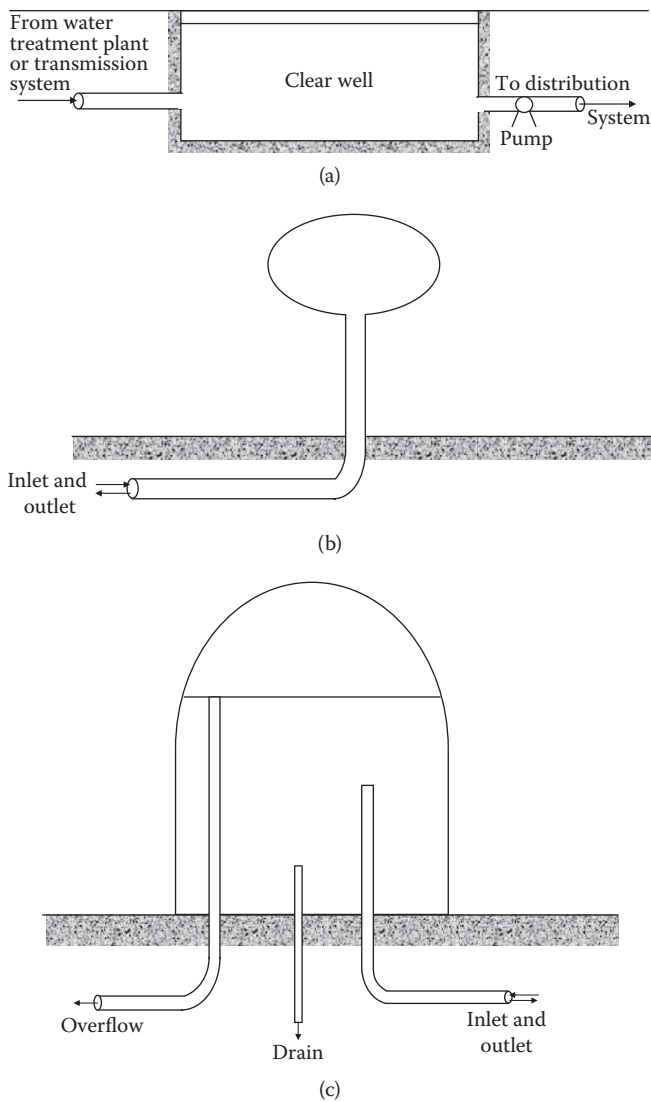


Figure 9.4 (a) Clear well, (b) elevated storage tank, (c) standpipe. (Continued)

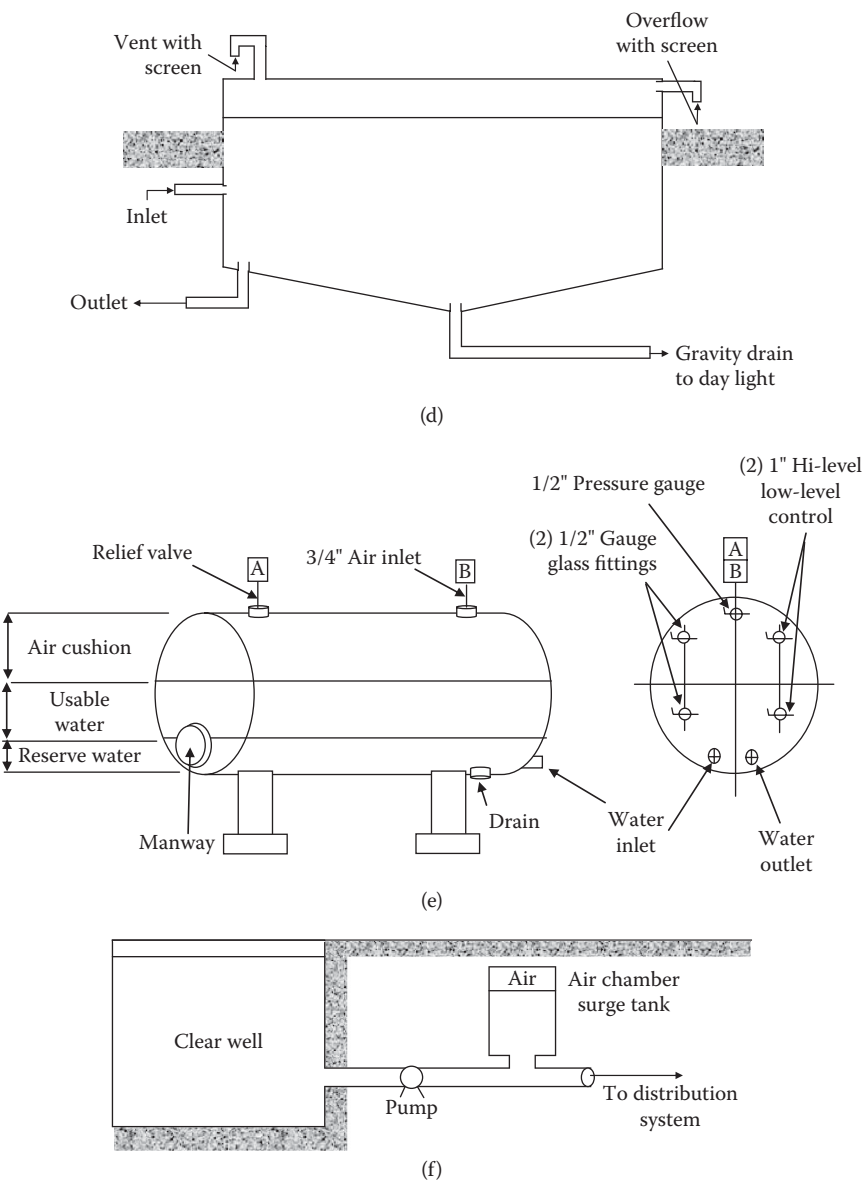


Figure 9.4 (Continued) (d) ground-level service storage reservoir, (e) hydropneumatic tank, (f) surge tank.

coliform presence. Monitoring includes determining chlorine residual levels, turbidity, color, coliform analysis, decimal dilution, most probable number (MPN) analysis, and taste and odor analysis.

Summary

Once a water treatment plant has delivered potable water to a consumer and the consumer begins to use it, whether that consumer is within a household, business, or industry, the water begins the journey that leads it to the other side of water treatment—wastewater treatment. Section III, “Basics of Wastewater Treatment,” covers those treatment processes.

Reference and recommended reading

McGhee, T.J. 1991. *Water supply and sewerage*. 6th ed., New York: McGraw-Hill.

section three

Basics of wastewater treatment

chapter ten

Wastewater regulations, parameters, and characteristics

Purpose: Wastewater parameters

The outcomes of the unit processes used to treat wastewater before outfall into a receiving body of water are controlled and determined by wastewater effluent quality parameters. Set by Congress through federal regulation, these parameters are supported and strengthened by state law. To maintain permit to discharge into natural water systems, facilities must follow regulated programs of testing and reporting to prove their discharge will consistently meet regulatory standards.

Purpose: Wastewater treatment

Wastewater treatment takes effluent from water users (consumers, whether from private homes, businesses, or industrial sources) as influent to wastewater treatment facilities. The waste stream is treated in a series of steps (unit processes, some similar to those used in treating raw water, and others that are more involved), then discharged (outfalled) to a receiving body, usually a river or stream.

Wastewater treatment takes the wastes and water that comprise the waste stream and restores the wastewater to its original quality. Wastewater treatment's goal is to treat the waste stream to the level that it is harmless to the receiving body. Most facilities actually set their goal higher: to treat the waste stream to achieve water of a higher quality than the water contained in the receiving water body.

Wastewater regulations

The condition of the effluents discharged into water bodies, of course, affects the water supplies of communities downstream from the discharge point. The Water Pollution Control Amendments of 1972 radically changed how wastewater effluent was disposed. The quality of effluent released into receiving waters significantly improved, positively affecting our water supply conditions.

DID YOU KNOW?

On average, 50 to 70% of household water is used outdoors (watering lawns, washing cars, etc.).

With the Water Pollution Control Act of 1972 (Clean Water Act (CWA)), the USEPA established standards for wastewater discharge. Municipal wastewater must be given secondary treatment, and most effluents must meet set conditions. Secondary treatment goals are set to the principal components of municipal wastewater, so that suspended solids, biodegradable material, and pathogens can be reduced to acceptable levels. Industrial dischargers must use their industry's best available technology (BAT) to treat their wastewater.

The Clean Water Act also established a National Pollution Discharge Elimination System (NPDES) program based on uniform technological minimums for each point source discharger. The NPDES program issues discharge permits that reflect secondary treatment and best available technology standards to each municipality and industry discharging effluent into streams.

Wastewater characteristics

Wastewater parameters provide a yardstick by which to assess the physical, chemical, and biological characteristics of wastewater. Meeting these parameters before discharge ensures the wastewater released into surface waters presents no chance of harm or disruption to the environment or to humans within a wide range of possible water uses.

Physical wastewater characteristics

Wastewater physical characteristics of concern include the presence and quantity of solids in the waste stream, the degree of turbidity, and the wastewater's color, temperature, and odor (see Figure 10.1).

Solids in water

Solids removal is of great concern to wastewater treatment. Suspended materials provide adsorption sites for biological and chemical agents and give microorganisms protection against chlorine disinfectants. As suspended solids degrade biologically, they can create objectionable by-products.

Solids can be either suspended or dissolved in water, and are classified by their size and state, by their chemical characteristics, and by their size distribution. These solids consist of inorganic or organic particles, or

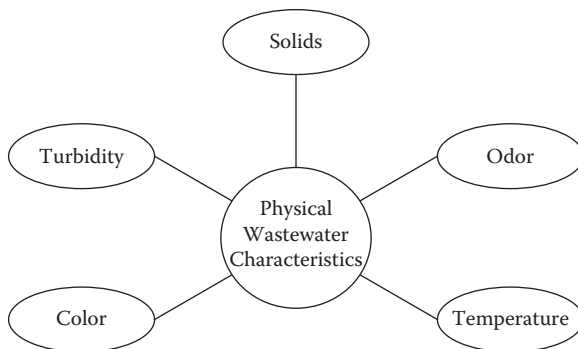


Figure 10.1 Wastewater's physical characteristics.

of immiscible liquids such as oils and greases. Human water uses contribute other suspended materials. Large quantities of suspended solids (mostly organic in nature) are found in domestic wastewater. Industrial water use can add a wide variety of either organic or inorganic suspended impurities. Wastewater also often contains immiscible oils and greases.

Filtration provides the most effective means of removing solids in treatment, although colloids and some other dissolved solids cannot be removed by filtration. Use of membrane technologies (reverse osmosis and electrodialysis) to remove dissolved solids is effective, and use of these processes is increasing.

The level of suspended solids (SS) is an important water quality parameter for wastewater treatment. It is used to monitor performance of several processes, to measure the quality of the wastewater influent, and to measure the quality of effluent. Most treated wastewater discharges must meet a maximum suspended solids standard of 30 mg/L.

Turbidity

Water's clarity is usually measured against a turbidity index. Insoluble particulates scatter and absorb light rays, impeding the passage of light through water. Turbidity indexes measure light passage interference. Wastewater influent, of course, is expected to be turbid, but much of the materials that cause turbidity are removed with treatment.

Industrial and household wastewaters often contain many different turbidity-producing materials (detergents, soaps, and emulsifying agents); these are frequent wastewater constituents.

In wastewater treatment, whenever ultraviolet radiation (UV) is used for disinfection, turbidity measurements are essential. UV light must penetrate the waste stream flow to effectively kill pathogenic microorganisms, and turbid waste stream flow reduces irradiation (penetration of light) effectiveness.

Color

Color is not a common concern for wastewater treatment, though it acts as a wastewater condition indicator for judging wastewater's age. Ideally, wastewater early in the waste flow is a light brownish gray color. The flow becomes increasingly more septic as travel time through the collection systems increases and as more anaerobic conditions develop. As this occurs, wastewater's normal color changes from gray to dark gray and then to black.

Odor

Odor is a never-ending problem in wastewater treatment. Most urban treatment plants physically cover odor source areas (treatment basins, clarifiers, aeration basins, and contact tanks). This helps to prevent odors from leaving the unit processes to solve problems of local objection. However, these contained spaces can cause problems with toxic concentrations of gas. Such units must be positively vented to wet chemical scrubbers to prevent toxic gas buildup.

Temperature

Temperature can play an important role in how efficiently wastewater unit treatment processes perform. Biological wastewater treatment systems are generally more efficient at higher temperatures. Temperature affects how quickly and effectively chemicals dissolve and chemical reaction times as well. In general, the colder the influent temperature, the more chemical is needed for treatment. However, summer heat increases chlorine demand, and promotes algae and microbial growth.

Chemical wastewater characteristics

The major chemical parameters of concern in wastewater treatment are total dissolved solids (TDS): alkalinity, metals, organics and nutrients, pH, and chlorides. These chemical parameters are directly related to the solvent capabilities of water (see Figure 10.2).

Total dissolved solids (TDS)

Solids in water occur either in solution or in suspension. The solids in the water that would remain after filtration and evaporation as residue are called total dissolved solids (TDS). Dissolved solids can be removed from water by filtration and evaporation, and also by electrodialysis, reverse osmosis, or ion exchange. A routine solids test used in wastewater treatment to determine the efficiency of the treatment process is the measurement of settleable solids, the coarser fraction of the suspended solids that settle out from gravity.

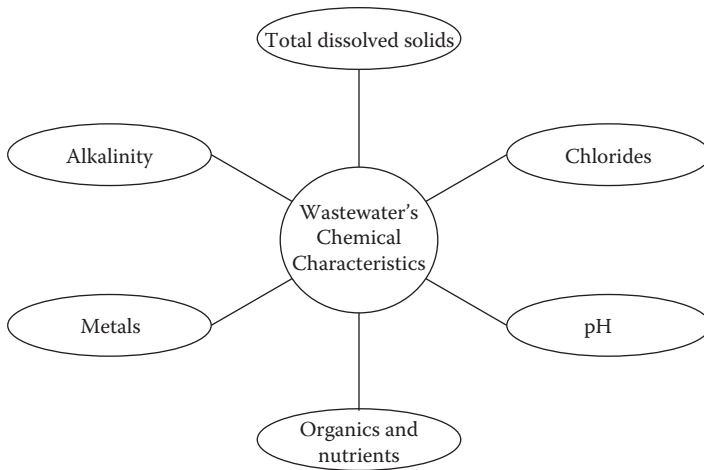


Figure 10.2 Wastewater's chemical characteristics.

Metals

Metals in wastewater (heavy metals such as cadmium, copper, lead, zinc, mercury, and others) are of high concern because they are often toxic to humans, and can be extremely harmful if discharged to the environment. They also can cause problems within treatment processes. Metals content is measured to determine toxicity levels.

Metals in sufficient concentrations will kill microorganisms in the activated sludge process. They are removed by chemical treatment, though that doesn't end the metals toxicity problem for waste stream processing. Industrial wastes with high levels of toxic metals or organic substances can contaminate sewage biosolids, thereby limiting biosolids disposal options and raising disposal costs.

Organics

The microbes that function in some biological treatment processes that rely on microbial decomposition consume dissolved oxygen (DO). This demand for oxygen is called the biochemical oxygen demand (BOD). BOD levels are measured by testing that determines how much DO aerobic decomposers use decay organic materials in measured amounts of water held at 68°F (20°C) over a 5-day incubation period. Without continuous oxygen replacement, dissolved oxygen levels decrease until the cycle fails from lack of available oxygen as the microbes consume and decompose the organics.

"In wastewater of medium strength, about 75% of the suspended solids and 40% of the filterable solids are organic in nature," according to Metcalf and Eddy (1991, p. 65). Organics often present in wastewater

include proteins, lipids (oils and grease), carbohydrates, and detergents. About 30+% of this organic matter is not biodegradable.

Proteins, which consist totally or in large part of many amino acids, also contain carbon, hydrogen, oxygen, sulfur, phosphorous, and a fairly high and constant proportion of nitrogen. The greater mass of wastewater biosolids material is made up of protein, or coated with protein so that chemically, it reacts as protein would. Most of wastewater's nitrogen comes from proteins and urea. Microorganisms decompose the nitrogen, in the process creating end products with foul odors.

Lipids (these include fats, oils, and waxes) are a heterogeneous collection of biochemical substances soluble to varying degrees in organic solvents such as ether, ethanol, and acetone, but only marginally water soluble.

Food wastes contain high levels of lipids, mostly fats (compounds of alcohol and glycerol), oils, and grease. Fats are very stable organic compounds, and do not easily decompose.

Grease causes many problems in wastewater treatment. High amounts of grease can severely reduce the efficiency of filters, nozzles, and sand beds. Grease adheres to sedimentation tank walls, where it decomposes and adds to the amount of scum. When grease discharges with the effluent, surface water biological processes and aesthetics are affected.

Carbohydrates (widely found in nature and a common component of wastewater) include starch, cellulose, sugars, and wood fibers. Some are soluble (sugars, for example), and others are insoluble (starches, wood fibers). Lower organisms (including bacteria) use carbohydrates to synthesize fats and proteins, as well as for energy. Without oxygen, carbohydrate decomposition end products are organic acids—alcohols and gases that include carbon dioxide and hydrogen sulfide. Large quantities of organic acids hinder treatment by overburdening wastewater's buffering capacity, dropping pH levels, and halting biological activity.

Detergents (surfactants) are slightly soluble in water and cause foaming when outfallen in effluent into surface waters. Detergents can reduce the oxygen uptake in biological processes. Use of synthetic detergents has reduced or eliminated these problems.

Inorganics

Several inorganic constituents affect wastewater treatment. pH, chlorides, and nutrients including nitrogen and phosphorous, sulfur, toxic inorganic compounds, and heavy metals influence treatment processes.

pH

pH (hydrogen ion concentration) indicates the intensity of acidity or alkalinity in wastewater and affects biological and chemical reactions. Wastewater's chemical balance (equilibrium relationships) is strongly influenced by pH. Weak acids, bases, and salts in wastewater cause

wastewater's predictable behavior in treatment. For example, wastewater's pH levels directly impact certain unit processes, including disinfection with chlorine. Increased pH increases the contact time needed for chlorine disinfection.

Chlorides

Chloride (a major inorganic constituent in wastewater) generally does not cause any harmful effects on public health. Wastewater's chloride concentration is higher than raw water's from sodium chloride (salt), which commonly passes unchanged through human digestive systems.

Nutrients

The nutrients of greatest concern in wastewater treatment are nitrogen and phosphorous. Other nutrients include carbon, sulfur, calcium, iron, potassium, manganese, cobalt, and boron—all essential to the growth and reproduction of plants and animals.

As the primary component of the earth's atmosphere, nitrogen occurs in many forms in the environment and takes part in many biochemical reactions. Municipal wastewater discharges are a principal source of nitrogen in surface water, as is runoff from animal feedlots, fertilizer runoff, and some kinds of bacteria and blue-green algae that directly obtain atmospheric nitrogen.

Nitrogen in the form of nitrate (NO_3) in surface waters indicates contamination with sewage. An immediate health threat to both human and animal infants, excessive nitrate concentrations in drinking water can cause death.

Though the presence of phosphorous (P) released into drinking water supplies has little effect on human health, too much phosphorus in water supplies causes problems that contribute to algae bloom and lake eutrophication. Again, municipal wastewater discharges are a principal phosphorous source. Other sources include phosphates from detergents, fertilizers, and feedlot runoff.

Biological wastewater characteristics

The presence or absence of pathogens in wastewater is of primary importance. Normal sewage contains millions of harmless microbes per milliliter. However, wastes from people infected with disease can produce harmful pathogenic organisms that then enter the sewage and the water systems receiving the sewage. While the processes that treat wastewater involve using the life cycles of many types of bacteria and protozoa for removing the wastes from the water, the final effluent to be released must not carry dangerous levels of pathogens into the receiving waters (see Figure 10.3).

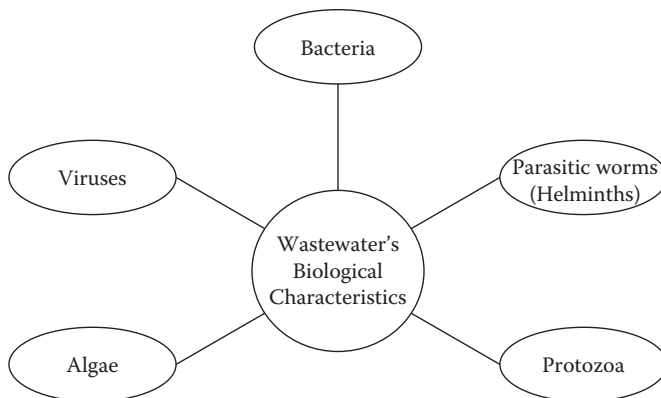


Figure 10.3 Biological water quality characteristics.

Bacteria

Bacteria are fundamental to several wastewater treatment unit processes, especially those responsible for degradation of organic matter. These include processes that occur in trickling filters, activated biosolids processes, and biosolids digestion. These bacteria must be controlled, however. Excessive growth of some species of ordinarily useful bacteria (for example, *Sphaerotilus natans*—a filamentous organism) can reduce treatment efficiency. Bacterial presence in effluent must also be controlled. Waterborne pathogenic bacteria transmit diseases that cause common symptoms of gastrointestinal disorder. Improperly treated effluent returns these pathogens to the water supply.

Viruses

Viruses cause special concern in wastewater treatment for several reasons. Turbidity in water provides shelter for pathogenic organisms from some disinfection methods. Testing for viruses in water is difficult because of limited identification methods—viruses are unpredictable in appearance and behavior. Viruses also present other problems. They are not easily trapped by standard filtration methods, because the many varieties of viruses are extremely minute.

Waterborne viral infections generally cause nervous system disorders, not gastrointestinal ones. Viruses must have a host to live and reproduce. They don't possess the machinery necessary for their own replication. They remain dormant until an appropriate host provides that machinery. Because of their ability to remain dormant until an appropriate host ingests them, viruses that reenter the water supply from wastewater effluent can cause problems for downstream water use.

Algae

Algae are found in wastewater, as well as in freshwater, saltwater, and polluted water. Since most algae need sunlight to live, they only grow near the water surface.

Algae play an important role in some kinds of wastewater treatment stabilization ponds. In aerobic and facultative ponds, algae (through photosynthesis) often supply the oxygen needed for microbial breakdown of wastes, and in turn, use the waste products the bacteria and other microbial life leave behind as a food source—a natural, inexpensive, and simple way to remove wastes. However, algae growth is not as easy to control as aerators (the other common source of oxygen for aerobic or facultative treatment ponds). Algae rely on sunlight to produce oxygen and use up carbon dioxide. They use up oxygen and produce carbon dioxide at night and on dark days. In cold climates, algae die off in the winter. Heavy algae growths can also raise the level of suspended solids concentration in the effluent.

Protozoa

Protozoa are the simplest animal species, widely distributed and highly adaptable. Mobile, single-celled, completely self-contained organisms, some protozoa are free living, while a few others are parasitic. Protozoan populations are an essential part of activated sludge treatment processes.

Most of the protozoan population is removed by sedimentation after activated sludge treatment. While most protozoa are harmless—two important exceptions are *Entamoeba histolytica* (amebiasis) and *Giardia lamblia* (giardiasis)—effluent must not contain excessive protozoan levels. The cysts aquatic protozoans form during adverse environmental conditions make them difficult to deactivate by disinfection. Filtration is usually the most effective means to remove them from water.

Worms (helminths)

Worms are organisms with aerobic requirements that inhabit organic mud and slime. Frequent indicators of sewage contamination and pollution in streams, *tubifex*, bloodworms, and other helminths can metabolize solid organic matter that other microbes cannot degrade, and feed on sludge deposits. This helps to break down the organics in the waste stream. Parasitic worms are transmitted to humans (or to other carriers) through contact with untreated sewage or polluted waters.

Indicator organisms

Testing and identification of pathogens presents inherent problems. While some organisms are tough and persistent, and others form protective

spores that allow them to resist treatment processes designed to kill off pathogens, most pathogens grow and multiply rapidly while within the human body, and do not survive long in nature. These qualities make finding a method for obtaining a clear indication of the presence or absence of pollution in a source water difficult. Individual pathogens may be present in such small quantities that they are undetectable. Much testing and retesting for each pathogenic organism would have to be done to determine safety. Testing for a single species solved the problem of determining the biological safety of water and wastewater. The indicator organisms (coliforms) alert us to the possible presence of sewage contamination. Coliforms present in a water sample indicate sewage contamination, and may also mean that the water source could contain pathogenic microorganisms that present a threat to public health.

Coliforms

Coliform group testing involves estimating the number of fecal coliform bacteria present in a measured water sample. This information provides a ratio of contamination relative to a defined quantity of water. The results of testing correlate to the amount of pollution of the source water—wastewater will contain more coliform groups than polluted water, which will contain more coliform groups than a water source intended for drinking water.

Fecal coliforms are present in the intestinal tract of all mammals, but do not themselves cause illness. Since fecal coliforms are always present in fecal wastes, water recently contaminated with sewage will always contain them. Coliforms always outnumber disease-producing organisms in contaminated water—human bodily wastes contain coliforms by the millions.

Summary

Taking wastewater influent to accepted standards is the foundational task of wastewater treatment. The parameters and testing methods lay the groundwork for effective, efficient wastewater treatment processes.

Reference and recommended reading

Metcalf and Eddy, Inc. 1991. *Wastewater engineering: Treatment, disposal, reuse*. 3rd ed. New York: McGraw-Hill.

chapter eleven

Wastewater sources and types

Wastewater

Wastewater is the flow of used water from a community, and includes household wastes, as well as commercial and industrial waste stream flows, and storm water and groundwater. By weight, wastewater is generally only about 0.06% solids—dissolved or suspended materials carried in the 99.94% water flow. This extreme ratio of water to solids is essential to transport solids through the collection system.

Wastewater sources and general constituents

The solids found in wastewater rarely contain only what most people consider sewage—human wastes. In fact, the dissolved and suspended solids sewage can contain varies widely from community to community, and is dependent, of course, on what industrial and commercial facilities contribute to the inflow to the treatment system. These influents mix with the more predictable residential flows, and provide so many possible substances and microorganisms to wastewater that complete identification of every wastewater constituent is not only rarely possible, but also rarely a necessary undertaking.

This is not to say that the solids an area's wastewater contains cannot be predicted in a general way. In most communities, wastewater enters the wastewater treatment system through one of five ways, each with its own usual characteristic solids loads. Common industry practice puts these constituents into several general categories.

Human and animal wastes

Generally thought the most dangerous wastewater constituent from a human health viewpoint, domestic wastewater contains the solid and liquid discharges of humans and animals. These contribute millions of bacteria, viruses, and other organisms (some pathogenic) to the wastewater flow.

Household wastes

Domestic or residential wastewater flows also may contain paper, household cleaners, detergents, trash, garbage, and any other substance that a typical homeowner may pour or flush into the sewer system.

Industrial wastes

The materials that could be discharged from industrial processes into a collection system include chemicals, dyes, acids, alkalis, grit, detergents, and highly toxic materials. Individual industries present highly individual waste streams, and these industry-specific characteristics depend on the industry processes used. While many times industrial wastewaters can be treated within public treatment facilities without incident, often industries must provide some level of treatment prior to their waste stream entering a public treatment system. This prevents compliance problems for the treatment facility. An industry may also choose to provide pretreatment because its on-site treatment is more economical than paying municipality fees for advanced treatment.

Storm water runoff

In collection systems that carry both community wastes and storm water runoff, during and after storms wastewater may contain large amounts of sand, gravel, road salt, and other grit as well as flood levels of water. Many communities install separate collection systems for storm water runoff, in which case that influent should contain grit and street debris, but no domestic or sanitary wastes.

Groundwater infiltration

Old and improperly sealed collection systems may permit groundwater to enter the system through cracks, breaks, or unsealed joints. This can add large amounts of water to the wastewater flows, as well as additional grit.

Average wastewater physical characteristics

The different specific substances that comprise wastewater vary in amount or concentration, dependent on the source (see Table 11.1). However, an *average domestic wastewater* has the following physical and chemical characteristics.

Table 11.1 Typical Composition of Untreated Domestic Wastewater

Constituent	Abbreviation	Concentration (mg/L)
Biochemical oxygen demand	BOD ₅	100–300
Chemical oxygen demand	COD	250–1,000
Total dissolved solids	TDS	200–1,000
Suspended solids	SS	100–350
Total Kjeldahl nitrogen	TKN	20–80
Total phosphorus (as P)	TP	5–20

Source: Adapted from Davis, M.L., and Cornwell, D.A., *Introduction to Environmental Engineering*, New York, McGraw-Hill, 1991.

Physical characteristics

Color: Typical wastewater is gray and cloudy. The color of septic wastewater changes to black.

Odor: Fresh domestic wastewater smells musty. Septic wastewater develops a rotten egg odor from the production of hydrogen sulfide.

Temperature: Normally, wastewater temperature remains close to that of the water supply. Infiltration or storm water flow in significant amounts can cause major temperature changes.

Flow: Wastewater volume is normally expressed in gallons per person per day, using an expected flow of 100 to 200 gal per person per day. Expected flow rates are of principal concern in designing treatment plants. The expected flow figure may undergo revision to reflect the levels of infiltration or storm water flow the facility receives. Flow rates can vary throughout the day as much as 50 to 200% of the average daily flow (*diurnal flow variation*).

Chemical characteristics

Alkalinity: An indicator of wastewater's capacity to neutralize acids, alkalinity is measured in terms of bicarbonate, carbonate, and hydroxide alkalinity. Alkalinity is essential to hold the neutral pH (buffer) of the wastewater during biological treatment.

Biochemical oxygen demand (BOD): An indicator of the amount of biodegradable matter in the wastewater, normally BOD is measured in a 5-day test conducted at 20°C (BOD₅), and normally ranges from 100 to 300 mg/L.

Chemical oxygen demand (COD): A indication of the amount of oxidizable matter present in the sample, the COD is normally in the range of 200 to 500 mg/L. Industrial wastes present in the wastewater can significantly increase this.

DID YOU KNOW?

The average cost of water supplied to a home in the United States is about \$2.00 for 1,000 gal, which equals about 5 gal for a penny.

Dissolved gases: The specific gases and normal concentrations dissolved in wastewater are based on wastewater composition, and under septic conditions may typically include oxygen in relatively low concentrations, carbon dioxide, and hydrogen sulfide.

Nitrogen compounds: Nitrogen's type and amount varies from raw wastewater to treated effluent, but is mostly found in untreated wastewater in the forms of organic nitrogen and ammonia nitrogen (presence and levels determined by laboratory testing). *Total Kjeldahl nitrogen* (TKN) is the sum of these two forms of nitrogen. Normal wastewater contains 20 to 85 mg/L of nitrogen, with organic nitrogen ranging from 8 to 35 mg/L and ammonia nitrogen ranging from 12 to 50 mg/L.

pH: pH expresses wastewater's acid condition. For proper treatment, wastewater pH should generally range from 6.5 to 9.0.

Phosphorus: In secondary treatment processes, phosphorus must be present in at least minimum quantities or the processes won't perform. However, excessive phosphorus causes stream damage and excessive algal growth. Phosphorus normally ranges from 6 to 20 mg/L. Removing phosphate compounds from detergents has significantly impacted the amounts of phosphorus found in wastewater.

Solids: Most wastewater pollutants can be classified as solids, and wastewater treatment is generally designed to either remove solids or convert them to more stable or removable forms. General practice classifies solids by chemical composition as organic or inorganic, or by physical characteristics as settleable, floatable, or colloidal. Total solids concentration in wastewater normally ranges from 350 to 1,200 mg/L.

Water: In even the strongest wastewater, the contamination present makes up less than 0.5% of the total. In wastewaters of average strength, contamination is normally less than 0.1%.

Summary

Taking wastewater to accepted standards is the foundational task of wastewater treatment. Effective, efficient wastewater treatment removes the unwanted materials from inflowing waste streams, and prepares the

wastewater for safe discharge into a receiving body of water. We examine an overview of the wastewater treatment process and the individual processes in the remaining chapters of Section III.

Reference and recommended reading

Davis, M.L., and Cornwell, D.A. 1991. *Introduction to environmental engineering*. New York: McGraw-Hill.

chapter twelve

Wastewater treatment

Basic overview

Wastewater treatment

Wastewater must be collected and conveyed to a treatment facility and treated to remove pollutants to a level of compliance with its National Pollution Discharge Elimination System (NPDES) permit before a municipal or industrial facility can discharge it into receiving water (see Figure 12.1).

The most common systems in wastewater treatment employ (as does water treatment) processes that combine physical, chemical, and biological methods. Wastewater treatment plants are usually classified as providing *primary, secondary, tertiary* (or *advanced*) treatment, depending on the purification level to which they treat (see Table 12.1).

Once at a treatment facility, in primary treatment plants, physical processes (screening and sedimentation) remove a portion of the pollutants that will settle or float. Pollutants too large to pass through simple screening devices are also removed, followed by disinfection. Primary treatment typically removes about 35% of the biochemical oxygen demand (BOD) and 60% of the suspended solids.

Secondary treatment plants use the physical processes employed by primary treatment, but augment the processes with the microbial oxidation of wastes. When properly operated, secondary treatment plants remove about 90% of the BOD and 90% of the suspended solids.

Advanced treatment processes are specialized, and their use is dependent upon the pollutants for removal. While usually advanced treatment follows primary and secondary treatment, in some cases (especially in industrial waste treatment) advanced treatment replaces conventional processes completely.

DID YOU KNOW?

Industries as well as people need water. It takes, on average, 39,090 gal of water to manufacture a new car and its four tires.

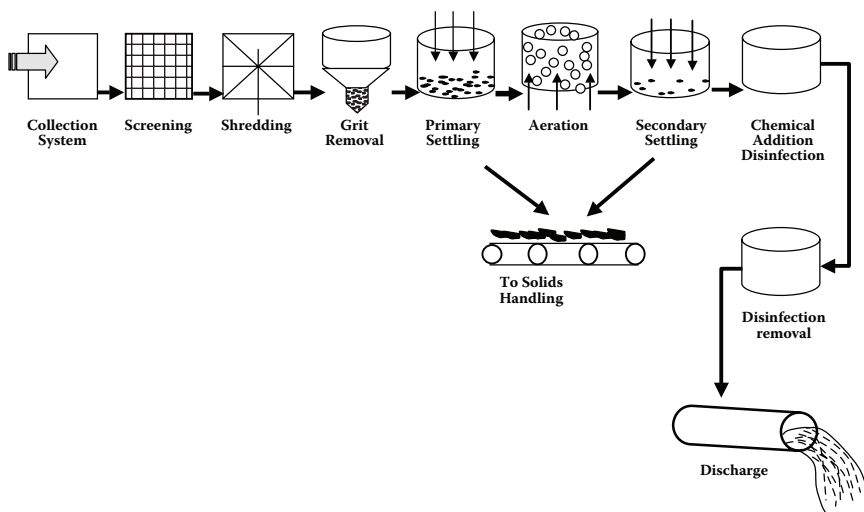


Figure 12.1 Unit processes for wastewater treatment.

Summary

The following chapters describe the unit processes for wastewater collection, treatment, and wastewater reclamation and reuse, as well as those for biosolids management.

Table 12.1 Wastewater Treatment Processes

Process/step	Purpose
Primary treatment	Removes 90–95% settleable solids, 40–60% total suspended solids, and 25–35% BOD ₅
Collection	Conveys wastewater from source to treatment plant
Screening	Removes debris that could foul or damage plant equipment
Shredding	Screening alternative that reduces solids to a size the plant equipment can handle
Grit removal	Removes gravel, sand, silt, and other gritty materials
Flow measurement	Provides compliance report data and treatment process information for hydraulic and organic loading calculations
Preaeration	Freshens septic wastes, reduces odors and corrosion, and improves solids separation and settling
Chemical addition	Reduces odors, neutralizes acids or bases, reduces corrosion, reduces BOD ₅ , improves solids and grease removal, reduces loading on the plant, and aids subsequent processes
Flow equalization	Reduces or removes the wide swings in flow rates for plant loadings
Primary sedimentation	Concentrates and removes settleable organic and floatable solids from wastewater
Secondary treatment	Produces effluent with not more than 30 mg/L BOD ₅ and 30 mg/L suspended solids
Biological treatment	Provides BOD removal beyond that achievable by primary treatment, using biological processes to convert dissolved, suspended, and colloidal organic wastes to more stable solids
Secondary sedimentation	Removes the accumulated biomass that remains after secondary treatment
Tertiary or advanced treatment	Removes pollutants, including nitrogen, phosphorus, soluble COD, and heavy metals to meet discharge or reuse criteria with respect to specific parameters
Effluent polishing	Filtration or microstraining to remove additional BOD or TSS
Nitrogen removal	Removes nutrients to help control algal blooms in the receiving body
Phosphorus removal	Removes limiting nutrients that could affect the receiving body

Continued

Table 12.1 (Continued) Wastewater Treatment Processes

Process/step	Purpose
Land application	Controlled land application used as an effective alternative to tertiary treatment methods; reduces TSS, BOD, phosphorous, and nitrogen compounds as well as refractory organics
Disinfection	Destroys any pathogens in the effluent that survived treatment
Dechlorination	Protects aquatic life from high chlorine concentrations, needed to comply with various regulations
Discharge	Releases treated effluent back to the environment through evaporation, direct discharge, or beneficial reuse
Solids treatment	Transforms sludge to biosolids for use as soil conditioners or amendments

chapter thirteen

*Collection systems**

Process purpose: Collection

Wastewater collection systems carry wastewater (along with the solids accumulated in it) from the source (residential, commercial, or industrial) to the treatment facility for processing. Modern, fully enclosed sewage systems ensure that water contaminated with wastes and pollutants does not pose health, safety, or environmental problems (see Figure 13.1).

To handle the needs of a service area (the area that a sewerage system will service), to take advantage of gravity and the natural drainage afforded by area geography, and to lessen the costs of installing lift stations or pumps to move waste flows, treatment facilities are usually constructed in or near low-lying community outskirts, frequently along the edge of a natural waterway.

Collection system types

Three types of sewerage systems are in general use: sanitary sewers, storm sewers, and combined sewer systems that carry both sanitary and storm water flows.

Sanitary sewers

Sanitary sewers (by definition, sanitary sewers carry human wastes) convey wastewater from residences, businesses, and some industries to the treatment facility. Unlike industrial waste flows, which may have some treatment prior to entry into a municipal system, the wastes sanitary sewerage carries are untreated. Of primary concern in sanitary sewerage management is preventing sewerage overflows, since these wastes contain infectious materials and, if released into the environment, cause serious risks to public health (see Figure 13.2).

* Information in this chapter adapted from Parcher, M.J., *Wastewater Collection System Maintenance*, Lancaster, PA: Technomic Publishing Co., 1998.

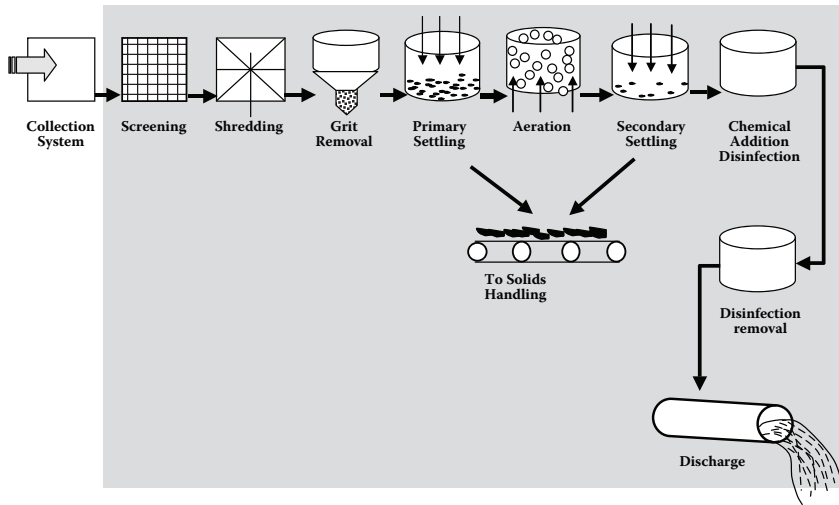


Figure 13.1 Unit processes for wastewater treatment: pretreatment.

Storm sewers

Storm sewers handle the influx of water into a collection system from surface runoff as the result of rainstorms or snowmelt. The more highly an area is developed, the more important effective storm water collection systems are. As buildings and impermeable surfaces cover more area within a community, opportunities for storm flow to percolate into the ground to recharge groundwater are reduced, the heavier surface runoff becomes, and the more contaminants and pollutants can be carried by runoff. Storm systems must be designed to handle sudden heavy flows that can contain large quantities of sand, silt, grit, and gravel, as well as plant materials and trash.

As long as these flows do not carry infectious or human wastes, storm sewers can often be shunted, untreated, to natural drainage, although primary treatment may be required to meet NPDES permit requirements.

Combined sewerage systems

Combined sewerage systems carry both sanitary and storm water flows. Combination systems always carry sanitary wastes, but are designed to handle large flows as well (commonly up to three times the average flows), so that during heavy rainfall, the same sewerage system can handle storm water runoff as well as the normal sanitary flows.

While some older systems are still in operation, combined sewers are now seldom installed in the United States, because heavy precipitation can overwhelm the system, causing flows that exceed the treatment

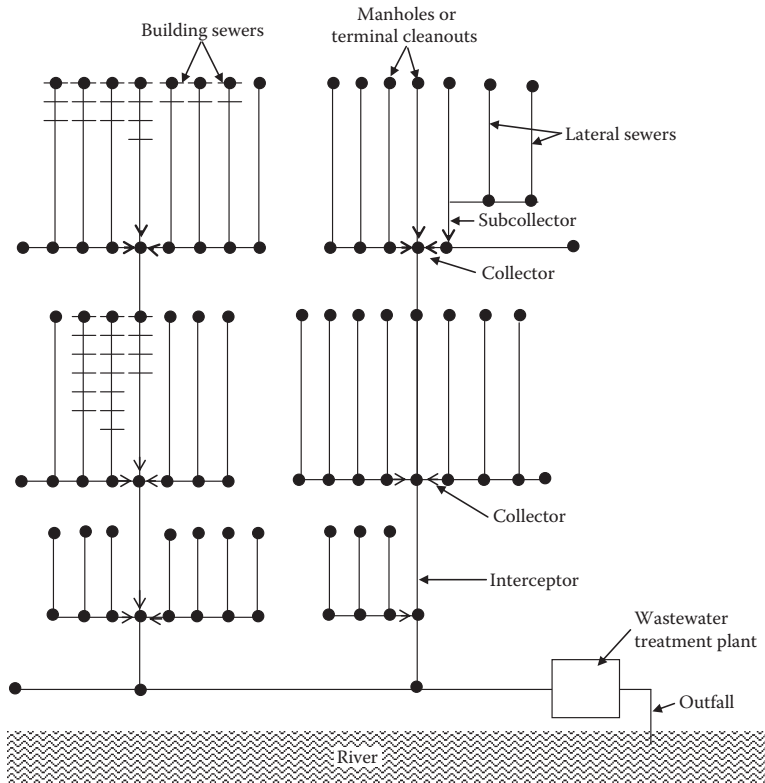


Figure 13.2 Collection system. (Adapted from Qasim, S.R., *Wastewater Treatment Plants: Planning, Design, and Operation*, 2nd ed., Lancaster, PA, Technomic Publishing Co., 1999, p. 153.)

facility's ability to effectively treat them. Combined sewer overflows present a serious threat to public health.

Collection system components

A community's sewerage system consists of:

- Building services that carry the wastes from the generation point to mains
- Mains that carry the wastes to collection sewers
- Collectors or subcollectors that carry the wastes to trunk lines
- Trunk lines that carry the wastewater flow to interceptors
- Interceptors that carry the wastes to the treatment plant
- Other system elements that may include lift stations, manholes, vents, junction boxes, and cleanout points

All of these components except building connections are built under streets, easements, and right-of-ways, on layouts that take into consideration ground elevation, gradient, and natural drainage. They are designed to meet considerations of population size, estimated flow rates, minimum and maximum loads, velocity, slope, depth, and the need for additional system elements to ensure adequate system flows and access for maintenance.

Lift stations: At points where gravity's force isn't enough to move wastewater through a system, lift stations are installed to pump the wastes to a higher point through a force main. Municipalities try to avoid installing lift stations; installation, operation, and maintenance of lift stations is expensive.

Manholes: Access into the sewerage system for inspection, preventive maintenance, and repair is provided by manholes at regular intervals.

Vents: Gases that build up within sewer systems from the wastes they carry must be vented safely from the system. Human wastes in sanitary sewers carry sulfides, and hydrogen sulfide is deadly. Industrial wastes can carry risks related to the composition of their wastewater components.

Junction boxes: Sewerage systems are a network of piping, moving from small pipes that carry wastes from individual services to larger mains, collectors, trunk lines, and interceptors. The constructions that occur when individual lines join are junction boxes or chambers. They are of special concern because leakage and infiltration can commonly occur at system joints.

Cleanout points: Effective cleanout points provide access for cleaning equipment and maintenance into the sewer system.

Construction materials

Sewer lines are made from a wide variety of materials, and construction material selection is based on a variety of possible conditions and factors.

Materials

Rigid piping can be made from:

- Cast iron, ductile iron, corrugated steel, sheet steel
- Concrete, reinforced concrete, asbestos-cement
- Vitrified clay, brick masonry
- Flexible piping

- Plastics, including PVC, CPVC, and other thermoset plastics, and polyfins, polyethelene, and other thermoplastics

Iron and steel piping offers the advantage of strength, but is affected by corrosion from both the wastes the pipes carry and soil conditions. These materials are frequently used in exterior spans (piping runs that bridge gullies, for example). Concrete types offer high strength for heavy loading, especially for large volume pipes, but are heavy. Only short lengths of pipe are possible, so pipe runs must have many joints (joints provide areas in sewerage systems that allow for the advent of potential weak points through general deterioration, shifting, and root growth). Clay is highly resistant to corrosion, but is heavy and brittle. This type of piping is limited in length as well.

Plastics offer advantages of corrosion resistance, high strength-to-weight ratios, ease of handling, long pipe runs (so fewer joints), impermeability, and a certain amount of flexibility without loss of strength. They must be bedded carefully to avoid damage caused by soil voids.

Selection factors

- How resistant the material is to corrosion
- How resistant the material is to flow and scour
- How resistant the material is to external and internal pressure
- Soil conditions and backfill
- The potential wastewater load's chemical makeup
- Requirements pertaining to strength, useful life, joint tightness, infiltration and inflow control, and other physical considerations
- Costs, availability, ease of installation
- Ease of maintenance

Maintenance

Collection systems that are not properly and regularly maintained will cause interruptions in service in ways that will directly affect the residents in a community and cause public outcry very quickly. Regular and thorough preventive maintenance can prevent this.

Effective maintenance programs must accomplish two basic tasks. First, they should ensure that local residents, businesses, and industries (the collection system users) follow regulations and ordinances as to what may be properly and safely disposed of in the system, and how disposal is properly and safely accomplished, and that the collection system users meet plumbing codes and local ordinances that protect sewerage systems from damage and blockage. This is usually accomplished through a

regular inspection program. The second part of an effective maintenance program involves a planned program of preventive maintenance and speedy repair. Preventive maintenance programs involve regular sewer line flushing and cleaning, clearing stoppages, and controlling the materials that cause odors or gases like hydrogen sulfide to build up, as well as maintaining the structural integrity of the system components.

Line cleaning

Well-designed sewer lines are self-cleaning. A combination of factors (including effective slope, velocity, and low friction coefficient) combine to ensure that the systems use the water in the wastes the systems carry to move the solids through the systems, rather than leaving the solids, sand, grit, grease, slime, roots, trash, and mineral buildup behind to clog the lines.

However, not all sewers meet this ideal. Mechanical and hydraulic line cleaning are essential to maintaining the influent flow (see Table 13.1). Mechanical cleaning moves tools through the lines to dislodge heavy debris. Hydraulic cleaning uses water pressure, flushing out lighter materials trapped within the pipes. All hydraulic cleaning tools run the risk of flooding sewer services, and are only effective at removing light to medium accumulations of debris.

Line cleaning involves unblocking the line, then removing the debris that caused the line blockage in the first place. Light to moderate amounts of debris can be carried by water pressure to points in the collection system where they can be easily removed. Working through heavy debris or blockages takes mechanical cleaning methods; large amounts of heavy debris usually must be removed by more labor-intensive means.

Table 13.1 Line Cleaning Methods and Purposes

Method	Purpose	Force used	Water pressure
Jetting	Moderate cleaning/ flushes light debris	Hydraulic/ mechanical	High pressure/ low volume
Flushing	Light cleaning/poor debris removal	Hydraulic	Low pressure/ high volume
Balling	Light cleaning and debris removal	Hydraulic	Low pressure
Rodding	Clears heavy obstructions, debris removed other ways	Mechanical	None
Bucketing	Heavy debris removal	Mechanical	None

Source: Adapted from Parcher, M.J., *Wastewater Collection Systems Maintenance*, Lancaster, PA, Technomic Publishing Company, Inc., 1998, p. 46.

Collection system operators handle debris by flushing it into a trunk sewer, trapping it with screens, traps, or “grit catchers,” vacuuming it out, manually hauling it out with bucket and shovel, pulling it out with gaffs or grabbers from topside, or using devices that winch the debris from the sewer line.

Jetting

Jetting is a versatile technique that effectively clears out moderate amounts of line blockage. Jetting cleans and flushes the line in a single operation, using a high-pressure hose and a variety of nozzles to combine the advantages of hydraulic cleaning with mechanical cleaning.

Jetting is useful for routine line cleaning, for scheduled cleaning of high-problem lines, for quickly clearing sewer backups, and for clearing sewer lines after construction or roadwork.

Basic jetting equipment includes a jet truck—which carries a water tank, a high-pressure, high-volume pump, around 600 ft of 1 in. hose, and a variety of nozzles. In operation, the hose and nozzle are set in the manhole, facing upstream. When the pump is started, it drives the nozzle through the line to the next manhole. At that point, the hose is pulled back, still pushing water through the nozzle and carrying the debris within the line back to the first manhole for removal.

Different types of nozzles extend jetting capabilities. When lines are regularly maintained and obstructions are not extensive, jetting with the proper nozzle type can effectively clear a variety of obstructions. Hydraulic root saws and other cutting tools, pipe brushes, chain knockers, tornado spinner nozzles, skids, cages, nozzle extensions, and bangers are mechanical aids used with jetters to clear line blockages.

Flushing

Flushing adds large volumes of water to the sewer at low pressures. While useful after rodding for pushing leftover loose debris downstream, flushing uses water inefficiently, and does not effectively move accumulated solids. Jetting is generally a better use of resources for regular line cleaning.

In tank dumping, the contents of a jet truck tank or water tanker are dumped through a manhole to clear a single run. Any effective water pressure is quickly lost as the water moves downstream.

Power flushing (the most efficient flushing technique) uses an open-ended jet hose to add water, accelerate wastewater movement, and flush grit into a downstream main. Power flushing can effectively clean outfall lines and is useful for cleaning in hard-to-access sewers.

Flow from a hydrant can also be directed into a manhole for line flushing, temporarily increasing water volume. With hydrant use, care

must be taken not to make an illegal cross-connection between the potable water system and the collection system by laying the fire hose line into the manhole.

Balling

Balls (and other hydraulic line cleaning devices, which include kites, pills, pigs, scooters, and bags) work by partially plugging a flooded upstream main. Attached to a cable or rope to control its downstream path, the ball (or other cleaning device) moves through the pipe by upstream water pressure. As the water rushes past the cleaning device, movement of both the tool and the partially trapped water loosens debris, and the water flushes it downstream, where it can be collected and removed at the downstream manhole.

In general, balls and pills are most effective at clearing soft solids and light sludge cleaning in small-diameter mains. Kites and bags (parachute-like devices that open within the line to partially block the sewer) work more effectively than pills or balls for large-diameter lines (see Figure 13.3). Scooters and tires are heavier devices that operate under

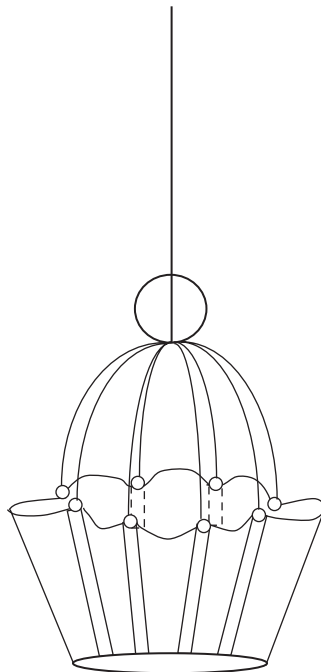


Figure 13.3 Debris catcher basket. (Adapted from Parcher, M.J., *Wastewater Collection Systems Maintenance*, Lancaster, PA, Technomic Publishing Co., 1998, p. 248.)

the same mechanical principles—the obstruction holds back an increased water supply, allowing the water pressure head to both clear accumulated obstructions and move the device down the line, while the operators control the device movement rate by rope, cable, or chains. Pigs, used for cleaning water mains and pressure sewers, are not restrained, but are inserted into the pipe, driven through by adding hydrant flow behind the device, then retrieved at the end of the pipe.

Rodding

Rodders can clear obstructions like heavy root accumulations that jetting can't handle. They work well to remove large soft obstructions to restore flow. Brush attachments can also be attached to rods to scour the pipe after clearing roots or other obstructions. Rodders don't need water to remove debris, and can work either with water flow or against it.

Rodding uses two basic movements to work through an obstruction, rotation (torque) and pushing against and pulling back on the obstruction (thrust). Mechanical rod drivers push the rod into the line from the surface, while pinch rollers mechanically thrust the line in and out of the pipe. Rods can be sectional or continuous. Rodding equipment can be either truck or trailer mounted and is powered by either the truck engine or an auxiliary engine.

Bucketing

To clean large-diameter mains of heavy solids accumulation, operators can winch a bucket through the line. This technique is simple, and the most effective method for cleaning large amounts of debris from a line, though it is labor-intensive and dangerous because of confined spaces concerns. While operators enter the line with the bucket attached to a line and shovel the solids accumulation onto the bucket, top operators pull out the full bucket and dump it, returning it to the line for another load.

Common collection system problems

All collection systems have to deal with the same problems, although some communities may have their normal, everyday sewerage problems compounded by problems caused by aging infrastructures. Some sewerage problems are caused by the nature of the materials collection systems carry, and others by the environment in which collection systems must be built.

Aging systems

Many sewerage systems in operation today were constructed in the 1950s and 1960s. Keeping these aging systems in operation can present

a challenge; overcoming the decay of the original materials is expensive, whether it is approached through retrofitting or replacement, or simply by keeping after the maintenance. Loosened joints, cracked tiles, and corroded concrete let in root growths and inflow and infiltration. Old sewerage lines are frequently less efficient, trapping solids and grease and clogging more easily. Population growth may mean a system has outgrown its ability to effectively handle the current population.

Roots

Wastewater collections systems, installed for the most part underground, share their underground environment with various elements that are not always physically compatible with system materials or construction. Shifting earth, and water infiltration from the surface or from groundwater all cause problems, but these problems are mostly passive. Of prevalent concern in sewerage systems are the problems caused by the root systems of natural vegetation—in short, trees.

Tree roots mindlessly and insidiously grow into the soil, working root-lets into the smallest cracks and crevices, and then expanding the cracks as they grow larger. They are also attracted to water. An aging joint in a sewer pipe or a joint that is not tight is an open invitation to root invasion, and the invading roots can grow to monster proportions relatively quickly.

Root growth in collection systems must be controlled. Regular line cleaning can clear root growth before it builds to a serious blockage, and frequent inspection and cleaning of noted problem areas helps keep known problems under control.

Techniques for removing roots include jetting lines with root cutters for light to moderate root growth, rodding to remove heavy root growth, and chemical treatments to control regrowth.

Grease

Oil and water don't mix—in the sewer line or anywhere else. Grease, oils, and fats are a common and never-ending problem for collection systems and in wastewater treatment in general. Grease sources are residential (usually light, expected, and manageable), commercial, and industrial. Restaurants as well as businesses that are sources of petroleum fuels, oils, and grease need special arrangements to control the wastes that enter the collection system.

Grease traps, sand and oil traps, and interceptors are used to prevent these wastes from entering the collection system and causing problems downstream.

New technologies

New equipment and technology are rapidly changing the ways that collection systems are inspected, maintained, and repaired. Electronic tools have increased visual access to the sewer lines and have made possible increased use of more accurate mapping and database tools. Trenchless technologies are changing the methods by which sewerage systems are repaired or upgraded.

Electronic technology for collection systems

The task of visually inspecting sewer lines presents some challenges. While sewer lamping, manhole inspection, and large sewer main entries are still used, technologies of miniaturization have provided collection systems with new tools to inspect and evaluate sewer lines, including visual entry into piping too small to effectively view in the past.

Specialized video equipment allows operators to assess line conditions quickly and accurately. With a waterproof video camera, lights, a system to transport the camera through the lines, and a closed-circuit TV system, sewer line conditions can be viewed, evaluated, and recorded. With sophisticated camera control equipment and robotics, operators can finally get a good look at problems far out of visual reach.

Video technology is not the only modern technology changing the way sewerage systems are managed. Computer record keeping, maintenance programs, and databases allow easy access to more information than was previously possible. Computer mapping techniques ensure that the information operators take out on the job is current and accurate. Geographic information systems (GIS) provide spatial referencing that was not feasible only a few years ago.

Trenchless technologies

The costs, dangers, and disruptions that traditional open cut work causes when installing new lines, making repairs, or performing line rehabilitation make new trenchless technologies a very attractive alternative. These techniques are now more or less competitive in price, and new techniques, materials, equipment, and tools are increasing the useful possibilities for sewerage repairs and upgrades.

While individual methods present advantages and disadvantages, such techniques as horizontal directional drilling (HDD) and cured-in-place liners are offering alternatives to digging out lines for traditional excavation and open-trench pipe laying or replacement.

For new installations, HDD, pipe jacking, tunneling, microtunneling, and auger boring in general drill or bore a tunnel through the soil and pull or push new pipe in behind the drill head. In a similar technology for replacing old pipe, pipe bursting destroys the old pipe while pulling the new pipe in behind.

To repair or replace existing lines with trenchless technology, all operations are carried out through existing manhole entrances. Cured-in-place pipe, man-entry liners, spiral wound liner strips, and segmental liners are trenchless techniques now useful for replacement or repair. Thermosetting resins, delivered to the needed repair location by a wide variety of methods, are used to reline existing pipes, and inversion and winched-in-place methods are used to install cured-in-place pipes. Tap cutting robots (remote-controlled, air-powered routers) are used to clear the new liner from the taps.

Slip lining slides a new, smaller-diameter, polyethylene pipe liner into old damaged pipe. Because of the possible long pipe runs and butt fusion joints possible in polyethylene, this method is very popular.

The new electronic methods of line evaluation have made exacting point repair possible. In the past, exactly which segment of a stretch of pipe was damaged was often a matter of guesswork. Now, with video technology and GIS mapping, the exact segment can be determined, and repairs effected that disturb only that point, rather than rehabilitating a whole run. Often the exact trouble spot can be pinpointed and accessed directly, rather than the involved and expensive process of digging up long stretches of piping to locate and repair the source of the problem.

Summary

Wastewater collection begins wastewater's journey from potable water use and discard to outfall. Once wastewater is collected, the processes necessary for treatment can begin. Pretreatment of the influent begins the active treatment processes.

References and recommended reading

Parcher, M.J. 1998. *Wastewater collection systems maintenance*. Lancaster, PA: Technomic Publishing Co.

chapter fourteen

Preliminary treatment

Preliminary treatment processes

Preliminary treatment may include several processes, each designed to remove specific materials. Selection of what processes are included in pretreatment depends on the collection system (e.g., combined sewer systems, which collect storm water, bring more grit into the influent than do sanitary sewers) and the nature or makeup of the wastewater in the community. Moreover, the balance between residential wastewater contents and industrial wastewater contents, and the individual industries that add wastes to the system will be determining factors in process selection for a treatment system.

Once the influent has entered the treatment facility via the collection system, pretreatment may include some or all of the following processes: screening, shredding, grit removal, flow measurement, preaeration, chemical addition, and flow equalization (see Figure 14.1).

Process purpose and equipment:

Preliminary treatment

Preliminary treatment provides the first rough pass at removing waste solids from the waste stream. Each pretreatment unit process works to remove a specific kind of material that should be removed before the influent flows on to downstream unit processes (see Figure 14.2).

Screening

Coarse screening is the first unit process in wastewater treatment, as it is in water treatment, for the same reasons. Screening removes large solids from the flow. These may include natural and man-made trash (leaves,

DID YOU KNOW?

The average American uses over 100 gallons of water per day; the average residence uses over 100,000 gallons during a year.

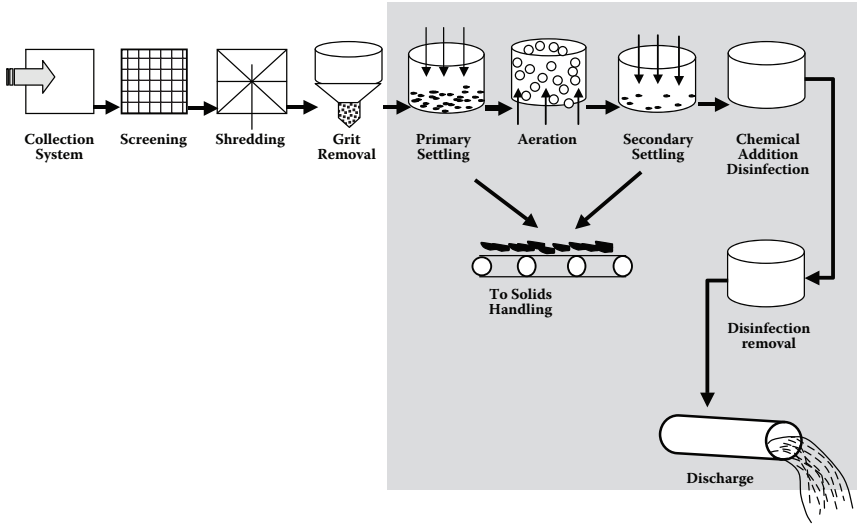


Figure 14.1 Unit processes for wastewater treatment: pretreatment.

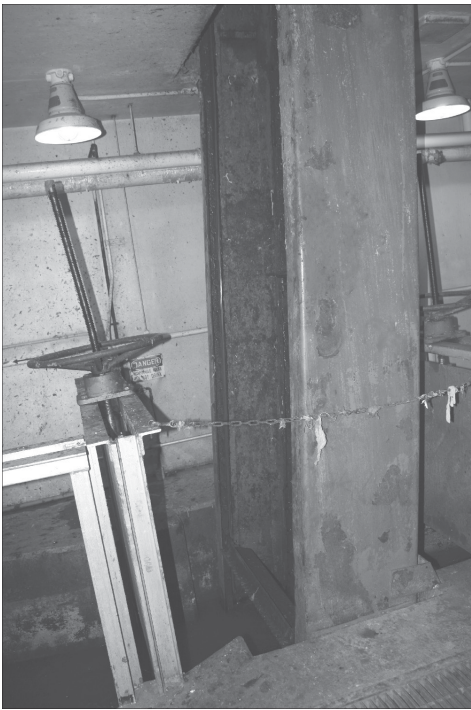


Figure 14.2 Bar screen.

branches, roots, and rocks, rags and cans). From each million gallons of influent, a typical plant could remove from 5 to 12 ft³ of screenings.

Wastewater screening generally employs a *bar screen*, which consists of parallel, evenly spaced metal bars, or a perforated screen. Bar screens can be coarse (2 to 4 in. spacing) or fine (0.75 to 2.0 in. spacing). Placed across a channel, the waste stream carries through the screen, leaving behind trapped large solids for removal. Solids removal from the screens may be either manual or mechanical, but should occur frequently enough that trash buildup does not block influent flow. Screens that are cleaned manually are placed at a 30° angle for ease of cleaning; those mechanically cleaned are placed at a 45 to 60° angle for improved mechanical operation.

Plant design, solids load, and whether or not screening should be intermittent, constant, or only for emergency use are factors in determining what screening methods are used for a facility.

Shredding

Shredding approaches the problems that large solids create differently than does screening. Shredding reduces solids to a size that can enter the plant without damage to equipment or process interruption. The two common shredding processes used in wastewater treatment are comminution and barminution.

Wastewater treatment facilities generally prefer comminution devices for shredding. The entire influent stream flows through the comminuter's grinder assembly (objects too large to fit through the entry slots or that float are shunted aside and must be removed manually). Grinder assemblies include a screen or slotted basket, and two cutters, one rotating or oscillating and the second stationary. The solids are shredded between the cutters and pass through the screen or slots for removal in downstream processes.

Barminution combines bar screening with comminution. The solids collected on the bar screen are shredded, then passed along to downstream processes.

In operation of both comminution and barminution devices, proper cutter alignment and edge are essential factors in effective operation. Checking and maintaining alignment, and cutter sharpening or replacement are common maintenance needs for these devices.

Grit removal

Wastewater influent (especially influent from combined sewer systems) may carry gritty materials (sand, silt, coffee grounds, eggshells, and other inert materials). Heavier than organic solids, these solids may cause

excessive equipment wear (e.g., pump impellers). Grit removal takes these materials out of the waste stream.

All grit removal methods rely on the grit's weight. Since grit is heavier than organic solids, the organic solids can be kept in suspension to be carried on for treatment, while the grit is separated out by processes that employ gravity/velocity, aeration, or centrifugal force. Some grit removal processes take place in a channel or tank, others in a centrifugal chamber.

Gravity/velocity-controlled grit removal takes place in a tank or channel. Within the enclosure, the velocity of the wastewater is strictly controlled, to an ideal rate of about 1 ft per second (fps). As long as the wastewater velocity remains between 0.7 and 1.4 fps, the grit will settle and the organic material stay suspended. Velocity control is maintained by the amount of water flowing through the channel, by channel width and depth, or by the cumulative width of service channels.

Cleaning of gravity systems can be manual or mechanical. Generally, manual cleaning involves ventilating the channel, taking the channel out of service and draining it, then cleaning. Mechanical cleaning is either continuous or on a timed cycle. Frequency depends on grit buildup, and cleaning should occur often enough to prevent grit carryover into downstream processes.

Aeration keeps inorganic suspended solids in suspension in *aerated grit removal systems*, allowing heavier grit particles to settle out.

The aeration rate is determined by observing mixing and aeration, and sampling fixed suspended solids. In practice, the aeration rate is adjusted to produce the desired separation. Too much aeration keeps both the grit and organic materials in suspension. Too little aeration allows both the grit and the organics to settle out.

While aerated grit removal systems can be manually cleaned, the majority of these systems are mechanically cleaned.

Cyclone degritters separate heavier grit particles from lighter organic particles by centrifugal force. Usually used on primary sludge rather than the entire wastewater stream, the critical process control factor is inlet pressure. Excessive pressure will flood the unit and carry grit with the flow. Separated grit discharges directly into a storage container.

Flow measurement

Wastewater treatment processes use *flow measurement* to ensure process efficiency, to provide information for hydraulic and organic loading, and for data needed to prepare regulatory compliance reports. Flow rates are measured by finding a physical measurement that can be related to the quantity of liquid moving past a given point in a specified length of time. The three most common methods are fill and draw, weirs, and flumes.

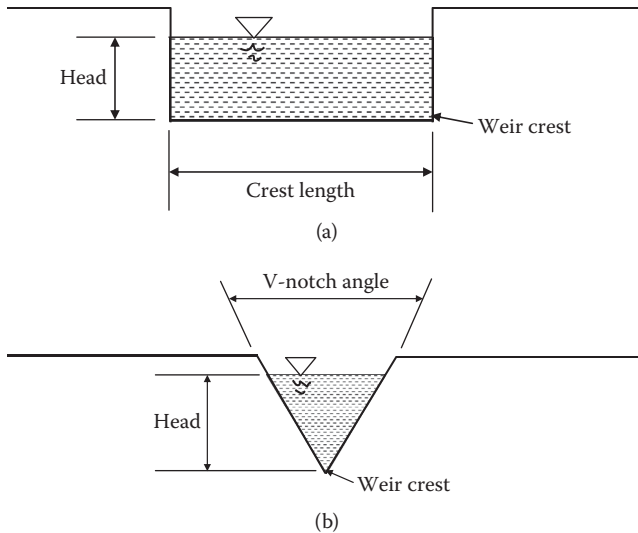


Figure 14.3 (a) Rectangular weir, (b) triangular v-notch weir.

The *fill and draw* method measures the time required for liquid to fill a container of known volume. Dividing the liquid volume by the required time provides the flow rate.

Weirs and *flumes* both use the principles involved in placing a constriction or barrier in an open channel. The amount of water that passes over or through the constriction is directly proportional to the height of the water behind the constriction (the head) and the area of the flow opening in the constriction. The constriction's opening area remains constant, so the only required measurement for calculating flow rate is the head behind the constriction (see Figure 14.3a and b).

In flume design, the throat of the flume (a narrow section) widens gradually in the converging section to the width of the channel. The flume's throat produces a head in the converging section that is measured to convert to the flow rate. Critical depth is measured at the flume. For *Parshall flumes* (the most common flume type), the head is measured at about two-thirds the length of the converging section, either manually or mechanically, and flow rates can be read from a chart, calculated, or determined mechanically or electronically (see Figure 14.4).

Preaeration

The process of *preaeration* forces air through the waste stream, achieving and maintaining an aerobic state. Aeration for 10 to 30 min freshens septic wastes, reduces odors and corrosion by stripping off hydrogen sulfide,

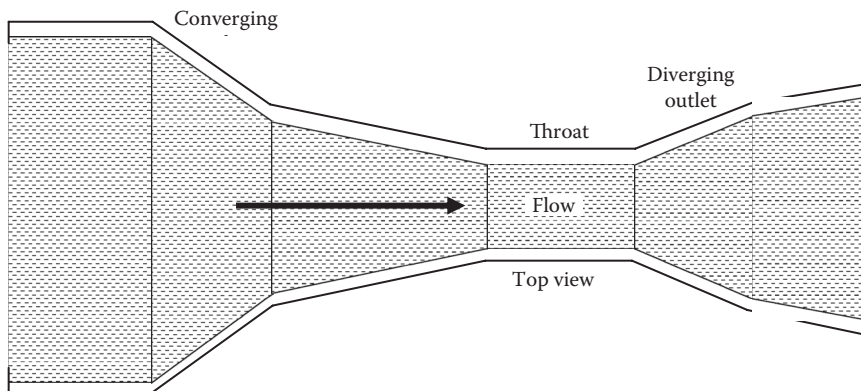


Figure 14.4 Top view of a Parshall flume.

and improves solids separation and settling by agitating the solids to release trapped gases. Preaeration for 45 to 60 min also reduces BOD_5 . Aeration tank or channel blowers send air through diffusers on the tank bottom. The air bubbles carry trapped gases and hydrogen sulfide with them as they travel to the waste stream surface. Ideal air bubble size and rate depend on individual process and waste stream needs, but in general, the smaller the air bubbles, the more air introduced into the tank, and the more effective the process.

Chemical addition

Chemicals used in primary treatment include peroxide, acids and bases, mineral salts (ferric chloride, alum, etc.), bioadditives, and enzymes. What chemicals are used is determined by the desired outcome. For example, typical pretreatment problems that are treated chemically include reducing odors, neutralizing acids or bases, reducing corrosion, reducing BOD_5 , improving solids and grease removal, reducing loading in the plant, and helping along subsequent processes. Attention to ensure mixing is essential to successful chemical pretreatment.

Chemical feeders

Chemical feeders are available in two types: *dry feeders*, which apply dry or powdered chemicals, and liquid or *solution feeders*, which apply chemical in solution or suspension.

The two most common types of dry feeders are *volumetric* and *gravimetric*. Choosing which type to select for a particular application depends on whether the chemical is measured by volume (volumetric type) or weight (gravimetric type). Volumetric dry feeders are simpler and less expensive

than gravimetric pumps, but they are also less accurate. Gravimetric dry feeders are extremely accurate and can deliver high feed rates.

Liquid feeders are generally small positive-displacement metering pumps. *Positive-displacement pumps*, normally used in high-pressure, low-flow applications, deliver a specific volume of liquid for each stroke of a piston or diaphragm. Three types are common (1) reciprocating (piston-plunger or diaphragm feeders), (2) vacuum type (gas chlorinators), or (3) gravity feed rotameter (drip feeders).

Flow equalization

Wastewater treatment plants are subject to wide swings in influent levels and organic loading. *Flow equalization* directs excessive flow into storage basins, maintaining adequate mixing and aeration during storage for the waste stream to control odor and solids buildup during storage. The stored influent is then pumped back into the treatment process during low-flow periods. Flow equalization reduces or removes wide flow rate swings, preventing flows above maximum plant hydraulic capacity and reducing diurnal flow variations. Equalized flows allow treatment plants to perform optimally by providing stable hydraulic and organic loading.

Summary

The pretreated waste stream is stripped of much of its organic solids in the next treatment step: primary sedimentation.

chapter fifteen

Primary sedimentation

Process purpose and method: Sedimentation

Though screening, comminuting, and grit removal take away much of the waste stream's solids mass, after preliminary treatment the influent still contains suspended organic solids. These settleable organic and floatable solids are readily concentrated and removed by primary/plain sedimentation (or clarification) under relatively quiescent conditions (see Figure 15.1). Primary clarification can be expected to remove 90 to 95% of settleable solids, 40 to 60% of total suspended solids, and 25 to 35% of BOD₅.

Sedimentation is used in primary treatment, secondary treatment, and advanced wastewater treatment processes to remove solids. Primary sedimentation occurs in either long rectangular tanks or circular tanks, usually called primary clarifiers (see Figure 15.2). After wastewater enters a settling tank or basin, velocity reduces to about 1 ft/min. Within these basins, the heavier primary settled solids settle to the bottom. The primary settled solids are removed as sludge, and are generally pumped to a sludge processing area.

Solids that are lighter than water (oil, grease, and other floating materials) float to the top, forming scum. These floating solids are skimmed from the surface and removed. Wastewater flow leaves the sedimentation tank over an effluent weir for further treatment. Process efficiency is controlled by detention time (normally about 2 h), temperature, tank design, and equipment condition.

Process equipment: Sedimentation tanks

The sedimentation tanks or clarifiers commonly used in primary sedimentation include septic tanks, two-story (Imhoff) tanks, and plain settling tanks. Secondary and advanced wastewater sedimentation processes normally use plain settling tanks.

Septic tanks

Septic tanks combine setting, skimming, and unmixed anaerobic digestion in one prefabricated unit. Small facilities may use septic tanks for sedimentation, but long detention time and no control for solids separation means

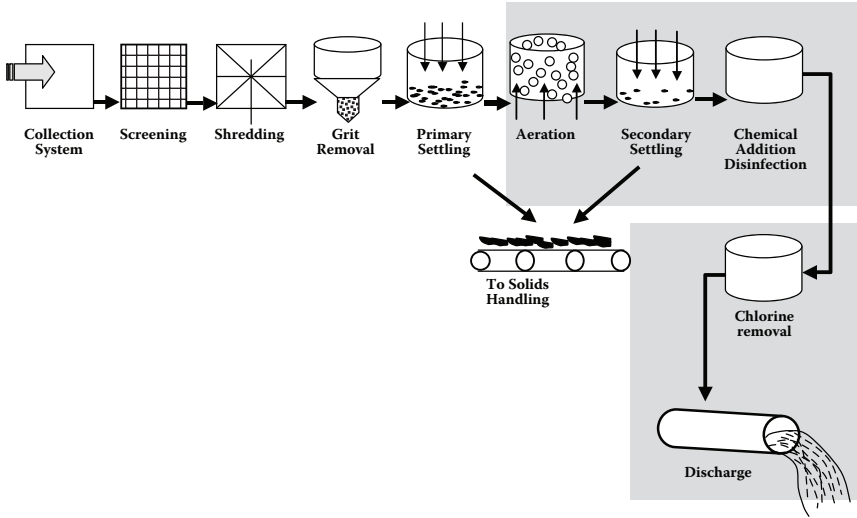


Figure 15.1 Unit processes for wastewater treatment: pretreatment.



Figure 15.2 Primary clarifier.

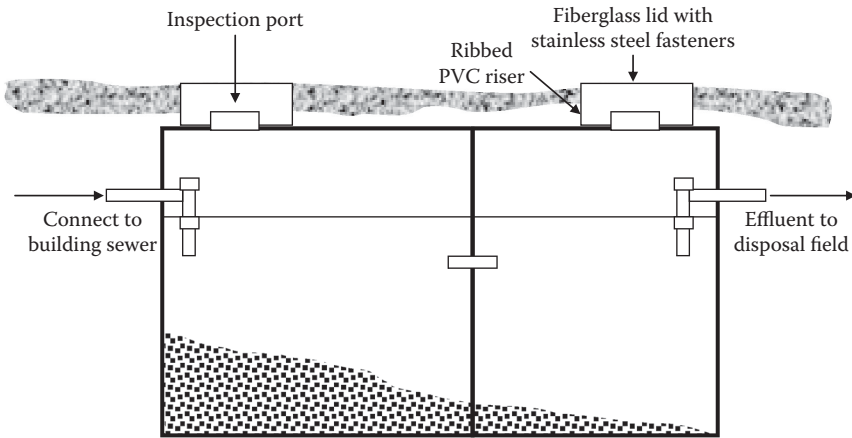


Figure 15.3 Septic tank.

that they should not be used for larger applications. Since the decomposing solids are not separated from the wastewater flow, when the solids fill the tank, they overflow into the discharge stream (see Figure 15.3).

Two-story tanks

In *two-story (Imhoff) tanks*, the problem of solids separation in septic tanks is solved. Imhoff tanks consist of a settling compartment for sedimentation, a lower compartment for solids collection and digestion, and gas vents. Slots in the bottom of the settling compartment allow solids to pass into the lower collection chamber, where they decompose anaerobically. Digestion gases are released through the settling compartment vents.

Plain settling tanks

The optimum settling process tanks, *plain settling tanks* (or *clarifiers*) can accomplish sludge removal either continuously or intermittently.

As influent enters the tank, it is slowed and distributed evenly across the width and depth of the unit. After a detention time of from 1 to 3 h (2 h average), wastewater passes through the unit, and leaves over the effluent weir. The settled sludge is removed for further processing. In continuous operation (which may produce sludge with solids percentages of less than 2 to 3%), the sludge may require further dewatering processes to remove excess water. In intermittent sludge removal, the sludge should settle long enough to obtain 4 to 8% solids, but should be removed frequently enough that clumps of solids don't rise to the surface.

Mechanical scum removal on the tank surface should occur frequently enough to prevent excessive buildup and scum carryover.

Housekeeping requirements for settling tanks include keeping baffles (used to prevent scum carryover), scum troughs, scum collectors, effluent troughs, and effluent weirs free from heavy biological growths and solids accumulations.

Performance of the settling process is evaluated through process control sampling and testing, including tests for settleable solids, dissolved oxygen, pH, temperature, total suspended solids and BOD₅, as well as sludge solids and volatile matter testing.

Settling tank effluent

After preliminary treatment and primary sedimentation, the waste stream (cleaned of large debris, grit, and many settleable materials) is now called *primary effluent*. Primary effluent still contains large amounts of dissolved food, waste, and other chemicals (nutrients), and is usually cloudy and gray in color.

Summary

Most of the nutrients left in primary effluent are removed in secondary treatment processes.

chapter sixteen

Biological treatment

Process purpose

Gravity is the moving force in primary treatment. Primary treatment unit processes (screening, degritting, and primary sedimentation) remove pollutants that either float or settle out of the effluent, leaving behind about 50% of the raw pollutant load. Biological activity is the moving force behind secondary treatment. Secondary treatment includes methods that use biological processes to convert dissolved, suspended, and colloidal organic wastes to more stable solids, which can be either removed by settling or harmlessly discharged to the environment. *Biological treatment* (sometimes called secondary treatment, but in practice, biological treatment is part of secondary treatment processes) provides biochemical oxygen demand (BOD) removal well beyond the levels that primary treatment can achieve, producing an effluent with not more than 30 mg/L BOD₅ and 30 mg/L total suspended solids to meet Clean Water Act (CWA) requirements (see Figure 16.1).

Microorganisms can convert organic wastes (via biological treatment) into stabilized, low-energy compounds. Three commonly used approaches take advantage of this. *Trickling filters*, *rotating biological contactors* (RBCs), or the *activated sludge* process follow normal primary treatment sequentially. The third treatment process, *ponds* (oxidation ponds or lagoons), however, can provide equivalent results without preliminary treatment.

Most biological treatment processes decompose solids aerobically, producing carbon dioxide, stable solids, and more organisms. All of the biological processes must include some form of solids removal (usually settling tanks or filtration), since the processes produce solids.

Ponds, trickling filters, and rotating biological contactors have been successfully used for wastewater treatment for several years. Trickling filters, for example, have been used since the late 1800s. These systems, however, have common problems, as well as problems in common. Ponds, trickling filters, and RBCs are temperature sensitive, can remove less BOD, and in some cases, can cost more to build than the more modern activated sludge systems, though activated sludge systems may cost more to operate because of energy requirements for running pumps and blowers.

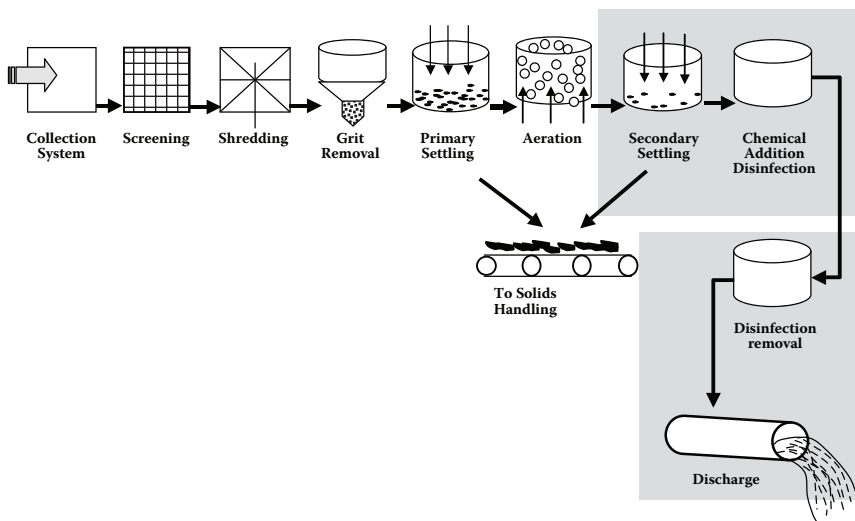


Figure 16.1 Unit processes for wastewater treatment: secondary or biological treatment.

Process systems

Biological treatment processes fall into two large categories: fixed film systems and suspended growth systems.

Fixed film systems (trickling filters and RBCs) use biological growth (biomass or zoogeal slime) that forms on a media. The media provides a large area for slime growth, as well as ventilation. Wastewater passes over and around the slime on the media. With contact between the wastewater and slime, microbial organisms remove and oxidize the organic solids.

Suspended growth systems use biological growth that mixes with the wastewater. Typical suspended growth systems are various modifications of the activated sludge process (see Figure 16.2).

Trickling filters

Trickling filter systems usually follow primary treatment. They generally include a secondary settling tank or clarifier. Widely used for the treatment of domestic and industrial wastes, the trickling filter biological treatment process is a fixed film method designed to remove BOD₅ and suspended solids.

Wastewater containing organic contaminants contacts a population of microorganisms attached (or fixed) to the surface of filter media. Fist-sized stone or redwood, synthetic materials such as plastic, or any other



Figure 16.2 Trickling filter.

substance capable of withstanding weather conditions for many years are typically used as filter media (see Figure 16.3).

The primary effluent is disbursed over the top of the filter media by a fixed distributor system or a rotating distribution arm. The wastewater forms a thin layer as it flows down through the filter media and over the microorganism layer on the media surfaces. As the distributor arm rotates, a flow of wastewater and air alternates contact with the microorganism layer (the zoogeleal slime). The spaces between the media allow air to circulate easily, maintaining aerobic conditions. The biological slime absorbs and consumes the wastes trickling through the media bed, while the organisms aerobically decompose the solids, producing more organ-

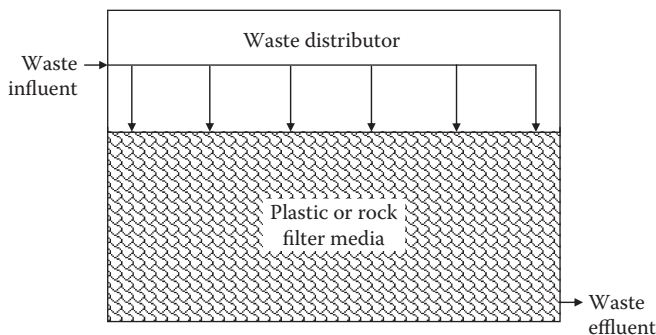


Figure 16.3 Trickling filter.

isms and stable wastes. These wastes either become part of the slime or return to the wastewater flowing over the media.

Zoogleal slime comprises mostly bacteria, but may also contain algae, protozoa, worms, snails, fungi, and insect larvae. As the slime accumulates, it builds up and occasionally sloughs off the media materials. The *sloughings* collect at the bottom of the trickling filter with the treated wastewater, and pass on to the secondary settling or sedimentation tank for removal. In a fixed distributor system, the wastewater flow cycles on and off at a specific dosing rate, ensuring that the microorganisms receive an adequate oxygen supply. The trickling filter system's overall performance depends on hydraulic and organic loading, temperature, and recirculation.

Trickling filter systems are typically *roughing filters*, used to reduce organic loading on a downstream activated sludge process. In domestic wastewater treatment, trickling filters are often used for treating waste streams that produce sludge with poor settling characteristics and poor compactibility (bulking sludge), because the microbial film that sloughs off the trickling filter is relatively dense and can be readily removed by sedimentation.

Trickling filters are also used for the treatment of industrial wastes, including organic chemicals, plastics, and by synthetic fibers industries to treat aqueous waste containing such contaminants as toluene and ethylbenzene.

Trickling filter definitions

- **Biological towers:** A type of trickling filter that is very deep (10 to 20 ft). Filled with a lightweight synthetic media, these towers are also known as oxidation or roughing towers or (because of their extremely high hydraulic loading) super-rate trickling filters.
- **Biomass:** The total mass of organisms attached to the media. Similar to solids inventory in the activated sludge process, it is sometimes referred to as the *zoogleal slime*.
- **Distribution arm:** The device most widely used to apply wastewater evenly over the entire surface of the media. In most cases, the force of the wastewater being sprayed through the orifices moves the arm.
- **Filter underdrain:** The open space provided under the media to collect the liquid (wastewater and sloughings) and to allow air to enter the filter. It has a sloped floor to collect the flow to a central channel for removal.
- **Hydraulic loading:** The amount of wastewater flow applied to the surface of the trickling filter media. It can be expressed in several ways: flow per square foot of surface per day (gpd/ft²), flow per acre per day (MGAD), or flow per acre-foot per day (MGAFD). The hydraulic loading includes all flow entering the filter.

- **High-rate trickling filters:** A classification in which the organic loading is in the range of 25 to 100 lb of BOD₅ per 1,000 cubic ft of media per day. The standard rate filter may also produce a highly nitrified effluent.
- **Media:** An inert substance placed in the filter to provide a surface for the microorganism to grow on. The media can be field stone, crushed stone, slag, plastic, or redwood slats.
- **Organic loading:** The amount of BOD₅ or chemical oxygen demand (COD) applied to a given volume of filter media. It does not include the BOD₅ or COD contributed to any recirculated flow and is commonly expressed as pounds of BOD₅ or COD per 1,000 cubic ft of media.
- **Recirculation:** The return of filter effluent back to the head of the trickling filter. It can level flow variations and assist in solving operational problems, such as ponding, filter flies, and odors.
- **Roughing filters:** A classification of trickling filters in which the organic is in excess of 200 lb of BOD₅ per 1,000 cubic ft of media per day. A roughing filter is used to reduce the loading on other biological treatment processes to produce an industrial discharge that can be safely treated in a municipal treatment facility.
- **Sloughing:** The process in which the excess growths break away from the media and wash through the filter to the underdrains with the wastewater. These sloughings must be removed from the flow by settling.
- **Staging:** The practice of operating two or more trickling filters in series. The effluent of one filter is used as the influent of the next. This practice can produce a higher-quality effluent by removing additional BOD₅ or COD.

Trickling filter performance classifications

Trickling filter classifications (hydraulic and organic loading capabilities) determine the expected performance and the trickling filter construction. Classification types include standard rate, intermediate rate, high rate, super high rate (plastic media), and roughing rate. Currently, standard rate, high rate, and roughing rate are the filter types most commonly used.

- **Standard rate filter:** Hydraulic loading (gpd/ft³) of 25 to 90, seasonal sloughing frequency, no recirculation, typically 80 to 85% BOD₅ removal rate, 80 to 85 % total suspended solids (TSS) removal rate.
- **High-rate filter:** Hydraulic loading (gpd/ft³) of 230 to 900, continuous sloughing frequency, employs recirculation, typically 65 to 80% BOD₅ removal rate, 65 to 80% TSS removal rate.

- **Roughing filter:** Hydraulic loading (gpd/ft^3) of >900 , continuous sloughing frequency, recirculation not normally included, typically 40 to 65% removal rate, 40 to 65% TSS removal rate.

Trickling filter equipment

Distribution systems evenly spread wastewater over the entire media surface. *Rotary distributors*, which move above the media surface and spray the surface with wastewater, are the most common systems. Rotary systems are driven by the force of the water leaving the distributor arm orifices. The distributor arms usually have small plates below each orifice that spray the wastewater in a fan-shaped distribution pattern. In *fixed nozzle* systems (frequently used with deep bed synthetic media filters), the nozzles remain in place above the media and are designed to spray effluent over a fixed portion of the media.

The primary consideration for media selection is that it be capable of providing the desired film locations for biomass development. Media may be 3 to 20 or more ft in depth, depending on the type of media used and the filter classification.

Trickling filters that use ordinary rock are usually only about 3 m deep. The weight of the rocks causes structural problems, and also requires wide bed construction—in many cases up to 60 ft in diameter. Lighter weight synthetic media allows much greater bed depths.

The *underdrains* support the media, collect the wastewater and sloughings and carry them out of the filter, and provide ventilation to the filter. The underdrains should never be allowed to flow more than 50% full of wastewater, which ensures sufficient airflow to the filter.

Effluent channels carry the flow from the trickling filter to the secondary settling tank.

The *secondary settling tank* provides 2 to 4 h of detention time to separate the sloughing materials from the treated wastewater. Though design, construction, and operation are similar to primary settling tank design and usage, sloughings are lighter and settle more slowly than does sludge, requiring longer detention times.

Recirculation pumps and *pipings* recirculate a portion of the effluent back into the filter influent. This improves the trickling filter or settling tank performance. Systems that include recirculation must also involve pumps and metering devices.

The trickling filter effluent collects in the underdrain system, then travels to a sedimentation tank called a *secondary clarifier*. Secondary clarifier (or final clarifier as it is sometimes called) construction is similar in most respects to the primary clarifier, although differences occur in operation that can include detention time, surface settling rate, hydraulic



Figure 16.4 Rotating biological contactors.

loading, sludge pumping, overflow rate, weir loading, and other details (see Figure 16.4).

Rotating biological contactors (RBCs)

The *rotating biological contactor* (RBC) is a biological treatment system that provides an alternative method for the attached growth idea used by trickling filters. RBCs also rely on microorganisms growing on a media surface. The RBC is a *fixed film* biological treatment device, and the basic biological process is similar to that occurring in the trickling filter.

RBCs comprise a series of closely spaced circular plastic (synthetic) disks mounted side by side, and usually about 3.5 m in diameter. These disks are attached to a rotating horizontal shaft. In use, each disk unit is set up so that about 40% of each disk surface is submerged in a tank containing the wastewater for treatment. The RBC unit rotates slowly, and the biomass film (zooglear slime) that grows on the disk surfaces is carried in and out of the wastewater. The microorganisms that form the portion of the biomass that is submerged in wastewater absorb organics; when they rotate out of the wastewater, they receive the oxygen needed for aerobic decomposition. When the zooglear slime reenters the wastewater, any excess solids and waste products slip off the media as sloughings, which are transported with the effluent to a settling tank for removal.

Modular RBC units are placed in series (individual contactor units are *stages*; the group is a *train*) because a single contactor cannot achieve the

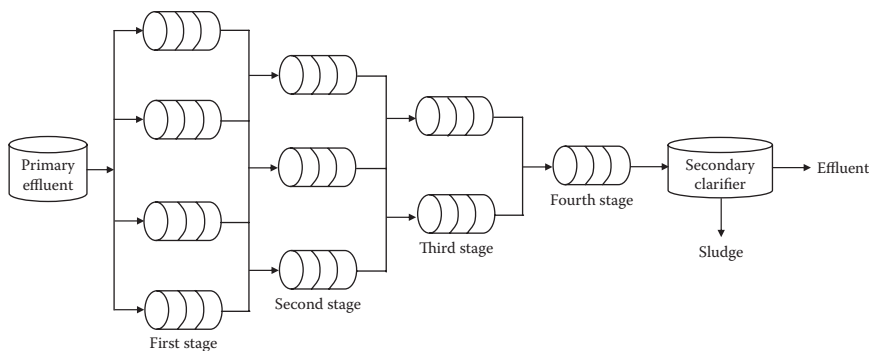


Figure 16.5 RBC system.

required treatment levels; with a properly designed and operated RBC, the treatment achieved can exceed conventional secondary treatment.

RBC systems are usually made up of two or more trains consisting of three or more stages in each. RBCs are easier to operate under varying load conditions than are trickling filters, since keeping the solid medium wet at all times is easier. With multiple-stage RBC systems, the achievable level of nitrification is significant (see Figure 16.5).

RBCs are used to treat dilute aqueous wastes that contain biodegradable organics, including solvents. RBC systems can withstand organic and hydraulic surges effectively, because they possess a large biological cell mass to handle the loading. RBCs allow a greater degree of control over treatment variables than trickling filters. The microorganisms, organic waste, and atmospheric oxygen—and their rate of contact—can be controlled by adjusting the submerge depth for the disks, and the disk rotation rate. RBC operational problems can include central shaft deflection and difficulty in controlling growth (the slime layer tends to overgrow or slough off completely).

RBC equipment

An RBC is made up of the rotating biological contactor with disks built out of either standard or high-density media mounted on a center shaft, a drive system, a tank, baffles, a housing or cover, and a settling tank (see Figure 16.6).

The rotating biological contactor disks (the media) contain large surface areas for biomass growth.

The *center shaft* supports the media. While shafts are designed to support the weight of the media and the biomass, a major problem has been support shaft collapse.

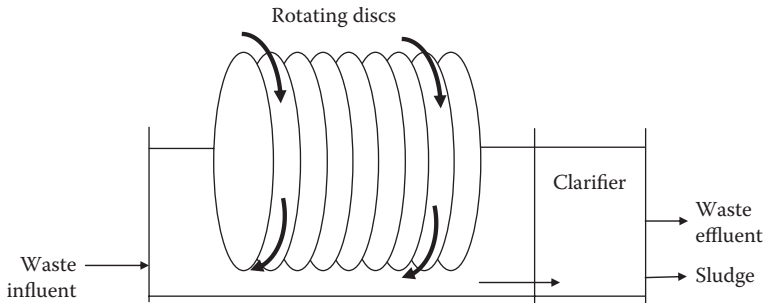


Figure 16.6 Rotating biological contactor.

The *drive system* rotates the shaft and disks. Drive systems can be air driven, mechanical, or a combination of both. Major operational problems can arise if the drive system does not provide uniform RBC movement.

The *tank* holds the wastewater that the RBC rotates in, and should possess enough volume to permit depth and detention time variations.

Baffles permit proper adjustment of the loading applied to each stage of the RBC process. Baffles should allow for adjustment to increase or decrease RBC submergence.

Normally RBC stages are enclosed in a protective structure (*cover*) to prevent biomass loss from severe weather changes (snow, rain, temperature, wind, and sunlight). Housing can significantly restrict access to the RBC for operational assessment, adjustment, or repair.

The *settling tank* removes the sloughing material created by biological activity. Similar in design to the primary settling tank, the RBC settling tank provides 2 to 4 h detention time to permit settling of lighter biological solids.

Like trickling filters, RBC systems need a secondary clarifier to settle out excess biological solids that slough off the disks as the slime layer thickens. Because microbial metabolic rates slow down with temperature decreases, RBC process efficiency is adversely affected by low temperatures.

Treatment ponds and lagoons

In terms of construction and operation costs, *ponds* or *lagoons* for secondary treatment can provide many advantages for areas where property costs are low and land is available.

Ponds are generally much more simple to build and manage than mechanical systems; large fluctuations in flow generally do not present much problem, and they can produce a highly purified effluent at a level of treatment that approaches conventional systems at much lower cost. In

fact, economic concern drives many managerial decisions for the pond/lagoon option.

The level of treatment a pond or lagoon system provides depends on the type and number of ponds used. Ponds can be used as the only secondary treatment, or with other forms of wastewater treatment—that is, other treatment processes followed by a pond or a pond followed by other treatment processes.

Ponds are beginning to be used with increasing frequency in areas where land is readily available, despite potential difficulty in TSS removal efficiency. Construction cost advantages, operation and maintenance advantages, and negligible energy costs make this an attractive option, particularly for small communities.

A stabilization pond treatment system is the simplest to operate and maintain of any of the biological treatment systems. Operation and maintenance activities include collecting and testing samples for dissolved oxygen (DO) and pH, removing weeds and other debris (scum) from the pond, mowing the berms, repairing erosion, and removing burrowing animals.

Pond types

Ponds can be classified (named) based upon their location in the system, by the wastes they receive, and by the main biological process occurring in the ponds: raw sewage stabilization (RSS) ponds, oxidation ponds, and polishing ponds. Ponds are also classified by the processes that occur within them as aerobic ponds, anaerobic ponds, facultative ponds, and aerated ponds.

Ponds by location and waste

Raw sewage stabilization (RSS) ponds are the most common type. Effluent placed in these ponds receives no prior treatment except screening and shredding. Raw sewage stabilization ponds usually provide a minimum of 45 days detention time, and receive no more than 30 lb of BOD₅ per day per acre. Discharge quality depends on the time of the year. In summer, RSS ponds produce high BOD₅ removal and excellent suspended solids removal.

The pond consists of an influent structure, pond berm or walls, and an effluent structure designed to permit effluent selection for quality. An RSS pond's normal operating depth is 3 to 5 ft.

Bacteria decompose the organics in the wastewater (aerobically and anaerobically) and algae use the products of the bacterial action to produce oxygen (photosynthesis) in the biological processes that occur in RSS ponds.

When wastewater enters a stabilization pond, settling, aerobic decomposition, anaerobic decomposition, and photosynthesis all begin to occur.

The solids that enter the pond in the wastewater as well as the solids produced by the biological activity all settle to the bottom. Over the course of the pond's use, this eventually reduces detention time and pond performance, and the pond must be replaced or cleaned. This time span is usually 20 to 30 years.

Bacteria and other microorganisms ingest the organic matter as their primary food source. Through aerobic decomposition, they use oxygen, organic matter, and nutrients to produce carbon dioxide, water, and stable solids that can settle out, as well as more organisms. The carbon dioxide they produce feeds the photosynthesis process that occurs near the pond surface.

In the lower levels of the pond, organisms also use the settled-out solids as food material. The oxygen levels at the bottom of the pond are extremely low, so the process used is anaerobic decomposition, producing gases (hydrogen sulfide, methane, etc.) that dissolve in the water, stable solids, and more organisms.

A population of green algae develops near the pond surface. Using the carbon dioxide produced by the bacterial population, nutrients, and sunlight, the algae growth produces more algae and oxygen that is dissolved into the water. The dissolved oxygen is then used by organisms in the aerobic decomposition process.

Oxidation ponds

Oxidation ponds (usually designed from the same criteria as stabilization ponds) receive flows from stabilization ponds or primary settling tanks. These ponds provide biological treatment, additional settling, and some reduction of fecal coliform levels.

Polishing ponds

Polishing ponds use the same equipment as stabilization ponds. They receive flow from oxidation ponds or other secondary treatment systems. Polishing ponds remove additional BOD₅, solids and fecal coliform, and some nutrients. They generally provide 1 to 3 days detention time and operate at depths from 5 to 10 ft. If the wastewater for treatment is held in the pond too long, or the pond is too shallow, algae growth will begin, which causes increased influent suspended solids concentrations.

Ponds by pond biological process

Aerobic ponds

In *aerobic ponds*, oxygen is present throughout the pond. All biological activity is aerobic decomposition. These ponds are not widely used.

Anaerobic ponds

In *anaerobic ponds*, no oxygen is present in the pond and all biological activity is anaerobic decomposition. These ponds are normally used to treat high-strength industrial wastes.

Facultative ponds

Facultative ponds are the most common pond type by process. In the upper portions of the pond, the presence of oxygen means aerobic processes occur. In the lower levels of the pond, no oxygen is present and anoxic and anaerobic processes occur.

Aerated ponds

In *aerated ponds*, mechanical or diffused air systems provide oxygen throughout the pond. With aeration, pond depth or the acceptable loading levels may increase. Mechanical or diffused aeration can supplement or replace natural oxygen production.

Activated sludge systems

Currently the most widely used biological treatment, the *activated sludge process*, recirculates part of the biomass as an integral part of the process. This allows relatively short acclimation processes for microorganism adaptation to changes in wastewater composition, and a greater degree of control over the acclimated bacterial population.

Activated sludge terminology

- **Absorption:** Taking in or reception of one substance into the body of another by molecular or chemical actions and distribution throughout the absorber.
- **Activated:** To speed up reaction. When applied to sludge, it means that many aerobic bacteria and other microorganisms are in the sludge particles.
- **Activated sludge:** A floc or solid formed by the microorganisms. It includes organisms, accumulated food materials, and waste products forming the aerobic decomposition process.
- **Activated sludge process:** A biological wastewater treatment process in which a mixture of influent and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated mixed liquor by sedimentation and is returned to the process as needed. The treated wastewater overflows the weir of the settling tank in which separation from the sludge takes place.

- **Adsorption:** The adherence of dissolved, colloidal, or finely divided solids to the surface of solid bodies when they are brought into contact.
- **Aeration:** Mixing air and a liquid by one of the following methods: spraying the liquid in the air, diffusing air into the liquid, or agitating the liquid to promote surface adsorption of air.
- **Aerobic:** A condition in which free or dissolved oxygen is present in the aquatic environment. Aerobic organisms must be in the presence of dissolved oxygen to be active.
- **Bacteria:** Single-cell plants that play a vital role in stabilization of organic waste.
- **Biochemical oxygen demand (BOD):** A measure of the amount of food available to the microorganisms in a particular waste. It is measured by the amount of dissolved oxygen used up during a specific time period (usually 5 days, expressed as BOD₅).
- **Biodegradable:** From *degrade* (to wear away or break down chemically) and *bio* (by living organisms). Put it all together, and you have a “substance, usually organic, which can be decomposed by biological action.”
- **Bulking:** A problem in activated sludge plants that results in poor settleability of sludge particles.
- **Coning:** A condition that may be established in a sludge hopper during sludge withdrawal, when part of the sludge moves toward the outlet while the remainder tends to stay in place. Development of a cone or channel of moving liquids surrounded by relatively stationary sludge.
- **Decomposition:** Generally, in waste treatment, decomposition refers to the changing of waste matter into simpler, more stable forms that will not harm the receiving stream.
- **Diffused air aeration:** A diffused air activated sludge plant takes air, compresses it, then discharges the air below the water surface to the aerator through some type of air diffusion device.
- **Diffuser:** A porous plate or tube through which air is forced and divided into tiny bubbles for distribution in liquids. Commonly made of carborundum, aluminum, or silica sand.
- **Dissolved oxygen:** Atmospheric oxygen dissolved in water or wastewater, usually abbreviated DO. Note: The typical required DO for a well-operated activated sludge plant is between 2.0 and 2.5 mg/L.
- **Facultative:** Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

- **Filamentous bacteria:** Organisms that grow in thread or filamentous form.
- **Food-to-microorganisms ratio:** A process control calculation used to evaluate the amount of food (BOD or COD) available per pound of mixed liquor volatile suspended solids.
- **Fungi:** Multicellular aerobic organisms.
- **Gould sludge age:** A process control calculation used to evaluate the amount of influent suspended solids available per pound of mixed liquor suspended solids.
- **Mean cell residence time (MCRT):** The average length of time a mixed liquor suspended solids particle remains in the activated sludge process. This is usually written as MCRT and may also be referred to as *sludge retention rate* (STR).
- **Mixed liquor:** The contribution of return activated sludge and wastewater (either influent or primary effluent) that flows into the aeration tank.
- **Mixed liquor suspended solids (MLSS):** The suspended solids concentration of the mixed liquor. Many references use this concentration to represent the amount of organisms in the liquor. Many references also use this concentration to represent the amount of organisms in the activated sludge process.
- **Mixed liquor volatile suspended solids (MLVSS):** The organic matter in the mixed liquor suspended solids. This can also be used to represent the amount of organisms in the process.
- **Nematodes:** Microscopic worms that may appear in biological waste treatment systems.
- **Nutrients:** Substances required to support plant organisms. Major nutrients are carbon, hydrogen, oxygen, sulfur, nitrogen, and phosphorus.
- **Protozoa:** Single-cell animals that are easily observed under the microscope at a magnification of 100×. Bacteria and algae are prime sources of food for advanced forms of protozoa.
- **Return activated sludge (RAS):** The solids returned from the settling tank to the head of the aeration tank.
- **Rising sludge:** Rising sludge occurs in the secondary clarifiers or activated sludge plant when the sludge settles to the bottom of the clarifier, is compacted, and then rises to the surface in relatively short time.
- **Rotifiers:** Multicellular animals with flexible bodies and cilia near their mouths used to attract food. Bacteria and algae are their major source of food.
- **Secondary treatment:** A wastewater treatment process used to convert dissolved or suspended materials into a form that can be removed.
- **Settleability:** A process control test used to evaluate the settling characteristics of the activated sludge. Readings taken at 30 to 60

min are used to calculate the settled sludge volume (SSV) and the sludge volume index (SVI).

- **Settled sludge volume:** The volume of ml/L (or percent) occupied by an activated sludge sample after 30 or 60 min of settling. Normally written as SSV with a subscript to indicate the time of the reading used for calculation (SSV_{30} or SSV_{60}).
 - **Shock load:** The arrival at a plant of a waste toxic to organisms, in sufficient quantity or strength to cause operating problems, such as odor or sloughing off of the growth of slime on the trickling filter media. Organic overloads also can cause a shock load.
 - **Sludge volume index:** A process control calculation used to evaluate the settling quality of the activated sludge. Requires the SSV_{30} and mixed liquor suspended solids test results to calculate.
- Dissolved:** Solids present in solution. Solids that will pass through a glass fiber filter.
- Fixed:** Also known as the inorganic solids. The solids that are left after a sample is ignited at 550°C for 15 min.
- Floatable solids:** Solids that will float to the surface of still water, sewage, or other liquid. Usually composed of grease particles, oils, light plastic material, etc. Also called *scum*.
- Nonsettleable:** Finely divided suspended solids that will not sink to the bottom in still water, sewage, or other liquid in a reasonable period, usually 2 h. Nonsettleable solids are also known as colloidal solids.
- Solids:** Material in the solid state.
- Suspended:** The solids that will not pass through a glass fiber filter.
- Total:** The solids in water, sewage, or other liquids; include suspended solids and dissolved solids.
- Volatile:** The organic solids. Measured as the solids that are lost on ignition of the dry solids at 550°C.
- **Waste activated sludge:** The solids removed from the activated sludge process. This is normally written as WAS.

Activated sludge process operation

The activated sludge process removes BOD_5 and suspended matter through aerobic decomposition. With proper process controls adjustment, nitrogen and phosphorous may also be removed.

All activated sludge systems include an aeration basin followed by a settling tank (see Figure 16.7). The aeration tank receives effluent from the primary clarifier, as well as a mass of recycled biological organisms from the secondary settling tank—the *activated sludge*. Air or oxygen is pumped into the tank via blowers to maintain aerobic conditions, and the effluent, oxygen, and activated sludge are kept thoroughly agitated by mixers for about 6 to 8 h. The wastewater (*mixed liquor*) then flows into the secondary

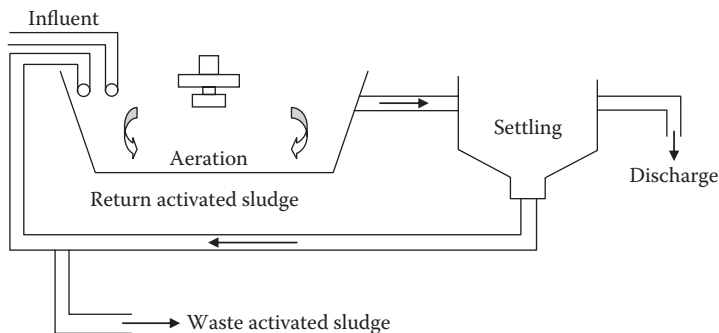


Figure 16.7 Activated sludge process (simplified).

settling tank, where the solids (mostly bacterial masses) settle from the liquid by subsidence. Some of the solids are returned to the aeration tank to maintain the proper bacterial population there, while the remainder is processed and disposed.

Factors that affect the performance of an activated sludge system include temperature, return rates, amount of oxygen available, amount of organic matter available, pH, waste rates, aeration time, and wastewater toxicity.

Obtaining desired performance levels in an activated sludge system means a proper balance must be maintained between the amount of food (organic matter), organisms (activated sludge), and oxygen (DO). Most problems with activated sludge systems are caused by an imbalance among these three items.

Activated sludge process equipment

More complex than for the other processes discussed, equipment for activated sludge treatment processes includes an aeration tank, aeration system, system settling tank, and return sludge and waste sludge systems (see Figure 16.8).

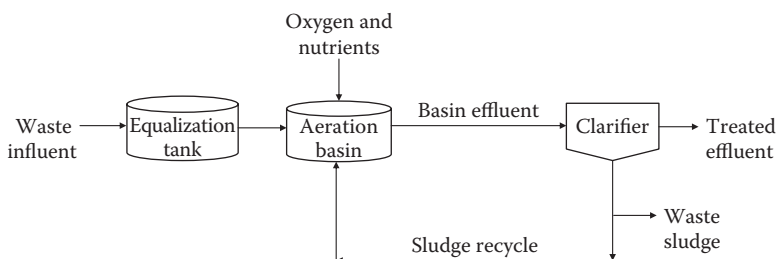


Figure 16.8 Activate sludge process.

Aeration tanks provide the required detention time, which depends on the specific modifications. Detention time ensures that the activated sludge and the influent wastewater are thoroughly mixed. Tank design normally attempts to ensure that all tank areas are thoroughly aerated, leaving no dead spots.

Both mechanical and diffused aeration are common. *Mechanical aeration* systems use agitators or mixers to combine air and mixed liquor, or *sparge rings* to release air directly into the mixer.

Diffused aeration systems release pressurized air through diffusers near the tank bottom. The size of the air bubbles produced directly affects system efficiency—the finer the bubble systems, the higher the efficiency levels that can be achieved. Diffused air systems have blowers that produce large volumes of low-pressure air (5 to 10 psi), lines that carry the air to the aeration tank, and headers that distribute the air to the diffusers, which release the air into the wastewater.

Activated sludge systems require plain *settling tanks* to provide 2 to 4 h of hydraulic detention time.

Return sludge systems include pumps, a timer or variable speed drive to regulate pump delivery, and a flow measurement device to determine actual flow rates.

Waste activated sludge withdrawal is sometimes accomplished by adjusting valves on the return system. For a separate system, equipment requirements include pumps, a timer or variable speed drive, and a flow measurement device.

Summary

When the biological treatment unit for treating wastewater is a trickling filter, rotating biological contactor, or activated sludge system, these unit treatment processes must be followed by secondary sedimentation to remove the accumulated biomass. Secondary sedimentation is covered in Chapter 17.

Secondary sedimentation

Process purpose: Secondary sedimentation

Secondary sedimentation immediately follows biological treatment, and is required before any advanced treatment processes can occur (see Figure 17.1). Sedimentation must also occur before disinfection prior to effluent discharge to the receiving water body.

The effluent from these systems contains considerable biomass—a significant organic load—that must be removed by secondary sedimentation to meet acceptable effluent standards. In secondary sedimentation, the effluent is sent to a sedimentation tank called a *secondary clarifier* or *final clarifier*. Similar to the primary sedimentation tank or primary clarifier, differences occur in detention time, overflow rate, and weir loading.

Activated sludge processes create high solids loading and fluffy biological floc. Operationally, secondary sedimentation units perform two important functions:

- They separate the mixed liquor suspended solids from the treated wastewater, resulting in an effluent sufficiently clarified to meet regulatory standards.
- They concentrate or thicken the return sludge to minimize the quantity of sludge that must be handled (see Figure 17.2).

Secondary settling

The function secondary sedimentation performs is essential to the overall treatment process. In operation of a typical activated sludge unit process, for example, organic pollutants are absorbed by the millions of microorganisms (the *activated sludge*) in an aeration tank, converting the contaminants to more stable forms of biomass (sludge). This activated sludge conversion process is only effective if proper clarification or separation of the sludge from the liquid portion of the mixed liquor occurs. The secondary sedimentation tank (or secondary clarifier) provides the environment whereby separation via gravity settling can take place (see Figure 17.3).

The critical process of gravity settling must be properly controlled and maintained. Unsettled sludge carries over the clarifier's effluent weirs and could contaminate the receiving body of water. The solids concentration within the secondary sedimentation basin is the key parameter to

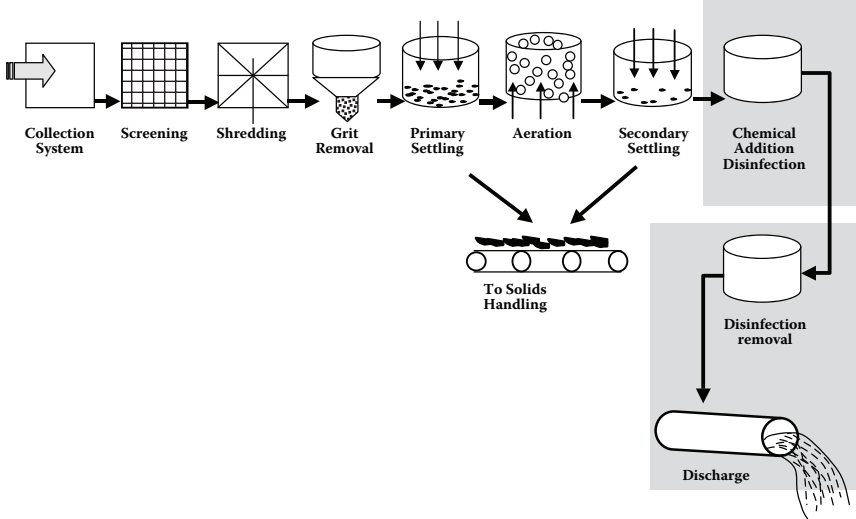


Figure 17.1 Unit process for wastewater treatment: secondary sedimentation.



Figure 17.2 Secondary clarifier.

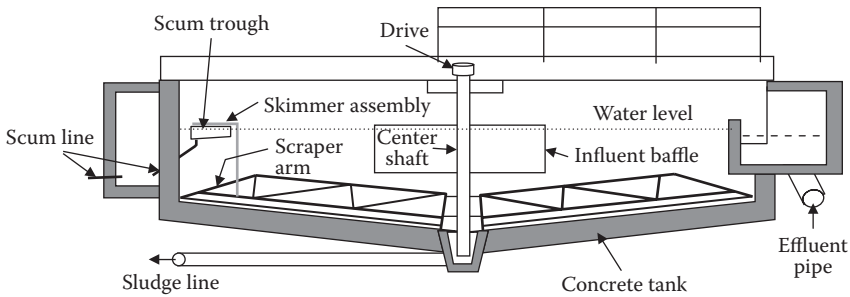


Figure 17.3 Sedimentation tank.

consider. Solids concentration is generally considered equal to the solids concentration in the aeration tank effluent. Solids concentrations can also be determined in the laboratory using a secondary clarifier core sample.

Gravity settling is the most important part of the activated sludge treatment system. Ensuring optimum operation—the removal of 90+% of the raw sewage biochemical oxygen demand (BOD) and TSS—means certain sedimentation tank observations are needed to maintain proper system control. Sedimentation tank observations include flow pattern to ensure normal uniform distribution, settling, normal very low amounts and type of solids leaving with the process effluent, and the usual very clear (low-turbidity) process effluent.

Summary

Sedimentation is essential at many stages of water and wastewater treatment, where settling prepares the waste stream for further treatment processes. After secondary sedimentation, some wastewaters are ready for disinfection and discharge, and other wastewaters require advanced treatment.

chapter eighteen

Advanced treatment

Process purpose

Secondary wastewater treatment coupled with disinfection normally removes 85+% of the biochemical oxygen demand (BOD) and suspended solids, and nearly all the pathogens. However, even a properly operating secondary treatment facility achieves only minor removal of nitrogen, phosphorus, soluble chemical oxygen demand (COD), and heavy metals. *Advanced wastewater treatment* (AWT) adds unit processes that remove more contaminants from wastewater than can usually be achieved by primary and secondary treatment.

Advanced or tertiary treatment is employed to meet specific parameters of discharge or reuse criteria. Nitrogen, phosphorus, soluble COD, and heavy metals are of major concern under some circumstances, especially when discharge requirements for a particular area may be more stringent than effluent from secondary treatment can achieve.

Each body of water has its own particular characteristics. Each reacts somewhat differently to the discharge of treated wastewater. Conventional secondary treatment is usually adequate to make the discharge safe for the receiving stream, but sometimes higher degrees of treatment must be provided. In these instances, advanced or tertiary treatment is needed. Under circumstances that include effluent discharge into delicate ecosystems, or discharge of large amounts of effluent into small receiving bodies, installing systems capable of removing these pollutants to a greater degree is the option usually put into place. These advanced or tertiary treatment processes improve the effluent quality to a level useful for many reuse purposes, but considerations and costs are involved.

Decisions to install advanced treatment processes are not made lightly. Usually expensive to build and operate, advanced systems also usually demand a highly trained operating crew. Sometimes the sludges they produce are difficult to dispose of economically. These techniques are installed (with need usually determined on a case-by-case basis) to tackle the toughest kinds of wastewater problems. The end result of advanced treatment produces enough treated water pure for industrial process uses. Different levels of advanced treatment produce effluent that can be used for golf course and other landscape irrigation, or to replenish groundwater.

While not all wastewater effluents are presently being treated beyond secondary treatment for beneficial reuse, increasing population levels

are applying pressure for more and considered wastewater recycling and reuse. Wastewater reuse at every level will soon have to be common practice, especially in areas with low rainfall or uncertain water supply.

That we are already indirectly reusing our waters is not always obvious to everyone. Discharging wastewater to watercourses has been practiced for many years. Communities downstream on watercourses use them as sources of water supply. Urban population growth causes problems associated with more people creating more sewerage discharge of both treated and untreated wastewaters. Downstream populations are reusing that water—heavily diluted, we hope. This practice is a form of indirect wastewater reuse.

Advanced treatment processes

Some of the more common tertiary treatment processes and operations include effluent polishing, nitrogen and phosphorus removal, and land application.

Effluent polishing

Tertiary treatment is often designed to “polish” the final effluent by removing BOD and TSS—additional suspended solids—mostly organic compounds. Polishing is generally accomplished by implementing a filter (usually granular media type), much like filters used for drinking water purification.

Gravity filtration in an open tank and filtration under pressure in closed pressure vessels are common filtration methods used for effluent polishing. Whatever method is used, special care must be taken with the filtration unit itself. The presence of these organic and biodegradable suspended solids in the secondary effluent means that tertiary filters must be backwashed frequently, usually followed by an auxiliary surface air wash to thoroughly scour and clean the filter bed. Without frequent backwashing, decomposition causes the filter bed to develop septic or anaerobic conditions.

In *microstraining*, another method of effluent polishing, microstrainers or microscreens composed of specially woven steel wire cloth are mounted around the perimeter of a large revolving drum. Partially submerged in secondary effluent, which flows into the drum and then outward through the microscreen, the drum rotates, capturing solids that the rotation carries to the top. There a water spray flushes them into a hopper.

Nitrogen removal

When nitrogen is present in wastewater, it can appear in soluble form as organic nitrogen, ammonia, or nitrate compounds. Nitrogen compound

removal is needed for several reasons, including nutrient removal to help control algal blooms in the receiving body. The ammonia forms of nitrogen can be toxic to fish, and removal prevents additional oxygen demand in receiving waters as nitrogen is converted to nitrate.

Wastewater nitrogen is removed using either a biological process (*nitrification/denitrification*) or a chemical process (*ammonia stripping*).

Nitrification/denitrification is a two-step process. In the nitrifying step, secondary effluent enters an additional aeration tank or other biological unit process (a trickling filter, for example), where nitrifying bacteria thrive. These microorganisms convert ammonia nitrogen to nitrate nitrogen, a form of nitrogen that is not toxic to fish and that does not cause an additional oxygen demand. In the second step (denitrification), different bacteria anaerobically convert nitrates to nitrogen gas (N_2).

In the ammonia stripping process, treated wastewater's pH is raised to at least 10, usually using quick lime (CaO). This forms dissolved ammonia gas, which is then freed from the effluent in a stripping tower. Ammonia stripping is generally more cost-effective than biological nitrification/denitrification, but has limitations. The lime added reacts with carbon dioxide in air and water, forming calcium carbonate scale, which must be periodically removed. In cold-weather conditions, air stripping loses efficiency. Low temperatures cause problems with icing and reduced stripping ability caused by the increased solubility of ammonia in cold water (Davis and Cornwell, 1991). The air stripping process also simply transfers the pollution problem from water to air, creating an additional burden on the atmosphere (Masters, 1991).

Phosphorus removal

Biological treatment unit processes used in wastewater treatment only remove about 30% of the phosphorus in municipal wastewater. This 30% removal has become unacceptable in many areas because phosphorus becomes a limiting nutrient when released to the receiving body, sometimes leading to increased eutrophication.

Phosphorus removal usually involves chemical addition (usually alum, ferric chloride, or lime) added to the wastewater at some point in the conventional process, avoiding the need for additional tanks and filters. Through *chemical precipitation* of the phosphate ions and coagulation, the organic phosphorus compounds become trapped in coagulant flocs and settle out in a clarifier (see Figure 18.1).

Membrane processes for advanced treatment

Semipermeable membranes are used to separate various contaminants and impurities from wastewater in reverse osmosis, by permeating high-quality

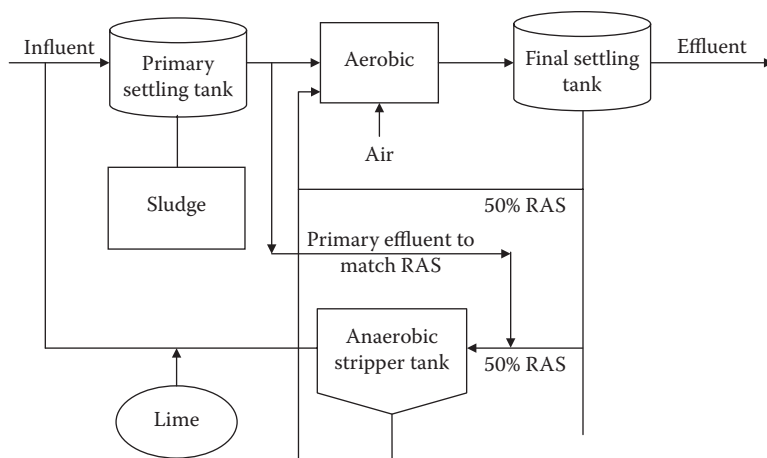


Figure 18.1 Side stream process for biophosphorus removal.

water and halting the passage of dissolved solids. Some of the constituents and contaminants that reverse osmosis can remove include arsenic, asbestos, atrazine, fluoride, lead, mercury, nitrate, radium, and volatile contaminants such as benzene, trichloroethylene, trihalomethanes, and radon.

In osmosis, water naturally passes from the weaker solution to the stronger solution, equalizing the chemical balance in the membrane-separated solutions. Osmotic pressure drives osmosis. In reverse osmosis, external pressure stronger than the natural osmotic pressure causes water to reverse flow from the natural osmotic direction through the membrane.

Pretreatment is essential to effective reverse osmosis. Organics, microorganisms, oil, and grease will coat and foul the membranes, and scale-forming constituents (calcium, iron, manganese, silicon, etc.) will damage and reduce membrane capability.

Equipment for reverse osmosis includes pretreatment equipment, the membrane structure and support, a high-pressure pump and piping, and a brine handling and disposal system.

In *electrodialysis*, water is demineralized using ion-selective membranes and an electric field to separate anions and cations in solution. Electrodialysis is finding increasing use in industrial waste treatment. Metals salts from plating rinses are sometimes removed by electrodialysis, although the most common use for the technique remains the treatment of brackish waters.

When an electric charge is applied to influent in cells (stacks) containing alternatively arranged cation and anion-permeable membranes, the cations and anions in the influent migrate to the opposite poles. There they pass through the selective membranes and separate into pure and brine streams.

Electrodialysis systems include a pretreatment system to prevent membrane fouling (as with reverse osmosis), the cellular membrane stack, and a system to handle and dispose the separated brine.

Land application

Land application provides inexpensive and effective tertiary treatment of wastewater, as well as adding the moisture and nutrients needed for vegetation growth, and recharge of groundwater aquifers. Land treatment allows direct beneficial water and nutrient recycling. However, effective wastewater application to land requires relatively large land areas. Determining the feasibility and design of land treatment processes involves assessing the critical factors of soil type and climate.

Soil's filtering characteristics are an effective alternative to expensive and complicated tertiary treatment methods. Natural filtering processes occur as the effluent flows over vegetated ground surface and percolates through the soil. Soil filtration can produce a high-quality effluent low in TSS, BOD, phosphorous, and nitrogen compounds, as well as refractory organics, inexpensively. While the basic objective of land application is wastewater treatment and disposal, another goal is to obtain economic and environmental benefits. This procedure can be used to conserve potable water by using secondary effluent to irrigate lawns and other landscaped areas, as well as to produce animal feed crops.

Variations of three basic types or modes of land treatment are common: irrigation or slow rate, infiltration-percolation or rapid infiltration, and overland flow (see Figure 18.2a–c). Conditions under which these types function best and basic objectives of these modes of treatment vary (USEPA, *Process Design Manual for Land Treatment of Municipal Wastewater*, 1977).

- **Irrigation, slow-rate land application mode:** Wastewater (applied or sprayed to the field surface by ridge-and-furrow surface spreading or sprinkler systems) enters the soil. Vegetation is the critical component for this treatment process. Crops growing on the irrigation area use the available nutrients the effluent contains, while soil organisms stabilize the flow's organic content. The water enters surface water or groundwater, or evaporates (see Figure 18.2a).
- **Infiltration-percolation, rapid infiltration mode:** Wastewater pumped to spreading basins begins to evaporate. The remainder infiltrates into the soil. The solids are removed by soil filtration while the remaining water recharges the groundwater system. Soils must be highly permeable for this method to work properly (see Figure 18.2b).
- **Overland flow mode:** Wastewater (sprayed over sloped terraces) flows slowly over the surface. Physical, chemical, and biological

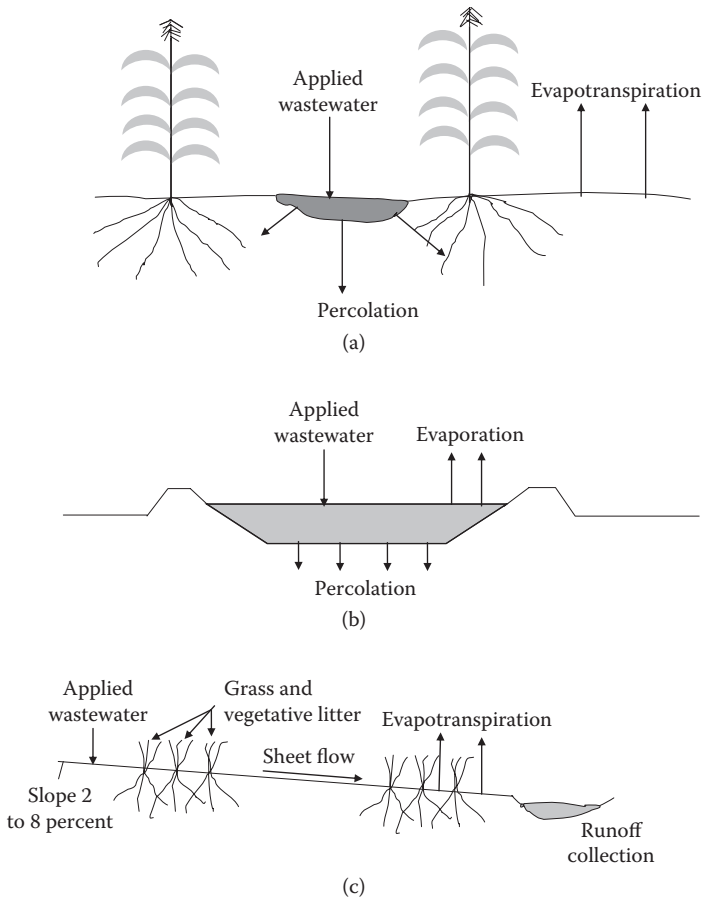


Figure 18.2 (a) Slow land treatment, (b) rapid filtration, (c) overland flow.

processes work to purify the effluent as the wastewater flows in a thin film down the relatively impermeable surface. Soil and vegetation remove suspended solids, nutrients, and organics while a small amount of wastewater evaporates. The remaining wastewater flows to collection channels, and the collected effluent is usually discharged to surface waters (see Figure 18.2a–c).

Summary

After advanced treatment procedures, the waste stream is ready for the final stage of treatment—disinfection.

References and recommended reading

- Davis, M.L., and Cornwell, D.A. 1991. *Introduction to environmental engineering*. New York: McGraw-Hill.
- Masters, G.M. 1991. *Introduction to environmental engineering and science*. Englewood Cliffs, NJ: Prentice Hall.
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chapter nineteen

Wastewater disinfection

Process purpose

The final unit process before effluent discharge into a receiving body, *disinfection* has several important objectives (see Figure 19.1). Disinfection's main purpose is to protect public health by reducing the organism population in the wastewater to levels low enough to ensure that pathogenic organisms will not be present in sufficient quantities to cause disease when discharged. Disinfection helps to prevent the spread of disease and protects our waters: drinking water supplies, beaches, recreational waters, and shellfish growing areas.

Chlorine is the most common disinfectant in use, for water and wastewater treatment both. Alternatives to chlorine use include chlorine dioxide, ozonation, potassium permanganate, ultraviolet (UV) radiation systems, membrane processes, air stripping, and activated carbon adsorption.

The disinfection processes most commonly used for wastewater disinfection are chlorination and dechlorination, ultraviolet irradiation (UV), ozonation, and disinfection by bromine chloride.

Chlorination

Chlorine disinfection has advantages of cost, dependability, and performance predictability (see Table 19.1).

Chlorine is a very reactive substance and readily reacts with other substances, including many chemicals, organic matter, and ammonia. These chemical reactions reduce chlorine, using it up so that it is no longer available for disinfection. The amount of chlorine taken up by organic matter and ammonia in wastewater disinfection is known as *chlorine demand*. When chlorine reacts with ammonia, it produces chloramines, which consist of chlorine, nitrogen, and hydrogen. Chloramines possess some disinfecting capability, and are part of the *combined chlorine residual* in chlorine testing (see Figure 19.2).

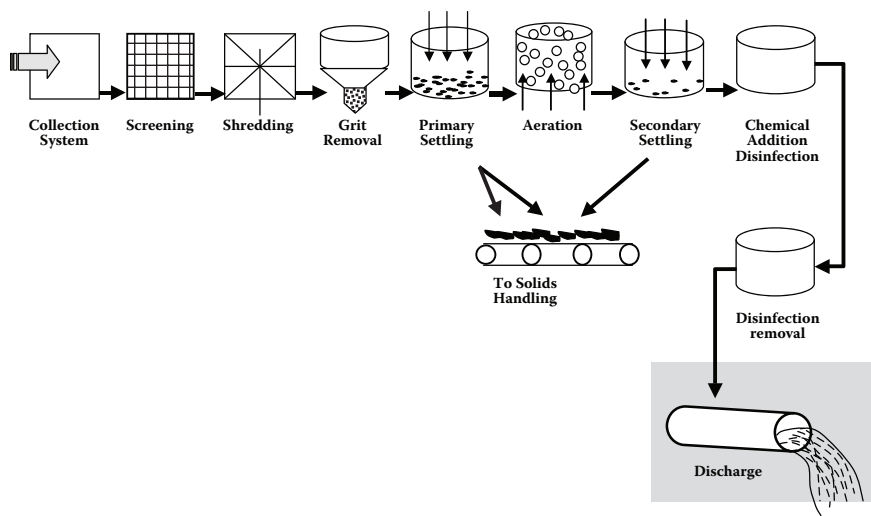


Figure 19.1 Unit processes for wastewater treatment: disinfection and disinfection removal.

Table 19.1 Chlorine Disinfection Advantages and Disadvantages

Advantages	Disadvantages
Relatively inexpensive compared with other disinfection methods	Increased safety and regulatory requirements caused increased operational and liability costs
Dependable chlorination equipment designs reduce breakdowns	Produces chloramines and other substances toxic to fish and aquatic organisms, even in very low concentrations
Process familiarity makes identifying and correcting problems fast and simple	Possible health hazards from chlorine by-products require additional treatment steps
Well-documented disinfection performance	Chlorine by-product compounds remain active in the receiving stream for very long periods
Easy-to-use control mechanism (residual and contact time)	Potential in-plant hazards demand safety precautions, personal protective equipment, emergency response plans, training, and regulatory monitoring and reporting



Figure 19.2 Chemical feed lines.

Table 19.2 Toxicity Levels of Total Residual Chlorine (TRC) mg/L

0.06	Toxic to striped bass larvae
0.31	Toxic to white perch larvae
0.5–1.0	Typical drinking water residual
1.0–3.0	Recommended for swimming pools

When all the chemical demands are met, chlorine reacts with water, forming hypochlorous (HClO) and hydrochloric (HCl) acids. The most effective chlorine disinfectant, hypochlorous acid, is known as *free residual chlorine*.

Chemicals present in the wastewater make achieving free residual impractical for most wastewater treatment plants, so disinfection is usually brought about by combined residual, and controlled by monitoring the *total residual chlorine* (TRC).

Residual level, contact time, and effluent quality all affect disinfection. Chlorine's efficacy decreases with increasing pH and decreasing temperature; it is also affected by ammonia or organic nitrogen. Maintaining the desired residual levels for the required contact time is essential. Failure to do so results in lower efficiency and the increased probability of disease organisms in the discharge. For disinfection of most domestic wastes, a total residual chlorine concentration of ≥ 1.0 mg/L should occur for at least 30 min at design flow (Table 19.2). High levels of solids in the effluent increase residual or detention time for proper disinfection (see Figure 19.3).

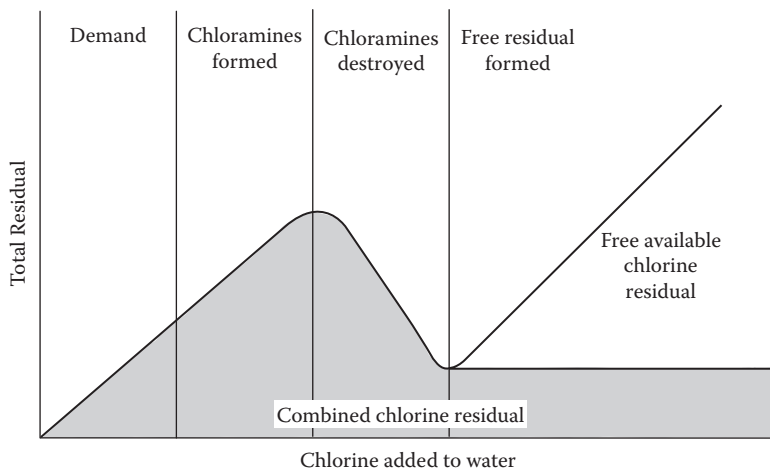


Figure 19.3 Breakpoint chlorination curve.

Other forms of chlorination: Hypochlorite

Chlorine substitutes used in disinfection are usually in the form of *hypochlorite* (similar to the chlorine oxidants used in home swimming pools) or free chlorine gas.

Though hypochlorite presents some minor hazards (skin irritation, nose irritation, and burning eyes), working with it is relatively safe. Available in dry form as powder, pellet, or tablet (calcium hypochlorite) or in liquid form (sodium hypochlorite), hypochlorite can be added directly using a dry chemical feeder, or dissolved and fed as a solution (see Figure 19.4).

Dechlorination

High chlorine concentrations released into the environment can present adverse environmental impact. Wastewaters heavy in chlorine released from wastewater treatment plant outfall pipes can kill fish and other aquatic life in that area. Many state water control boards have established chlorine water quality standards of total residual chlorine $\mu 0.011$ mg/L in fresh waters and $\mu 0.0075$ mg/L for chlorine-produced oxidants in saline waters.

To comply with these regulations and to protect aquatic life, sometimes dechlorinating the effluent is necessary. For compliance, many treatment systems have added additional treatment steps for chlorine removal prior to discharge. The *dechlorination* process uses sulfur dioxide, sodium

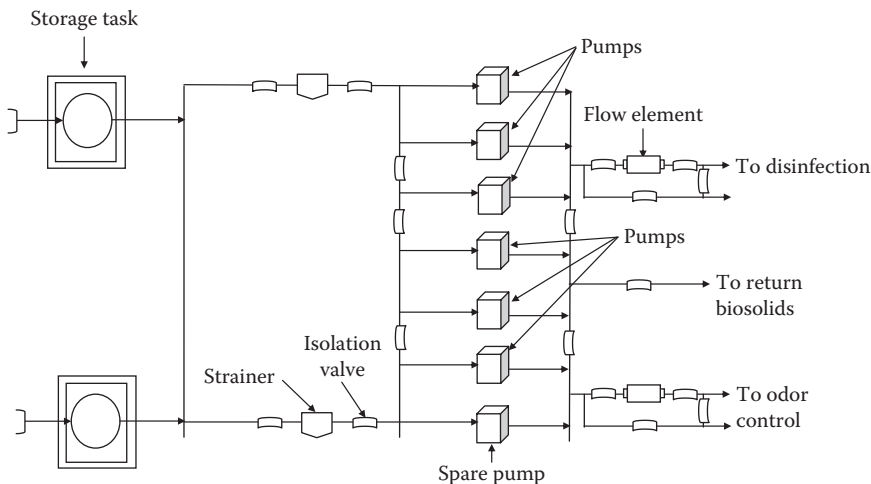


Figure 19.4 Process flow diagram sodium hypochlorite.

sulfite, or sodium metabisulfite, any of which react quickly with chlorine and convert it to a less harmful form.

No additional contact tanks are needed, though the dechlorination process does require additional chemical feed and monitoring equipment. Generally, the equipment required for dechlorination is similar to that required for chlorination and specific equipment depends on the chemical choice. Because chemicals used for dechlorination also react with dissolved oxygen, dechlorinated effluent usually requires aeration prior to discharge.

Sulfur dioxide dechlorination

Dechlorinating with sulfur dioxide involves adding it to the chlorinated waste stream right before outfall. Liquid sulfur dioxide is converted to gaseous form in an evaporator. From the evaporator, the gaseous sulfur dioxide enters the sulfonator, which is similar in design and function to a chlorinator. The sulfonator injects the gaseous sulfur dioxide into the waste stream, where it forms sulfurous acid, which is transported to the application site (see Figure 19.5). At the application site, sufficient mixing ensures uniform solution distribution in the waste stream. Because reaction time is very short, no contact tank is needed.

Exposure to sulfur dioxide causes damage to the central nervous system. Mixing chlorine gas and sulfur dioxide causes a violent reaction. Switching metering equipment from one gas to the other without first flushing thoroughly with clean, dry air or an inert gas such as nitrogen is extremely dangerous.

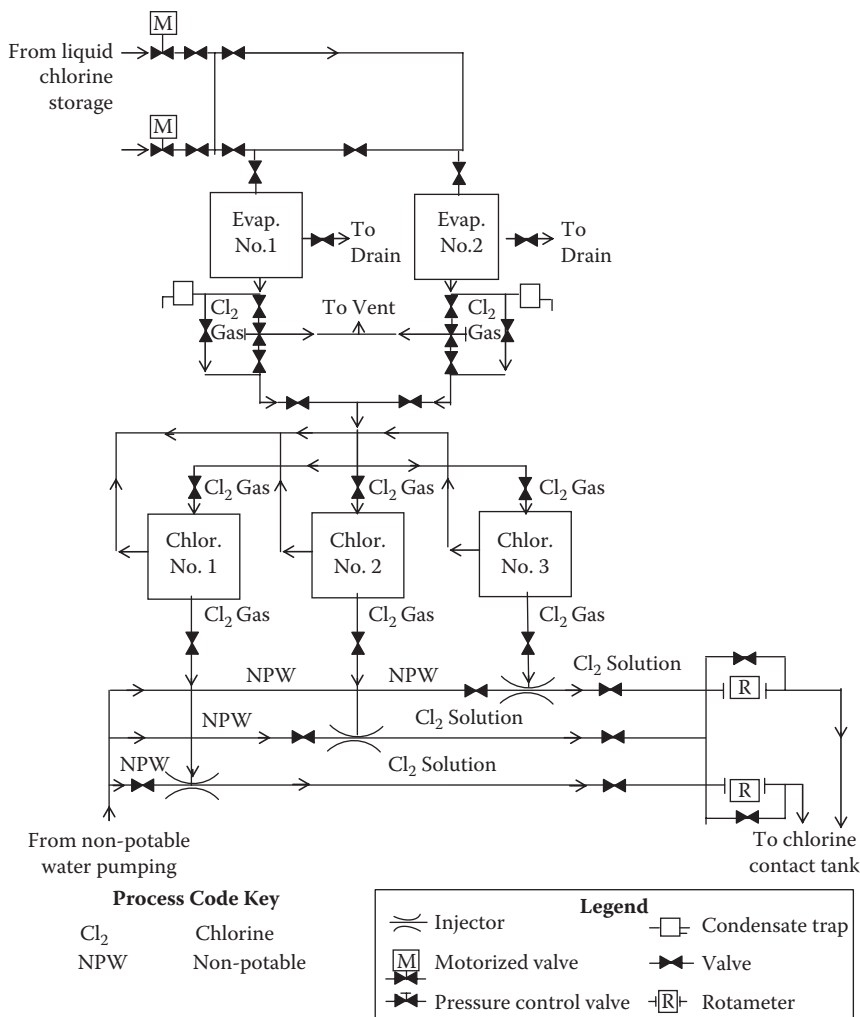


Figure 19.5 Disinfection chemical feeding process schematic diagram.

Ultraviolet (UV) radiation

Ultraviolet radiation disinfection is a highly effective disinfectant under ideal conditions (see Table 19.3).

When UV radiation is used in wastewater treatment, wastewater effluent is exposed to ultraviolet light of a specified wavelength and intensity for a specified contact period. The effectiveness of the process depends upon UV light intensity, contact time, and the waste stream turbidity levels.

Table 19.3 UV Radiation Advantages and Disadvantages

Advantages	Disadvantages
Excellent germicidal qualities	Turbidity levels affect UV radiation’s ability to disinfect, allowing possible microbial survival
Effectively destroys microorganisms	Maintenance includes regular tube cleaning and replacement as needed; periodic acid washing removes chemical buildup
Use in hospitals, biological testing facilities, and many other similar locations for sterilization means effectiveness is well tested	Extremely hazardous to the eyes; requires proper eye protection

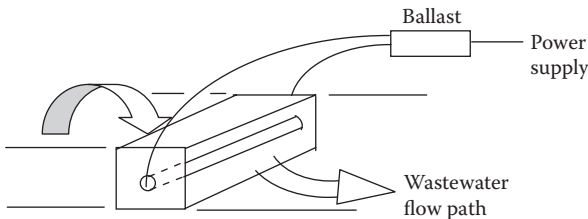


Figure 19.6 UV schematic. (Adapted from USEPA, *Design Manual: Municipal Wastewater Disinfection*, Washington, DC, 1986, p. 158.)

The effectiveness of UV radiation in wastewater treatment hinges on turbidity. UV light waves cannot penetrate solids; this can allow microbial life to survive disinfection. Many states limit UV disinfection usage to facilities that can regularly produce an effluent containing $\mu 30$ mg/L or less of BOD₅ and total suspended solids.

UV disinfection takes place in contact tanks, designed with the banks of UV lights in a horizontal position (either parallel or perpendicular to effluent flow) or with banks of lights placed in a vertical position (perpendicular to flow). The contact tank must provide a minimum 10 s exposure time (see Figure 19.6).

Ozonation

Ozonation provides several advantages over chlorination (see Table 19.4).

Ozone, a strong oxidizing gas, reacts with most organic and many inorganic molecules. Produced when oxygen molecules separate and collide with other oxygen atoms, the ozone molecule is formed of three oxygen atoms. Ozone is an excellent disinfectant for high-quality effluents,

Table 19.4 Ozonation Advantages and Disadvantages

Advantages	Disadvantages
Increases DO in the effluent	Extremely toxic substance
Briefer contact time	Potential to create an explosive atmosphere
No undesirable effects on marine organisms	Facility needs the capability to generate pure oxygen as well as an ozone generator
Decreases turbidity and odor	Use limited to filtered effluents

but less so for turbid wastewaters. For this reason, current regulations for domestic treatment systems limit its use to filtered effluents unless effluent quality from a system can be proven before installation of the ozonation equipment.

Ozonation unit process equipment includes an oxygen generator as well as an ozone generator. The contact tank requirements include a 10 min contact time at design average daily flow, and off-gas monitoring for process control. Ozone is extremely toxic, and safety equipment capable of monitoring ozone in the atmosphere and a ventilation system that prevents ozone levels higher than 0.1 ppm are required (see Figure 19.7).

Ozone unit process operation involves ozone generator monitoring and adjustment, and control system monitoring to ensure the required

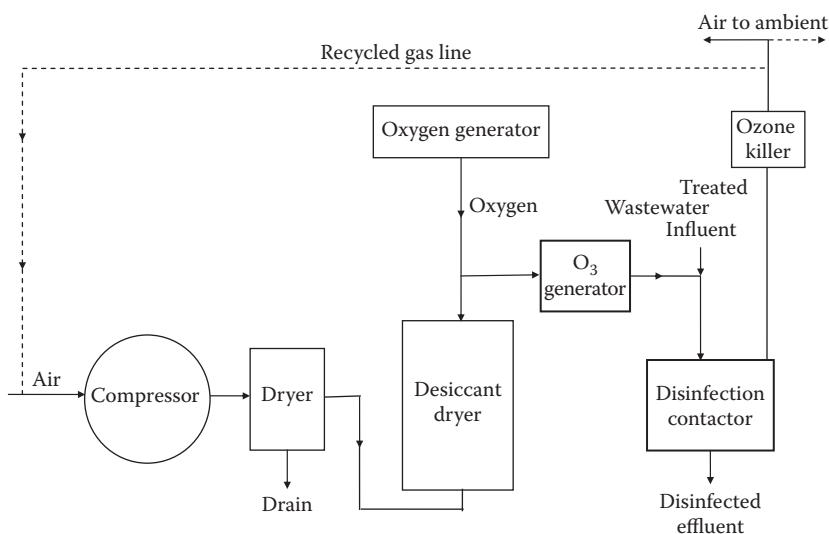


Figure 19.7 Ozone disinfection flow diagram. (Adapted from White, G.C., *Handbook of Chlorination*, 2nd ed., New York, Van Nostrand Reinhold, 1986, p. 937.)

Table 19.5 Bromine Chloride Advantages and Disadvantages

Advantages	Disadvantages
Excellent disinfectant	Extremely corrosive compound with low moisture concentrations
Reacts quickly	Bromamines are unstable and dissipate quickly
Produces no long-term residuals	
Bromamines decay into other, less toxic compounds rapidly	

ozone concentrations. Biological testing is used regularly to assess process effectiveness.

Bromine chloride

Bromine chloride, a mixture of bromine and chlorine, forms hydrocarbons and hydrochloric acid upon contact with water. An excellent disinfectant, bromine chloride reacts quickly and produces no long-term residuals under normal conditions (Table 19.5).

The chemical reactions that occur when bromine chloride contacts wastewater are similar to those that occur with chlorine disinfection, although bromamine compounds form rather than chloramines. Bromamine compounds are unstable and dissipate quickly, though they are excellent disinfectants. The compounds that form as bromamines decay are less toxic than chlorine by-products and are not detectable in plant effluent (see Figure 19.8).

Factors that affect bromine chloride's performance as a disinfectant are also similar to chlorine. Process performance depends on effluent quality and contact time.

No disinfection

On a case-by-case basis, in very limited numbers, discharge of effluent with no disinfection is allowed. Conditions governing this decision include potential for human contact with the discharged effluent and point of discharge, as well as many other factors.

Summary

Disinfection and dechlorination are the last steps in wastewater treatment before returning the wastewater effluent to the environment. Discharge and treated wastewater reuse conclude wastewater treatment.

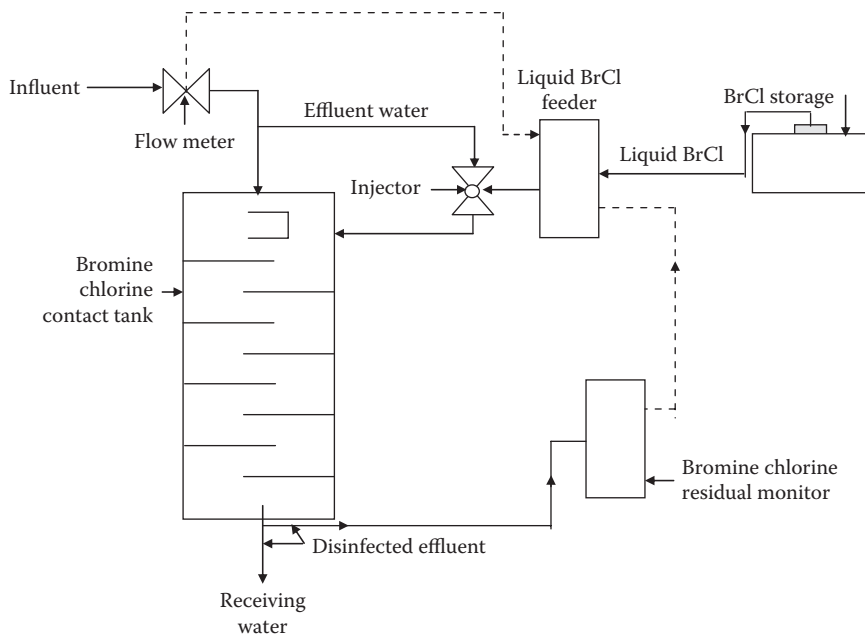


Figure 19.8 Bromide chloride feeder system.

chapter twenty

Discharge effluent

Process purpose: Discharge and reuse

Returning treated wastewater to the environment safely is the chief task of effluent discharge and reuse (see Figure 20.1). This can be accomplished by a number of different methods, each of which uses water's physical behaviors to accomplish wastewater's safe return to the hydrogeologic cycle. Wastewater reuse offers the attraction of both offsetting treatment costs and providing environmental benefit, especially in water-poor areas.

Wastewater discharge

Direct discharge into the environment is highly regulated, and meeting the National Pollution Discharge Elimination System (NPDES) standards for discharge is the goal of most wastewater treatment processes. Direct impacts on the discharge environment and on the populations in the discharge area are among the chief considerations for discharge. Methods to lessen effluent impact related to discharge include:

- Discharge to holding ponds or oxidation ponds, allowing evaporation, shifting water to vapor form and returning it to the environment
- Discharge to ocean waters for coastal areas, massively diluting the treated effluent for safe return to the environment by discharge at multiple points through a diffuser
- Discharge through beneficial reuse, allowing water-scarce areas to conserve potable water supplies, and returning effluent to the environment eventually by groundwater infiltration and evapotranspiration through landscape irrigation and other methods

Wastewater reuse

Wastewater reuse is an idea that is quickly gaining popularity in wastewater treatment. While circumstances may dictate the necessity of wastewater reuse (in some areas, wastewater effluent is an essential water resource), now, in general, water reclamation (treatment or processing of wastewater to make it reusable) and reuse are performed with increasing regularity. With current technologies and testing for effluent quality and assurance of process safety, education for public acceptance is often

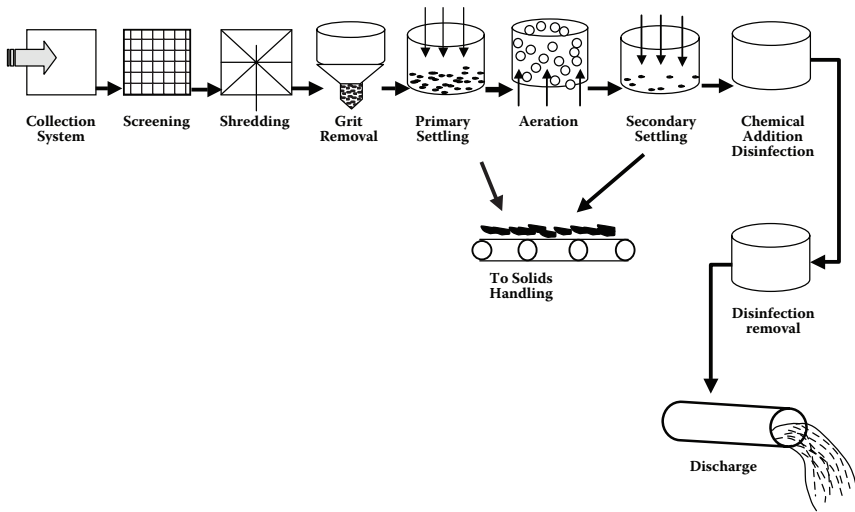


Figure 20.1 Unit processes for wastewater treatment: discharge.

a primary concern for treatment facilities. The idea that no higher-quality water (unless a water surplus exists) should be used for a purpose that can tolerate a lower grade is core to acceptance of this practice.

Wastewater reuse provides many advantages, and effluent can be reused easily for several purposes. Reuse offers an alternative disposal outlet that can accept a lower level of treatment, thus protecting delicate ecosystems and offsetting costs associated with advanced treatment to meet discharge effluent regulations. Wastewater can be reused to enhance or create recreational facilities, industrial water supplies, groundwater recharge, and for direct reuse for potable water supplies (though this use is highly controversial).

Nonpotable reuse

Current wastewater reuse practices in cities involve dual distribution systems that deliver two grades of water (one potable, the other nonpotable) to the same service area. This conserves the limited high-quality waters, allowing potable waters to serve a much larger population.

Using one system from a high-quality potable source, and the other of reclaimed water, the reclaimed water is used for nonpotable purposes. These include household, industry, commerce, and public facilities for landscape irrigation, lakes, public fountains, and environmental improvements.

Development of reuse and reclamation projects is partially driven by the need to conserve potable water, but also by costs. Reclaiming wastewater for nonpotable reuses is less expensive than meeting the nutrient

removal requirements for discharge, while making use of the nutrients present in the effluent through irrigation, as well as replenishing ground-water supplies and using soil's natural filtering processes.

Reclaimed wastewater is used in applications where the product poses no health threat to consumers. These can include:

- Irrigation of landscaped areas (parks, athletic fields, school yards, areas around public facilities and buildings, and highway medians and shoulders) and golf courses
- Irrigation of landscaped areas around family homes and nurseries
- Commercial activities—vehicle washing, window washing, concrete production
- Use for fire protection
- Toilet and urinal flushing in industrial, commercial, and residential buildings (especially high-occupancy facilities)
- Boiler-feed water, makeup water for evaporative cooling towers, and irrigation of facility grounds in industries that include textile production, chemical manufacture, petroleum products, and steel manufacture

An informative publication, USEPA's *Guidelines for Water Reuse* (1992), covers the current status of practice of urban nonpotable reuse. It includes all types of reclamation and reuse, and lists regulations and standards, state by state, as well as addressing international practices.

Potable reuse

The need for reducing freshwater withdrawal by reusing and reclaiming wastewater is growing. Population increases and diminishing freshwater sources will drive this need further in the coming years. How much wastewater reuse as potable water (with plant effluent piped directly into a potable water system) will occur is difficult to judge.

Potable reuse program success hinges on one major issue: public acceptance. The reclaimed water production can be technically feasible, approved by all concerned regulatory agencies, proven safe for human consumption, and still fail because public perception of the reclaimed water's quality.

In short, explaining to the public that they will eventually be drinking the same water they just flushed down their toilets is a hard sell. Public education is the answer to that problem, but another aspect of direct potable use is still not answered: health and safety concerns. The use of pipe-to-pipe water supply of reclaimed wastewater for human consumption involves concerns over chemical and pathogen transmission, a major constraint against direct potable reuse. We do not yet know the long-term con-

sequences of consuming water that has received such intensive chemical treatment. This is the biggest obstacle to pipe-to-pipe wastewater reuse.

Summary

Wastewater effluent is not the only possible wastewater process possible for reuse. Wastewater treatment involves both liquid and solid wastes. The treated wastewater effluent comprises the liquid half of wastewater treatment. Water solids treatment and wastewater biosolids treatment and reuse are the topics of Section IV.

section four

*Basics of water and wastewater
solids treatment and management*

chapter twenty-one

Water solids management

System overview*

Process purpose: Water treatment sludges

Surface water influent streams include solids, which must be removed and then somehow disposed. Two principal types of sludge result from water treatment: *coagulation sludge* and *softening sludge*. After large solids are separated from the raw water by screening, suspended solids and particulate matter remain in the influent until it is removed by coagulation and flocculation. More solids wastes are formed with water softening treatment. Other sludge sources in water treatment include grit from presedimentation, solids from filter backwash, from iron and magnesium removal, and from slow sand and diatomaceous earth filtration.

The conditions of coagulant sludge are dictated by the coagulant used—generally alum (aluminum sulfate). Separated from the raw water in the sedimentation step that follows coagulation and flocculation, these water solids contain alum floc, which makes a very fine sludge that presents dewatering problems. Coagulation sludges (commonly called alum sludge), produced from clarifier operations and from filter backwashing, are gelatinous and have high aluminum or iron salts concentration mixed with organic and inorganic solids. These solids are difficult to dewater, and in the past were released into water, where they caused environmental problems. Today, these wastes are processed and treated for ultimate disposal.

Softening sludges, the waste product of water softening, contain calcium carbonate and magnesium hydroxide precipitates mixed with organic and inorganic materials. Softening sludges dewater easily, and processing for disposal is standard practice (see Table 21.1).

* Source information in this chapter supplied from Pandit, M., and Das, S., *Sludge Disposal: Water Management Primer CE4124: Environmental Information Management*, Civil Engineering Department, Virginia Tech, 2011, <http://www.ce.vt.edu/enviro2/wtprimer/sldg/sldg.html>.

Table 21.1 Sludge Types and Concentrations

Sludge source and chemical additive	Solid concentration	
	before treatment	After thickening
Coagulation (alum)	1%	2%
Softening (lime)	1%	30%

Source: Adapted from AWWA, *Water Quality and Treatment*, 1990.

Water treatment sludge disposal regulations

While no federal regulations specifically target water treatment solids, several regulations affect use and disposal of these wastes. These include the Clean Water Act (CWA), Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR Part 257), Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and Clean Air Act (CAA). Direct discharges into a watercourse are controlled by the CWA. Any treatment facility that discharges waste into a receiving body of water must meet National Pollution Discharge Elimination System (NPDES) permit standards, in accordance with CWA Section 402. The other regulations govern other methods of disposal or use of solid wastes from water treatment. Individual states are responsible for setting state regulations that meet the federal requirements, and ensuring that the requirements are met (Burris and Smith, 1999, p. 2).

Alum sludge treatment processes

The coagulant solids are separated from the water by settling and collected for further treatment. In some locations, alum sludge is discharged into the sewerage system, where it is classified as an industrial waste, and can cause special considerations to work into the normal waste stream flow. In facilities that handle their own solids treatment, processes include thickening, conditioning, and dewatering before disposal.

Softening sludge (lime sludge) treatment processes

Because of the high volume of sludge softening produces, and because these sludges form lime deposits on wastewater collection and treatment facility components, lime sludge cannot be piped into sewerage systems for disposal.

Lime sludges are thickened, dewatered, and can be centrifuged and calcified into calcium carbonate and magnesium hydroxide. This recalcined lime is a usable product—quicklime.

Summary

To meet regulation requirements and ensure environmentally safe disposal, water treatment sludge must undergo treatment. We discuss the basics of treatment processes and disposal in Chapter 22.

References and recommended reading

- AWWA. 1990. *Water quality and treatment*.
- Burris, B.E., and Smith, J.E. 1999. Management of water treatment plant residuals for small communities: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, MO. Washington, DC: USEPA.
- Pandit, M., and Das, S. 2011. *Sludge disposal: Water management primer CE4124: Environmental information management*. Civil Engineering Department, Virginia Tech. <http://www.ce.vt.edu/enviro2/wtprimer/sldg/sldg.html>.

chapter twenty-two

Water solids treatment and disposal^{,†}*

Water sludge treatment processes

Water solids can be handled through a number of different processes, and a variety of disposal options are available. The process steps are thickening, coagulant recovery, conditioning, dewatering, drying, disposal and reuse, and recovered and nonrecovered water handling (for more on solids equipment and handling, see Chapters 23 and 24) (see Figure 22.1).

Alum sludge treatment

After sedimentation, the solids are mechanically raked from the tank bottom and piped away for treatment. Typically, water treatment sludges are partially dewatered, thickened, and conditioned, then disposed by landfill or, in some cases, land application. Because of the high aluminum content, alum sludge and cake are considered hazardous waste, and disposal must meet regulation requirements.

Alum sludge typically has a water content before treatment of 95 to 99%. The solids content (0.1 to 0.5% inorganic clays and various organic compounds, trapped in the alum floc) must be separated from the water content, often by using thickeners and settling ponds. Additional treatments with centrifuge or filters are also used. The dewatered sludge is then generally disposed by landfill.

Alum sludge presents difficulties in dewatering. The dewatered sludge frequently can have a water content of 75%. This raises transport and landfill costs, so more effective dewatering processes are of benefit.

* Source information from this chapter from Burris, B.E., and Smith, J.E., *Management of Water Treatment Plant Residuals for Small Communities: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop*, Kansas City, MO, USEPA, 1999.

† Pandit, M., and Das, S., *Sludge Disposal: Water Management Primer CE4124: Environmental Information Management*, Civil Engineering Department, Virginia Tech, <http://www.ce.vt.edu/enviro2/wtprimer/sldg/sldg.html>.

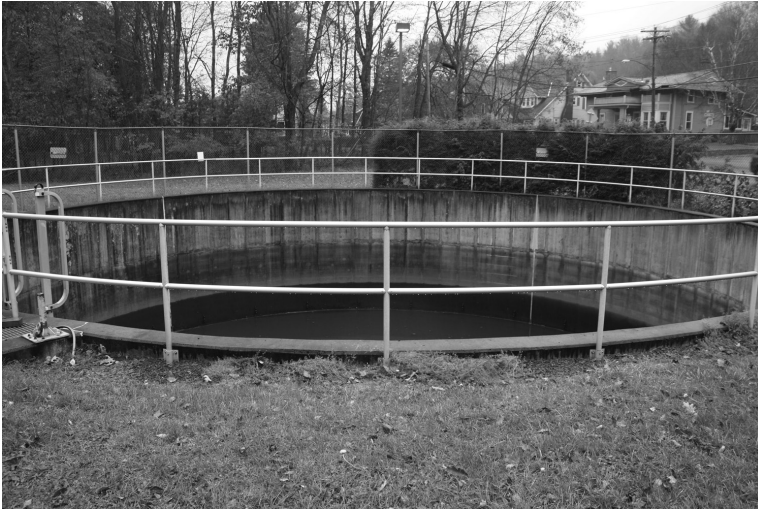


Figure 22.1 Sludge tank.

Thickening

Gravity thickeners are most commonly used to concentrate water sludges; however, flotation thickeners and gravity belt thickeners are also used. Thickening directly affects conditioning and dewatering processes.

Gravity thickening: In gravity settling tanks, sludges of a specific gravity of greater than 1% are flowed at a rate that allows the solids enough time to settle. Solids thickened by gravity may also need polymers in conditioning.

Flotation thickening: This solids handling method is effective for sludges of low-density particles. More common in wastewater bio-solids handling, the three types of flotation thickeners are currently attracting attention for treating water sludges. Dissolved air flotation (DAF), dispersed air flotation, and vacuum flotation all use air bubbles to absorb particles and float them to the surface for separation.

Gravity belt thickening: This emerging technology for the water industry involves direct discharge of sludge onto a horizontal porous screen. Gravity removes the water from the sludge as the sludge travels along the screen length. Polymers are generally necessary for effective solids capture with this technique.

Coagulant recovery

Acidification with sulfuric acid can be used for alum recovery; this is not a practice in common use.

Conditioning

Conditioning is effected by either physical or chemical treatment.

Physical conditioning: By heating the solids in a reactor or by freezing and thawing the solids, water bound to the particles can be released, increasing solids concentrations by up to 20%.

Chemical conditioning: In chemical conditioning, the addition of ferric chloride, lime, or polymers encourages particles to give up more of the water bound with them. It is common for most mechanical thickening or dewatering processes. Raw water quality, the coagulant used, pretreatment methods, the degree of solids concentration needed, and the thickening and dewatering processes used are considerations for choosing the type of conditioner and the dosage.

Dewatering

Water solids dewatering is typically accomplished by a variety of possible methods. These include air-drying methods and mechanical methods.

Air-drying: Methods of sludge dewatering that remove water by evaporation, gravity, or drainage (air-drying) are easy and generally inexpensive to operate (Table 22.1). However, they also require large land areas, are affected by climate, and can be labor-intensive. Air-drying methods in current use include sand drying beds, freeze-assisted sand beds, solar drying beds, vacuum-assisted drying beds, and lagoons.

Mechanical dewatering: Mechanical methods (Table 22.2) of sludge dewatering include belt filter presses, centrifuges, pressure filters, and vacuum filters (see Figure 22.2).

Drying

Drying can reduce transportation and disposal costs by reducing solids volume and water content. In some states, drying to a solids concentration of more than 35% before disposal is mandated by regulation. Drying can occur by either open air or mechanical means.

Open air: Lagoon or solar bed methods commonly used for drying. Evaporation mechanism is key to successful drying; some sludges can take years to reach the required concentrations.

Disposal

Ultimate disposal methods possible include land application, mono-fill or codisposal landfilling, direct stream discharge, sewer discharge,

Table 22.1 Air-Drying Dewatering Methods

Sand drying beds	Freeze-assisted sand beds	Solar drying beds	Vacuum-assisted drying beds	Lagoons
Gravity drainage of free water, then decanting and evaporation; cover beds in high rainfall areas	Freezing releases water and alters solids cellular consistency; bound water thaws and drains before solids thaw	Paved bed on porous subbase with sand drains on edges and in the center collects and drain water	Vacuum to underside of rigid porous media pulls free water through the media and leaves even, solid cake	Used for sludge storage, thickening, dewatering and drying, for final disposal; 1–3 months retention time
Max loading and minimum application and removal cycles for best use	High costs for mechanical freezing; economic advantage in cold climates	Can use heavy equipment for handling and removal	Problems with poor conditioning and incomplete media cleaning, and cake removal time	Large land mass needed; sand/solar bed modifications possible, cold climates adapt freeze methods
Effective for lime sludges; conditions for alum sludges	Effective dewatering method for difficult to dewater alum sludge	Mixing and aerating sludge speeds dewatering evaporation	Conditioned sludges can dewater to 11 17%	Alum sludges concentrate 6–10%; lime sludge, 20–30%

Source: Information derived from Burris, B.E., and Smith, J.E., Management of Water Treatment Plant Residuals for Small Communities: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, MO, USEPA, 1999, pp. 17–19.

Table 22.2 Mechanical Dewatering Methods

Belt filter presses	Centrifuges	Pressure filters	Vacuum filters
Porous belts pass over rollers of varied diameter, applying pressure to sludge to squeeze out water	Rotational forces in a cylindrical bowl separate solids from liquids, discharging solid cake and liquid centrate separately	Fixed volume recessed plate filters: A series of plates with recessed sections filled with sludge are pressed against filter media to retain solids and pass liquid	
Diaphragm filter presses: Combine high-pressure pumping with pressure chamber volume variation to further compress cake	Commonly used into the mid 1970s; used to a small extent currently for water solids		
Includes polymer conditioning for both lime and alum	Polymer conditioning for sludges	Lime added to alum sludge for conditioning; no conditioning needed for lime sludge	Reasonably effective for lime sludges; not effective for alum sludges
Effective for lime sludge (50–60% solids); alum sludge must be dewatered at low pressure (15–20% solids; certain conditions, 20–40%)	Alum dewatering rates vary according to sludge type and water source; lime sludges dewater effectively to 55–60%	Alum sludges dewater to 30–60%; lime sludges easily dewater to 50–70% solids from a 1–3 h cycle	

Source: Information derived from Burris, B.E., and Smith, J.E., Management of Water Treatment Plant Residuals for Small Communities: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, MO, USEPA, 1999, pp. 19–21.

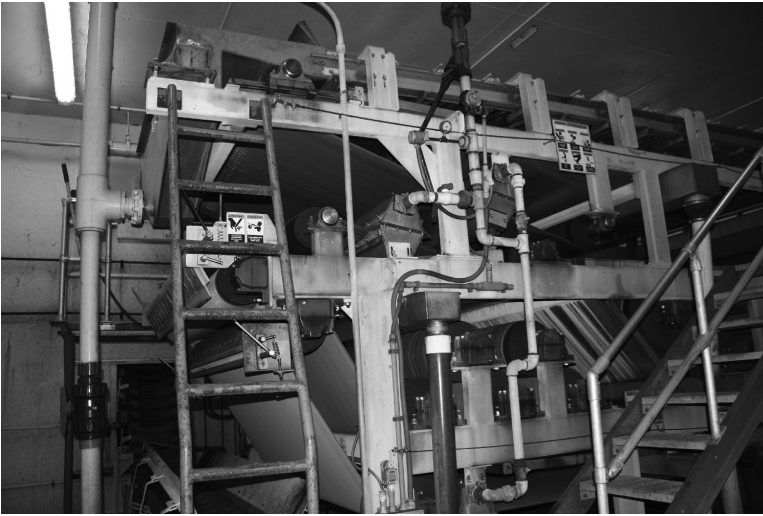


Figure 22.2 Belt filter press.

and residual reuse (Table 22.3). While water treatment solids do not have the fertilizer value that wastewater biosolids hold, some beneficial reuse is possible.

Recoverable and nonrecoverable water

The processes used to treat sludge separates the sludge into solid and liquid components. The liquid component must be returned to the water treatment processes, as long as it will not adversely affect the main treatment processes or finished water quality.

Summary

Biosolids systems, treatment, and disposal are covered in Chapters 23 to 25.

Table 22.3 Common Disposal Techniques

Land application	Landfilling	Direct stream discharge	Sewer discharge	Residual reuse
Agricultural land	Codisposal with municipal solid waste	Discharge to U.S. waters	Discharge to sewer ending at wastewater treatment plant (WWTP)	Coagulant recovery
Forestland	Daily landfill cover extender	Discharge to water district supply canal		Lime recovery
Marginal land	Monofill WTP residuals alone	Discharge to intermittent stream bed		Low solids—landscape nursery, turf farming
Designated site	Codisposal with WWTP solids	Discharge to dry arroyo		High solids brick making, portland cement

Source: Information derived from Burris, B.E., and Smith, J.E., Management of Water Treatment Plant Residuals for Small Communities: 6th National Drinking Water and Wastewater Treatment Technology Transfer Workshop, Kansas City, MO, USEPA, 1999, pp. 25–27.

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chapter twenty-three

Wastewater biosolids management

System overview

Process purpose: Wastewater biosolids treatment

Wastewater influent streams include solids, which must be removed and then somehow disposed: this now often ultimately involves beneficial reuse. Wastewater sludge or biosolids (the preferred term, as sludge implies a waste product and biosolids implies a substance with reuse value) must be properly treated, and biosolids management is an important part of wastewater treatment processes.

Beneficial reuse can mean that many treatment plants use biosolids reuse as a concrete and profitable treatment method of dealing with the solids that remain after wastewater treatment.

Sewage biosolids regulations

In the 1978 amendments to the Clean Water Act of 1972, the USEPA's 40 CFR Part 503 Final Rules for Use and Disposal of Sewage Biosolids came into effect. The final rules set forth a comprehensive program for reducing the potential environmental risks and maximizing beneficial biosolids use. In these final rules, the USEPA:

- Assessed the potential for pollutants in sewage biosolids to affect public health and the environment through a number of different routes of exposure
- Evaluated the risks posed by pollutants that might be present in biosolids applied to land, and considered human exposure through:
 - Inhalation
 - Direct ingestion of soil fertilized with sewage biosolids
 - Consumption of crops grown in the soil with sewage biosolids
- Assessed the potential risk to human health through contamination of drinking water sources or surface water when biosolids are disposed on land

Table 23.1 Composition of a Typical Raw Domestic Sewage

Raw Domestic Sewage (99.9% Water)					
0.1% Solids					
Organic 70%			Inorganic 30%		
Proteins 65%	Carbohydrates 25%	Fats 10%	Metals	Grit	Salts

Source: Adapted from Lester, F.N., in R. Harrison (ed.), *Pollution: Causes, Effects, and Control*, London, Royal Society of Chemistry, 1992, p. 33.

Process: Wastewater biosolids treatment

Wastewater biosolids are made up of solid particles suspended in water. Removing the water to the point that the remaining materials are easily handled is essential to biosolids treatment. This can be accomplished through drainage, thickening, or mechanical dewatering.

During wastewater treatment, the solids (sludge) are separated from the influent by settling and collected for further treatment (Table 23.1). The collected sludge is thickened and stabilized, which improves handling, removes pathogens, and reduces the organic content. Chemical (achieved by adding lime) or aerobic/anaerobic digestion is the method generally used in sludge stabilization. The stabilized sludge is conditioned and dewatered, then disposed via land disposal, composting, or incineration.

Public opinion and odor control

The major public relation problem associated with composting—and with wastewater processes in general—is reportedly the production of odors. At a biosolids composting facility, sensible odor control management must take into account all the areas and components of the composting process that might generate odors. While most odor problems are generated in the composting and curing process air systems, at enclosed composting operations, odors are also generated from ancillary processes within the enclosure. Enclosed systems must control or scrub airflow within the structure prior to outside environmental release. Open areas, including biosolids handling and mixing areas, can also cause odor control problems.

Odors generally do not present a problem until the neighbors complain. Long-established composting facilities may have enjoyed, at earlier times, few neighbors and thus a lack of public awareness of their facility and the odors generated by the composting process. If the local community has expanded and has become a close neighbor of an existing compost facility, and if the composting process is not carefully managed (controlled), the neighbors will complain. In short, if a community perceives a compost facility in its “backyard” as a potential nuisance that will

pollute the environment, decrease land values, and affect the quality of life, the struggle to bring the public onboard is not to be underestimated.

Summary

Though biosolids management is not a problem-free process, beneficial biosolids reuse does not merely present possible advantages. For many treatment plants, biosolids reuse is a concrete and profitable treatment method of dealing with that approximately 0.05% of wastewater influent that solids may comprise.

Reference and recommended reading

U.S. Environmental Protection Agency (USEPA). 1993. Standards for use or disposal of sewage sludge. Final rule, 40 CFR Part 503. *Federal Register* 58(32): 9248–15.

chapter twenty-four

Wastewater biosolids treatment

Biosolids *n* (1977) solid organic matter recovered from a sewage treatment process and used especially as fertilizer [or soil amendment]—usually used in plural.

—*Merriam-Webster's Collegiate Dictionary*,
10th edition (1998)

Note: In this text, *biosolids* is used in many places (activated sludge being the exception) to replace the standard term *sludge*. The authors view the term *sludge* as an ugly four-letter word inappropriate to use to describe biosolids. Biosolids is a product that can be reused; it has some value. Because biosolids has value, it certainly should not be classified as a waste product—and when biosolids for beneficial reuse is addressed, it is made clear that it is not a waste product.

Wastewater biosolids treatment and disposal alternatives

Turning sludge to biosolids is the goal of biosolids treatment before biosolids disposal. Alternative treatment methods and end uses are possible, and process selection depends on several factors, which include the nature of the sludge to be treated, the possible end uses, and of course, economic concerns. In ideal situations, biosolids management and disposal can have a positive effect on the municipality bottom line; in less than ideal circumstances, careful management and planning can keep costs down and provide environmentally sound alternatives to buying landfill space (for some of the alternatives available at different stages of treatment, see Table 24.1).

Turning sludge to biosolids involves thickening the sludge, reducing the sludge volume, controlling odor, killing pathogens, and removing water.

Thickening

Biosolids thickening is a physical process accomplished by gravity (solids are allowed to settle to the bottom), flotation (solids are floated to the top), or centrifugation. Biosolids thickening removes as much water as possible before other treatment processes, and increases treatment process efficiency.

Table 24.1 Biosolids Unit Processing Alternatives

Thickening	Stabilization	Conditioning	Dewatering	Disposal
Gravity	Anaerobic digestion	Chemical	Vacuum	Water
Flotation	Aerobic digestion	Thermal	Filtration	Landfill
Centrifugation	Thermal		Pressure filtration	Soil conditioning
	Chemical		Centrifugation	Composting Incineration

Gravity thickening

Similar to circular sedimentation basins in structure, gravity thickeners process thin biosolids concentrations to more dense biosolids. Gravity thickeners are usually used to handle watery excess biosolids from the activated biosolids process, and the process is common in plants where the biosolids are sent directly to digesters instead of to primary tanks. Gravity thickening can also concentrate biosolids from primary tanks, or a mixture of primary and excess biosolids prior to high-rate digestion.

Gravity thickening tanks generally house slowly moving biosolids scrapers with an attached vertical picket-fence-like structure. This moving structure agitates the biosolids and dislodges entrapped liquid and gas bubbles (McGhee, 1991). Biosolids are pumped continuously from the settling tank to the thickener, which has a low overflow rate. The excess water overflows and solids concentrate on the bottom. This method can produce biosolids with a solids content of 10% or more from an original solids concentration of 2% (see Figure 24.1).

Flotation thickening

In flotation thickening, a tiny air bubble attaches to suspended solid particles, causing the solids to separate from the water and float. With the air bubble, the solid particles have a specific gravity lower than water's.

Dissolved air flotation depends on forming small-diameter bubbles under pressure. Current flotation practice uses two general approaches to pressurization: (1) air charging and pressurization of recycled clarified effluent or some other flow used for dilution, with subsequent addition to the feed biosolids, and (2) air charging and pressurization of the combined dilution liquid and feed biosolids (see Figure 24.2).

Variables that affect flotation thickening systems include the type and quality of the biosolids used, pressure, feed solids concentration, recycle ratio, detention time, air-to-solids ratio, solids and hydraulic loading rates, and chemicals.

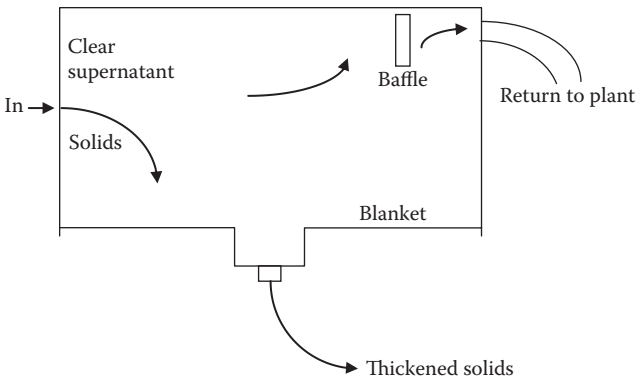


Figure 24.1 Gravity thickener.

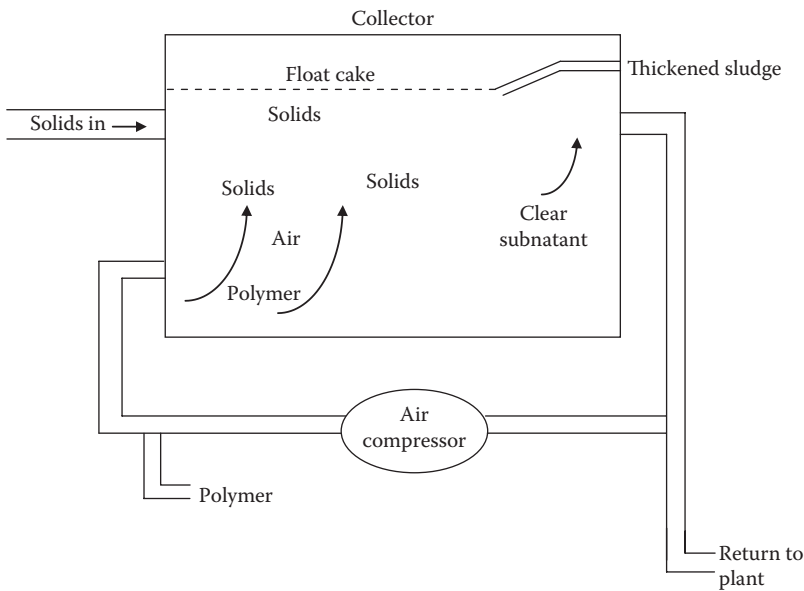


Figure 24.2 Flotation thickener.

Flotation thickening works best for activated biosolids. Equal or greater concentrations may be achieved by combining biosolids in gravity thickening units.

Centrifugation

As mentioned, centrifugation used in dewatering can also thicken a variety of biosolids, though for thickening purposes, it is generally limited to processing waste activated biosolids (Metcalf and Eddy, 1991). Centrifuges are compact, simple, flexible, self-contained units with relatively low capital costs, high maintenance and power costs, and poor solids capture efficiency without chemical use.

Stabilization

Stabilizing biosolids reduces the volume of the thickened biosolids further, eliminates offensive odors, reduces the possibility of putrefaction, and renders the remaining solids relatively pathogen-free (Peavy et al., 1991). Biosolids stabilization can be accomplished by anaerobic digestion, aerobic digestion, and thermal and chemical methods.

Anaerobic digestion

Anaerobic digestion biosolids digestion is carried out in the absence of free oxygen by anaerobic organisms—in short, anaerobic decomposition. The solid matter in raw biosolids is about 70% organic and 30% inorganic. Much of the water in wastewater biosolids is “bound” water, unable to separate from the solids. Facultative and anaerobic organisms break down the molecular structure of these solids and set free the bound water.

Anaerobic digestion can be simplified to two steps: (1) conversion of organic materials to volatile acid wastes, and (2) conversion of volatile acids into methane (Haller, 1995).

In the first step (waste conversion), acid-forming bacteria attack soluble or dissolved complex solids (fats, proteins, and carbohydrates), forming organic acids and gases such as carbon dioxide and hydrogen sulfide in a rapid process called *acid fermentation*. In the *acid digestion* process that follows, acid-forming bacteria attack the organic acids and nitrogenous compounds, liquefying (creating supernatant liquid) at a much slower rate (Masters, 1991).

In the second stage (the period of intensive digestion, stabilization, and gasification), the more resistant nitrogenous materials (the proteins, amino acids, and others) are attacked by methane-forming microorganisms, which produce large volumes of gases with a high percentage of methane (CH_4) and carbon dioxide. The relatively stable remaining solids are only slowly putrescible, and can be disposed of without creating

objectionable conditions. They have value in agriculture via liquid land application and compost.

Anaerobic digesters are airtight cylindrical, rectangular, or egg-shaped tanks in which digestion occurs. Standard rate, high-rate, and two-stage digesters are common. The most inefficient and unstable digesters, standard rate digesters generally do not heat or mix the sludge. High-rate digesters heat the sludge to optimum temperature and increase digestion rates by mixing. Two-stage digesters separate digested solids from the supernatant liquid, sometimes achieving high-rate digestion levels.

Aerobic digestion

An extension of the activated biosolids aeration process, in aerobic digestion (Table 24.2), waste primary and secondary biosolids are continually aerated for long periods. During this extended aeration, the microorganisms enter a phase (the endogenous stage) where materials

Table 24.2 Advantages and Disadvantages of Aerobic Digestion

Advantages	Disadvantages
Produces a humus-like, biologically stable end product	High power costs
Produces an end product with no odors; thus simple land disposal is feasible	Requires the supply of oxygen, which is energy-consuming
Can be accomplished with low capital costs compared to anaerobic and other digestion methods	Does not always settle well in subsequent thickening processes
Produces sludge with good dewatering characteristics that drain and redry well in sand drying beds	Does not dewater easily by vacuum filtration
Produces volatile solids reduction levels equal to anaerobic digestion	Variable solids reduction efficiency with varying temperature changes
Produces supernatant liquors with a lower biochemical oxygen demand (BOD) (generally lower than 100 ppm) than anaerobic digestion	
Fewer operating problems than from anaerobic methods, requiring less skilled labor for facility operation	
Recovers more of the biosolids basic fertilizer values than anaerobic digestion	

Source: Adapted from Metcalf and Eddy, Inc., *Wastewater Engineering: Treatment, Disposal, and Reuse*, 3rd ed., New York, McGraw-Hill, 1991.

previously stored by the cell oxidize, reducing the biologically degradable organic matter.

In simple terms, in the endogenous stage, food supplies to microbial life are depleted to the point where the microorganisms begin to consume their own protoplasm, oxidizing it to carbon dioxide, water, and ammonia. As the digestion process continues, the ammonia is further converted to nitrates. Eventually, the oxygen uptake rate levels off and the biosolids matter is reduced to inorganic matter and relatively stable volatile solids.

Aerobic digestion is affected by biosolids temperature, rate of biosolids oxidation, biosolids loading rate, system oxygen requirements, biosolids age, and biosolids solids characteristics.

Thermal stabilization

In thermal stabilization, the bound water in the biosolids is released by heating the biosolids in a pressurized tank for short periods of time. Thermal treatment is used for both stabilization and biosolids conditioning.

Exposing the biosolids to heat and pressure coagulates the solids, breaks down the cell structure, and reduces both hydration and the hydrophilic (water-loving) nature of the solids. Liquids can then be separated from the biosolids by decanting and pressing.

Chemical application

In chemical stabilization, the biosolids mass is treated with chemicals to stabilize the solids. Chemical costs can be high (in some cases cost-prohibitive).

Chlorine stabilization

The chemical reactions that occur in chlorine stabilization happen almost instantaneously. A high dose of chlorine gas applied directly to the biosolids in an enclosed reactor produces stabilized biosolids. Chlorine stabilization produces some breakdown of organic material, and forms carbon dioxide and nitrogen, with little volatile solids reduction.

Total solids, suspended solids, and volatile solids concentrations are similar to that of the raw biosolids. Chlorine-treated biosolids have a low pH value and require pH adjustment before conditioning. They may also contain undissolved heavy metals and chlorinated compounds, limiting their suitability for land application. For these reasons, chlorine stabilization is not often used for biosolids stabilization.

Lime stabilization

Lime stabilization (successfully used for many years) can be used to treat raw primary, waste activated, septage, and anaerobically digested

biosolids. Lime works by increasing the pH to levels high enough to destroy most microorganisms and to limit odor production. Lime stabilization denatures organic matter; it does not destroy it, so the treated sludge must be disposed before it putrefies.

The process involves mixing a large enough quantity of lime with the biosolids to increase and sustain the pH of the mixture to 12 or more. Along with reducing bacterial hazards and odor to negligible levels, lime stabilization also improves vacuum filter performance, provides a satisfactory means of stabilizing biosolids prior to ultimate disposal, and by maintaining the pH above 12 for 2 h or more, substantially improves the total reduction in microorganisms over that obtained in digestion processes (McGhee, 1991).

Conditioning

In biosolids conditioning, the solids are treated with chemicals or various other means to improve production rate, cake solids content, and solids capture, all of which prepare the biosolids for dewatering processes. Several different biosolids conditioning processes are available; the most commonly used are chemical addition and heat treatment.

Chemical conditioning

Chemical conditioning (biosolids conditioning) prepares the biosolids for better and more economical treatment with dewatering equipment by reducing the biosolids moisture content from 60 to 85%. Chemicals used for conditioning include organic polymers, alum, ferrous sulfate, and ferric chloride, with or without lime, and others, all of which are more easily applied in liquid form (Metcalf and Eddy, 1991). The choice of chemical type to use depends on the nature of the biosolids to be conditioned, and local costs.

Adding chemicals to the biosolids lowers or raises its pH value to the point that small particles coagulate into larger ones, and the biosolids give up water more readily. pH values vary with the chemical used, and different biosolids (primary, secondary, and digested biosolids) and even different biosolids of the same type have different optimum pH values (for more information of chemical feeders, see Chapter 14).

Thermal conditioning

Thermal conditioning destroys the biological cells in biosolids, which “permits a degree of moisture release not achieved in other conditioning processes” (McGhee, 1991, p. 497). The two most common basic processes for thermal treatment in current use are wet air oxidation and heat treatment.

Table 24.3 Thermal Conditioning: Wet Air Oxidation

Advantages	Disadvantages
Does not require preliminary dewatering or drying	Oxidized ash must be separated from the water in an additional process
Produces a more readily dewaterable biosolids than with chemical conditioning	Heat treatment ruptures the cell walls of microbial organisms, releasing bound organic material and creating the added problem of treating a highly polluted liquid side stream from the cells
Provides effective biosolids disinfection	High initial capital costs
	Higher levels of competence and training of operating personnel
	Significant production of odorous gases

In wet air oxidation, biosolids are flamelessly oxidized in a reaction vessel at temperatures between 450 and 550°F, and at pressures of about 1,200 psig. Heat treatment is similar to wet air oxidation; however, heat treatment temperatures fall between 350 and 400°F, with pressures of 150 to 300 psig (Table 24.3).

Both these processes release water that is bound up in the biosolids, facilitating the dewatering process (Davis and Cornwell, 1991). Wet air oxidation reduces the biosolids to an ash and heat treatment improves the dewaterability of the biosolids. Heat treatment is more widely used than the oxidation process.

Dewatering

According to the USEPA (1982), the objectives of dewatering “are to remove water and thereby reduce the [biosolids] volume, to produce a [biosolids] which behaves as a solid and not a liquid, and to reduce the cost of subsequent treatment and disposal processes” (p. 2).

Dewatering also:

- Reduces need for space, fuel, labor, equipment, and size of the composting facility
- Affects the amount of bulking agent needed for composting
- Lowers costs for transporting biosolids

Biosolids dewatering can be accomplished in a variety of ways. When the necessary land space is available for small quantities of sludge, lagoons and drying beds are a good option. For large quantities of sludge,

a variety of mechanical methods are common. These mechanical methods include vacuum filtration, pressure filtration and centrifuging (Qasim, 1999, pp. 728–34).

Natural dewatering methods

Sludge drying beds and lagoons are a low-cost dewatering option commonly used in small to medium-sized systems where land use issues are not a factor. The oldest technique for dewatering, new methods have improved drying bed efficiency, and are making this option more attractive for large plants as well. Sand beds, paved beds, wire-wedge, and vacuum-assisted drying beds are now available. In general, drying beds offer drying times of constant and rapid drainage for the more sophisticated wire-wedge and vacuum-assisted drying beds, compared to 30 to 40 days for conventional drying beds. Solids capture ranges from 60 to 70% for sand drying beds to 90 to 100% capture for paved beds.

Lagoons are similar to drying beds in that the dewatered biosolids is removed periodically, and the lagoon reused. Climate and sludge depth affect evaporation time. In general, 3 to 6 months is needed to reach a solids level of 20 to 40%. Solids capture can achieve 90 to 100%.

Mechanical dewatering methods

Mechanical methods offer advantages of speed in processing, but are generally more costly in terms of equipment.

Vacuum filtration

Vacuum filtration for biosolids dewatering involves laying filtering media (a cloth of cotton, wool, nylon, fiberglass, a plastic or stainless steel mesh, or a double layer of stainless steel coil springs) over a drum. The drum (on a horizontal axis) is submerged to about one-fourth its depth in a tank of conditioned biosolids. As a portion of the drum rotates slowly in and out of the biosolids, an arrangement of valves and piping functions to apply a vacuum to the inner side of the filter medium. This draws water out of the biosolids and holds the biosolids against the media surface. The vacuum's pressure continues while the drum rotates, carrying the biosolids into the atmosphere, pulling water away from the biosolids. A moist mat or cake remains on the drum's outer surface, which is scraped, blown, or lifted away from the drum just before the drum rotates again into the biosolids tank (see Figure 24.3).

Pressure filtration

Two types of pressure filtration systems are common: belt filter (see Figure 24.4) or recessed plate filter presses. In either pressure system,

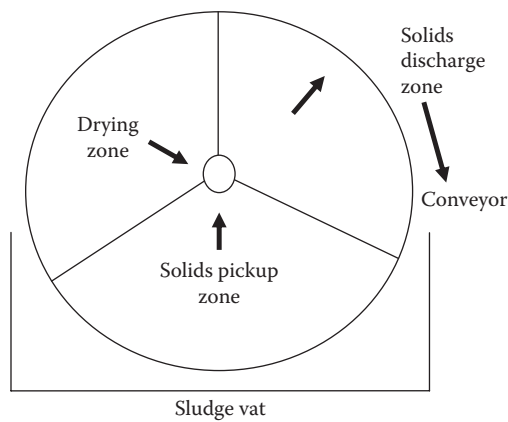


Figure 24.3 Vacuum filter.

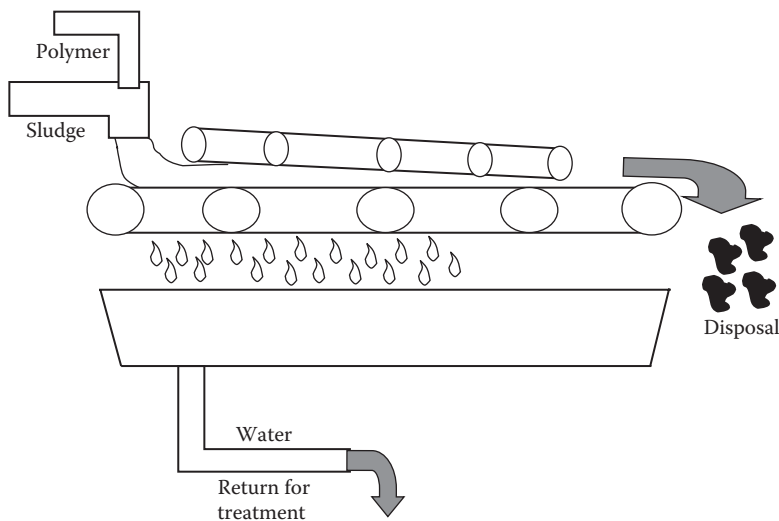


Figure 24.4 Belt filter press.

Table 24.4 Pressure Filtration Advantages and Disadvantages

Advantages	Disadvantages
Can be accomplished quickly in a small space	Batch operation
Good performance (>30% cake solids in some cases) when compared to the vacuum filter (18% cake solids produced in some cases)	High operation and maintenance costs

the filtration method resembles vacuum filtration. While recessed plate filter press units are most common, belt filter press usage has increased (Table 24.4).

As in vacuum filtration, recessed plate filter presses use a porous media to separate biosolids from water. Captured solids in the media pores build up on the media surface. Biosolids pumps provide the energy to force the water through the media.

Centrifugation

In centrifugation, solids separate from liquid through sedimentation and centrifugal force. In a typical unit, the biosolids mass feeds via a stationary feed tube along the centerline of the bowl through a screw conveyor hub. The screw conveyor, mounted inside the rotating conical bowl, rotates at a slightly lower speed than the bowl. As biosolids leave the end of the feed tube, they are accelerated, pass through ports in the conveyor shaft, and distribute to the bowl periphery. The solids settle through the liquid, compact by centrifugal force against the walls of the bowl, and the screw conveyor carries them to the bowl's drying (or beach) area, an inclined section where further dewatering occurs before the solids discharge. The separated liquid discharges continuously over adjustable weirs at the bowl's opposite end (Figure 24.5).

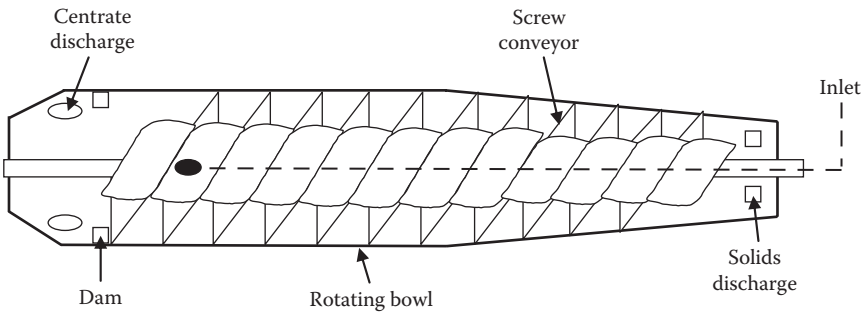


Figure 24.5 Centrifuge.

Summary

The thickened, stabilized, conditioned, and dewatered remains of what was once sludge are now ready for one of several disposal methods. These alternatives are covered in Chapter 25.

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chapter twenty-five

Wastewater biosolids disposal

Disposal alternatives

With or without biosolids thickening, stabilization, conditioning, or dewatering, wastewater treatment facilities must have a plan or routine to follow in disposing of treated or untreated biosolids (Table 25.1).

Biosolids produced during the wastewater treatment process may contain concentrated levels of contaminants originally contained in the wastewater. Any disposal method must take these contaminants into account. In ultimate disposal, the goal must not be to merely shift the original pollutants in the waste stream to a final disposal site where they may become free to contaminate the environment. Effective biosolids disposal involves economically and environmentally sound disposal or reuse that adheres to the EPA's 40 CFR Part 503 Final Rules for Use and Disposal of Sewage Biosolids.

Disposal methods

Methods for the disposal of biosolids include:

- Disposal in water (no longer permitted)
- Disposal on land
- Reuse as a fertilizer or soil conditioner
- Reuse in land reclamation projects
- Reuse in composting
- Incineration and ash disposal

Water

Water or ocean disposal was once thought an economical method of biosolids disposal, used by communities in coastal areas or along major rivers. It is now illegal. Common practice for biosolids disposal (raw or digested) was to either pipe it directly offshore or pump it to barges that carried it to deep water, distant enough from the shore so that dilution would (hopefully) prevent shoreline problems.

As sewage biosolids quantities increased, so did pollutional loads. When ocean-dumped biosolids began to creep back toward the shore,

Table 25.1 Biosolids Management Options

Use/disposal practice	Mass of sewage biosolids used/disposed by POTW size			
	>100 mgd	10–100 mgd	1–10 mgd	<1 mgd
Landfill	518.4	673.6	495.4	110.4
Land application	387.7	664.7	538.1	178.1
Surface disposal	79.5	264.6	122.1	87.2
Incineration	382.8	346.3	124.7	10.5

Source: USEPA, *Standards for Use or Disposal of Sewage Sludge*, 1993, pp. 9248–9415.

affecting beaches along the upper East Coast of the United States, the obvious problems inherent in ocean disposal caused widespread concern. The dumping of sewage biosolids was prohibited by Congress in 1992.

Land

Interest in biosolids disposal on land increased when ocean dumping was prohibited, and when new air quality regulations began to impact biosolids incineration. Common (and closely regulated) methods of land disposal include:

- Landfilling
- Application as fertilizer or soil conditioner
- Land reclamation

Landfilling

Once widely used, landfilling with biosolids is rapidly becoming a past practice, the result of two major influences:

- Large, densely populated areas are running out of space in landfills for any type of waste.
- USEPA 503 regulations directly affect disposal methods for wastewater biosolids.

Biosolids fill is confined almost entirely to well-digested biosolids with no applicable amount of raw or undigested mass. These digested biosolids can be exposed to air without creating serious or widespread odor nuisances.

With three common disposal methods no longer always feasible because of regulation or costs, beneficial reuse through land disposal became a much more attractive possibility.

Table 25.2 Soil Conditioning and Fertilizing with Land Applied Biosolids

Advantages	Disadvantages
Can contain as much nitrogen and phosphorus as farmyard manure; is agriculturally valuable	Nutrient content of sewage biosolids varies greatly and is always lower in potassium than farmyard manure
Recycles nutrients, including nitrogen, phosphorous, and potassium	Often contains nonessential metallic elements in quantities possibly toxic to plants and animals
Provides traces of other nutrients considered more or less indispensable for plant growth, including calcium, copper, iron, magnesium, manganese, sulfur, and zinc	Can contain heavy metals and other toxic agents; applied too often and for too long, increases in the levels of heavy metals, including copper, cobalt, boron, lead, mercury, and others; these toxins are not easily removed
Relatively simple to accomplish at a relatively reasonable cost	
Reduced disposal costs	
Humus-like quality furnishes plant food, and increases water holding capacity and tillage, improving heavy soils for seed bed use	
Helps to reduce soil erosion	

Land application: Soil conditioning/fertilizing

Land application of biosolids is popular because it is relatively simple to accomplish at a relatively reasonable cost (Table 25.2).

On estimate, the fertilizer nitrogen requirements of about 0.35 million ha (2.5 acre = 1 ha) of cropland could be supplied with sewage biosolids (Laws, 1993). In short, all the sewage biosolids the United States produces could provide only a small fraction of the annual fertilizer nitrogen required for U.S. crop production.

Land reclamation

Biosolids land application's most dramatic success has been strip-mined land restoration (Laws, 1993). Establishing vegetation on such land is extremely difficult, because typically, strip-mined land lacks nutrients and organic matter, has low pH and poor water retention, and often contains high levels of toxic metals in the soil (Sopper and Kerr, 1981).

In 1993, an estimated 15 to 20% of municipal sewage biosolids was applied to land (Laws, 1993). Biosolids applied to restore lands devastated through strip mining and other activities is an ecologically beneficial practice, and also a very practical disposal method.

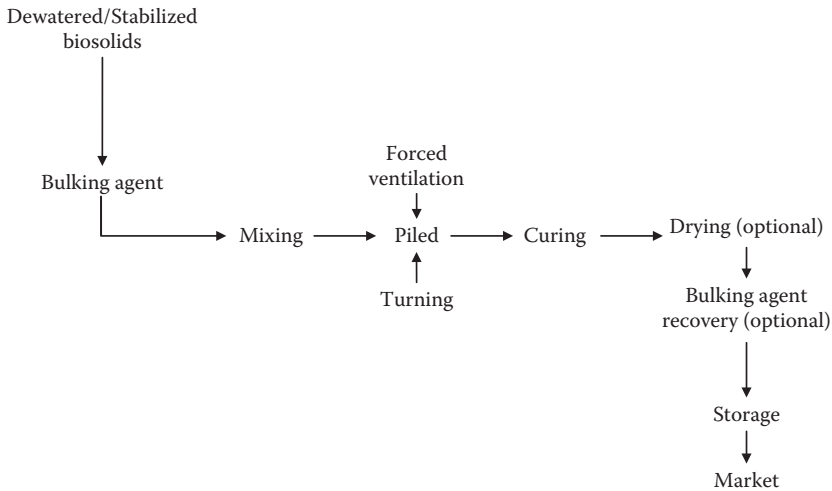


Figure 25.1 Flow diagram for composting biosolids.

Composting

Composting, a process that converts organic wastes into a soil amendment, has been known to be useful since ancient times (see Figure 25.1). When organic wastes are partially decomposed by bacteria, worms, and other living organisms, the result is a valuable fertilizer and soil conditioner. Composted materials were and are used to prevent erosion, provide nutrients to the soil, and replenish depleted organic matter lost through farming (Corbitt, 1990).

With several alternate biosolids disposal methods outlawed, unwanted, or declared unsafe, composting has become an attractive option for waste disposal. Today, with the use of treatment methodologies that include heat-drying, treatment with alkaline materials, and composting, municipalities convert biosolids into useful products safe for unrestricted public use.

Biosolids composting has four goals:

- To stabilize the product
- To control odor
- To dry the material enough to handle
- To raise the biosolids temperature high enough to kill pathogens

Aerated static pile composting

In the *static aerated pile method* of composting, the homogenized mixture of bulking agent (coarse hardwood wood chips) and dewatered biosolids

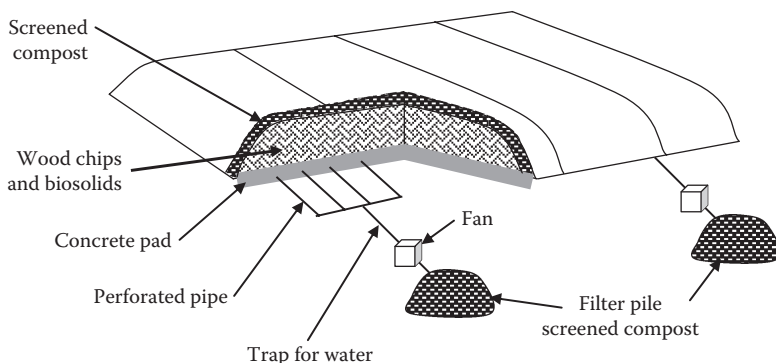


Figure 25.2 Aerated static pile.

is piled by front-end loaders onto a large concrete composting pad. There, the mixture is mechanically aerated via PVC plastic pipe embedded within the concrete slab. In a 26-day active composting period, adequate air and oxygen supports aerobic biological activity in the compost mass and reduces the compost mixture's heat and moisture content (see Figure 25.2).

Aeration is an important process control parameter in the aerated static pile composting system.

- It supplies oxygen for biological degradation of organic solids in the biosolids and wood chips (aerated static pile or ASP model).
- It removes heat generated by the biological activity in the compost pile and excess moisture from the compost mix.
- Improperly aerated composting leads to the onset of anaerobic conditions and putrefactive odors.

Curing and drying

After 26 days, the compost is dried or cured, or a combination of both.

In curing, compost stabilizes as microorganisms metabolize the nutrients that remain in the mixture. A 30-day curing period is required before final sampling/testing and distribution. Generally considered an extension of aeration processes, curing and any subsequent storage can create elevated temperatures, although somewhat lower than average temperatures associated with initial composting. Curing ensures total odor dissipation and total pathogen destruction. The cured compost product should not have an unpleasant odor.

Drying (accomplished by drawing or blowing air through aeration pipes in troughs, by mechanical mixing, or using a combination of these methods) is optional, but is usually necessary if compost is to be recycled as a bulking agent or if screening is required. Drying can occur in a roofed

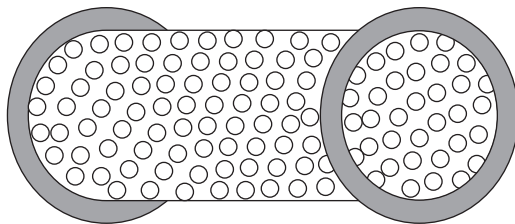


Figure 25.3 End view of trommel screen.

drying shed or structure to protect the compost from inclement weather, or if weather conditions permit, on any hard surface area.

Screening

Specialized screening equipment separates compost from the wood chips after curing or drying, recycling the wood chips for reuse. The compost moves to distribution for marketing in bulk or bags.

The most common compost screening devices are shaker screens and trommel screens.

Shaker screens

Shaker screens move and shake up and down, sifting the compost through the screen and separating the wood chips to another location. Screen size depends on bulking agent size.

The major disadvantage of shaker screens is their tendency to clog and the extensive amount of maintenance required to keep them online.

Trommel screens

Trommel screens (long cylindrical rotating screens) are usually placed on an angle so that materials flow through them. Trommel drums rotate on wheels and generally can be tilted from 3 to 12°. Large brushes mounted on top of the trommel drum extend through the screen to prevent clogging, making the trommel unit self-cleaning.

In the trommel drum, compost materials and bulking agents separate by a tumbling action. The smaller compost materials fall through the grate while the bulking agent eventually discharges at one end. Screened compost collects on an underbelt conveyor system that travels the length of the trommel drums. Conveyors transport both wood chips and compost from the screens (see Figure 25.3).

Incineration

Biosolids incineration (the complete destruction of biosolids by heat) is not actually a means of disposal, but of volume reduction to ash, a reuse

product (a resource) with some value. Incinerating biosolids is not only a beneficial process; it produces a beneficial reuse product: *biosolids ash*.

Incineration advantages

Compared to several other biosolids management options (especially land-filling or lagoons), biosolids incineration presents some obvious advantages:

- Reduces biosolids volume and weight
- Provides immediate reduction with long-term residence times
- Avoids transportation costs (on-site incineration)
- Controlled air discharges and abiding by regulatory requirements maintains air quality
- Leaves sterile and thus usually harmless ash residue
- Requires relatively small disposal area compared to land requirements for lagoons or land burial (Brunner, 1984)

Incineration process

Biosolids incineration can occur in four steps:

1. Biosolids temperature raised to 212°F
2. Water evaporates from the biosolids
3. Increase water vapor temperature and air temperature
4. Biosolids temperature elevated to the ignition point of the volatiles (USEPA, 1978, p. 5)

A key factor in incineration is the solids content of the biosolids. Before incineration, the biosolids must be dewatered (often by centrifugation), because even though the heat value of biosolids is relatively high, excessive water content means auxiliary fuel must be used to maintain incinerator combustion (USEPA, 1978). Providing auxiliary fuel impacts incinerator operation economics. Increased solids content directly affects the net heat value of the feedstock, allowing autogenous (self-sustained) combustion and eliminating auxiliary fuel costs.

Types of incinerators

Four different types of incinerators are currently commonly used for biosolids incineration: the multiple-hearth furnace (MHF), fluid bed furnace (FBF), cyclonic furnace (single-rotary furnace), and electric furnace (EF). While the multiple-hearth furnace is most commonly used for biosolids incineration, most new installations are fluid bed furnaces. Cyclonic and electric furnaces are not commonly used in the United States for biosolids incineration.

Multiple-hearth furnaces (MHFs)

The multiple-hearth furnace (MHF) provides easy operation, and good capacity for handling wide fluctuations in feed loading rate, and biosolids cake of differing quality. Vertically oriented and cylindrically shaped (see Figure 25.4), multiple-hearth furnaces are refractory lined with a steel shell, and contain several (from 4 to 14) horizontal refractory hearths, one above the other.

In multiple-hearth furnaces, a central shaft (which contains a fan-fed inner tube called the cold air tube) runs the height of the furnace. The central shaft supports rabble arms (toothed scrapers or plows) above each hearth, with either two or four rabble arms per hearth. The rabble arms rotate, and rake the biosolids spirally across the hearth. Each rabble arm connects to the cold air tube and has a return tube to send the heated cooling air to the space between the cold air tube and the central shaft's shell (an exhaust passageway for the cooling air). Returned (heated) cooling air enters the lowest hearth again as preheated combustion air.

In typical MHF operation, biosolids fed at the periphery of the top hearth are raked toward the center, then drop to the hearth below. The second hearth drop holes are at the periphery of the bed, and biosolids are raked outward to drop to the next hearth. Alternating drop-hole locations on each hearth, and countercurrent airflow or rising exhaust gases and descending biosolids provide good contact between the hot combustion gases and the biosolids feed to ensure complete combustion.

Usually divided into four distinct zones, multiple-hearth furnaces provide a series of combustion chambers (Table 25.3). In the first zone (*drying zone*), most of the remaining water evaporates. The *zone of combustion* (at the central hearths) burns the biosolids at temperatures that range from

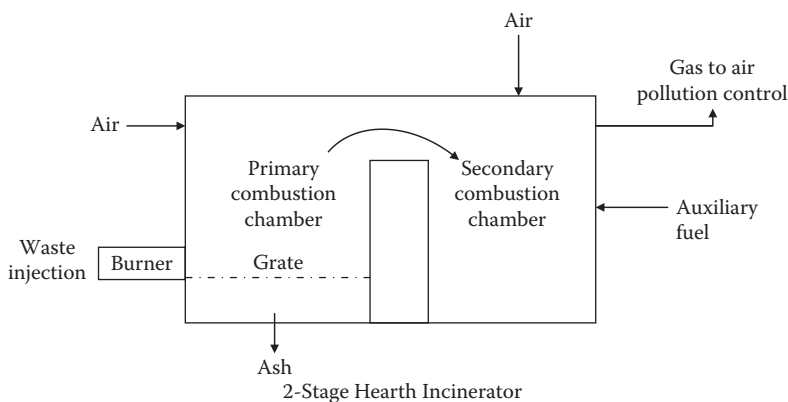


Figure 25.4 Hearth incinerator.

Table 25.3 Multiple-Hearth Furnace Operations

Zones	Operation
Drying zone	Dewatered solids supplied at top hearth outer edge Rotating rabble arms move the solids slowly to the hearth center Solids dry by hot gases produced by burning on lower hearths Dry solids pass to the lower hearths (may take several hearths) Process repeats, but this time from inside edge to outside edge
Combustion zone	High temperature on the lower hearth ignites the solids Burned solids pass to the lower hearths (may take several hearths) Burning continues to completion
Fixed carbon burning zone	Carbon oxidizes to carbon dioxide Ash passes to the lower cooling hearths
Cooling zone	Ash temperatures decrease from withdrawing heated air Ash is discharged for disposal or reuse Internal equipment is continuously cooled by air flowing inside center column and rabble arms

1,400 to 1,700°F. In the *fixed carbon burning zone*, carbon oxidizes to carbon dioxide, and in the *cooling zone*, reinjecting heat to the incoming combustion air cools the ash residue. Although the sequence of these zones is always the same, the numbers of hearths in each zone depends on feed-stock quality, operational conditions, and furnace design (USEPA, 1978).

Fluid bed furnace (FBF)

Fluid bed furnaces are vertically oriented, cylindrically shaped, refractory-lined steel shells (reactors) that contain a sand bed (media) and fluidizing air diffusers (orifices). They range in size from 9 to 25 ft in diameter (see Figure 25.5 for cross section). At rest, the sand bed is approximately 2.5 ft thick. It rests on a refractory-lined grid or brick dome that provides orifices (truyere) through which air is injected into the bed at pressure to fluidize the bed, expanding it by approximately 80 to 100%. Sand bed temperature is kept between 1,400 and 1,500°F by auxiliary burners. Some installations include heat control by water spray or a heat removal system.

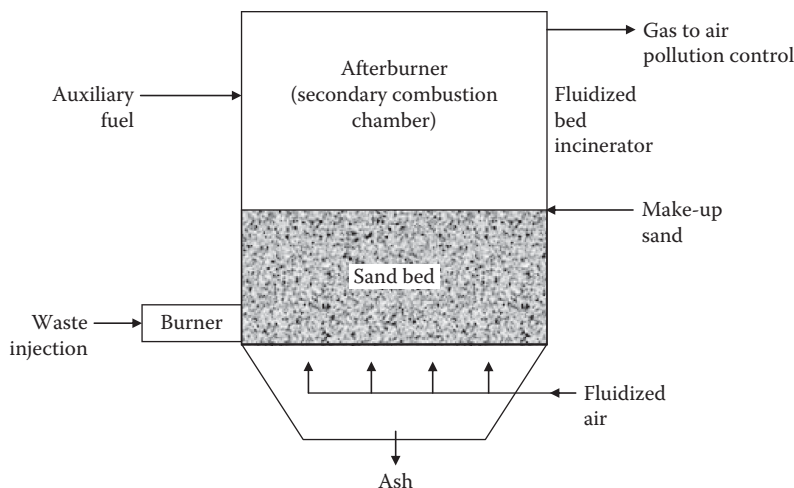


Figure 25.5 Fluidized bed incinerator.

Table 25.4 Fluid Bed Furnace Operations

Operation	
1	Air is pumped into the bottom of the unit.
2	Airflow expands (fluidizes) the sand bed.
3	Fluidized sand bed heats to between 1,200 and 1,500°F.
4	Auxiliary fuel added when needed to maintain temperature.
5	Solids injected into the heated sand bed.
6	Moisture immediately evaporates.
7	Organic matter ignites and reduces to ash.
8	Residues grind to fine ash by sand movement.
9	Fine ash particles flow up and out with exhaust gases.
10	Air pollution control processes remove ash particles.
11	Exhaust gas stack oxygen analyzers control airflow rate.

In fluid bed furnaces (Table 25.4), ash is carried to the furnace top and removed by air pollution control devices. Sand carried out with the ash must be replaced. Biosolids enter the furnace either above or directly into the sand bed.

Fluid bed furnace excess air requirements reduce supplemental fuel needs and reduce heat losses from heating and exhausting excess air. Complete contact between biosolids solids and the combustion gases occurs through mixing caused by airflow through the bed and direct sand bed biosolids injection. The high amount of retained heat in the sand means the system can operate as little as 4 h per day with little or no reheating.

Cyclonic furnace

Cyclonic furnaces are vertically oriented, single-rotary hearth furnaces with cylindrically shaped, refractory-lined domed steel shells. Cyclonic furnaces use one rotating hearth and a fixed rabble arm (scraper). A screw-type feeder deposits the biosolids near the periphery of the rotating hearth, and the rabble arm moves biosolids materials from the outer edge of the hearth to the center, where it discharges as ash.

Cyclonic furnaces have the advantage of low capital costs and low fuel requirements. A competitive alternative furnace for biosolids incineration, cyclonic furnace's high exhaust temperatures allow for easier compliance with air quality standards than the other furnace types.

Electric furnace

Electric or infrared (radiant heat) furnaces operate using horizontal conveyors. A steel alloy woven wire belt passes through a rectangular refractory-lined chamber equipped with electrical radiant heating elements. Furnaces range from 4×20 ft to 9.5×100 ft in length.

Electric furnaces are usually divided into feed, drying, combustion, and ash discharge zones. Because electric furnaces can provide complete burn of the biosolids without agitation, they generate very low levels of particulate emissions. See Table 25.5 for the disadvantages of the four furnace types.

Ash disposal vs. reuse

Wastewater biosolids and biosolids ash are waste products with some value and should be reused, not simply disposed. For safe biosolids ash reuse, it must be processed in accordance with EPA's 503 Rule to ensure negligible risk to human health and the environment.

Table 25.5 Ash Disposition

Application	% of Use (rounded)
Land application	42
Codisposal	20
Incineration	13.5
Surface disposal	9
Distribution and marketing	6
Ocean disposal	5
Monofilling	2
Other	2.5

Source: USEPA, National Sewage Sludge Survey, 1990.

DID YOU KNOW?

Sixty-two thousand six hundred gallons of water is needed to produce 1 ton of steel, 1,500 gal to process one barrel of beer, and 9.3 gal to process one can of fruit or vegetables.

In the past, biosolids ash had been reused in limited applications (Table 25.5). The USEPA's 503 Rule and increasingly more stringent regulations governing disposal at state and local levels have raised interest in developing additional beneficial biosolids ash applications. These applications include:

- Supplementary material added as bulking agents for biosolids composting
- Additives for construction materials (concrete aggregates for road building or other construction activities)
- Landfill cover material
- Composite material used for novelty product production
- Composite material used for shoreline erosion control product production

Summary

Biosolids reuse, as well as wastewater reclamation and reuse, are essential parts of the technological processes for ensuring that our water supply continues to meet our demands, as well as our needs. With a finite supply of water and a growing population, a constant cycle of use, treatment, and reuse becomes more and more necessary for providing for our water needs, in all aspects of water and wastewater processing.

References and recommended reading

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Glossary

Absorption Any process by which one substance penetrates the interior of another substance.

Activated sludge The solids formed when microorganisms are used to treat wastewater using the activated sludge treatment process: mixing primary effluent with bacteria-laden sludge, which is then agitated and aerated to promote biological treatment. This process speeds breakdown of organic matter in raw sewage undergoing secondary treatment. Activated sludge includes organisms, accumulated food materials, and waste products from the aerobic decomposition process.

Adsorption The process by which one substance is attracted to and adheres to the surface of another substance without actually penetrating its internal structure.

Advanced waste treatment A treatment technology used to produce an extremely high-quality discharge.

Aeration A physical treatment method that promotes biological degradation of organic matter. The process may be passive (when waste is exposed to air) or active (when a mixing or bubbling device introduces air).

Aerobic Conditions in which free, elemental oxygen is present. Also used to describe organisms, biological activity, or treatment processes that require free oxygen.

Aerobic bacteria A type of bacteria that requires free oxygen to carry out metabolic function.

Aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3$ (alum)) Coagulant added to raw water to form floc for solids removal in water treatment.

Alum cake Dewatered alum sludge.

Alum sludge Solids removed from sedimentation of raw water that has undergone coagulation, flocculation, and sedimentation.

Anaerobic Conditions in which no oxygen (free or combined) is available. Also used to describe organisms, biological activity, or treatment processes that function in the absence of oxygen.

Anoxic Conditions in which no free, elemental oxygen is present, and the only source of oxygen is combined oxygen such as that found in nitrate compounds. Also used to describe biological activity or treatment processes that function only in the presence of combined oxygen.

Autogenous/autothermic combustion (Incinerator) The burning of a wet organic material where the moisture content is at such a level that the heat of combustion of the organic material is sufficient to vaporize the water and maintain combustion. No auxiliary fuel is required except for start-up.

Average monthly discharge limitation The highest allowable discharge over a calendar month.

Average weekly discharge limitation The highest allowable discharge over a calendar week.

Beneficial uses The many ways water can be used, either directly by people or for their overall benefit.

Biochemical oxygen demand (BOD) The amount of oxygen required by bacteria to stabilize decomposable organic matter under aerobic conditions.

Biochemical oxygen demand (BOD_5) The amount of organic matter that can be biologically oxidized under controlled conditions (5 days at 20°C in the dark).

Biological treatment A process that uses living organisms to bring about chemical changes.

Biosolids From *Merriam-Webster's Collegiate Dictionary*, 10th edition (1998):

biosolid *n* (1977)—solid organic matter recovered from a sewage treatment process and used especially as fertilizer—usually used in plural.

Biosolids cake The solid discharged from a dewatering apparatus.

Biosolids concentration The weight of solids per unit weight of biosolids.

Biosolids moisture content The weight of water in a biosolids sample divided by the total weight of the sample. Normally determined by drying a biosolids sample and weighing the remaining solids,

the total weight of the biosolids sample equals the weight of water plus the weight of the dry solids.

Biosolids quality parameters Three main USEPA parameters used in gauging biosolids quality: (1) the relevant presence or absence of pathogenic organisms, (2) pollutants, and (3) the degree of attractiveness of the biosolids to vectors.

Bucketing Simple, effective, but labor-intensive method for cleaning large amounts of debris from a sewer line. Workers load buckets from within the line, hauling the solids to the surface for disposal.

Buffer A substance or solution that resists changes in pH.

Building service Collection system connection and pipe that carries wastewater flow from the generation point to a main.

Cake solids discharge rate The dry solids cake discharged from a centrifuge.

Carbonaceous biochemical oxygen demand (CBOD₅) The amount of biochemical oxygen demand that can be attributed to carbonaceous material.

Centrate The effluent or liquid portion of biosolids removed by or discharged from a centrifuge.

Chemical oxygen demand (COD) The amount of chemically oxidizable materials present in the wastewater.

Chemical treatment A process that results in the formation of a new substance or substances. The most common chemical water/wastewater treatments include coagulation, disinfection, water softening, and oxidation.

Chlorine A strong oxidizing agent that has strong disinfecting capability. A yellow-green gas, it is extremely corrosive, and is toxic to humans in extremely low concentrations in air.

Chlorine demand A measure of the amount of chlorine that will combine with impurities and therefore will not be available to act as a disinfectant.

Clarifier A device designed to permit solids to settle or rise and be separated from the flow. Also known as a settling tank or sedimentation basin.

Cleanout points Collection system points that allow access for cleaning equipment and maintenance into the sewer system.

Clean Water Act (CWA) Federal law dating to 1972 (with several amendments) with the objective to restore and maintain the chemical, physical, and biological integrity of the nation's waters. Its long-range goal is to eliminate the discharge of pollutants into navigable waters, and to make and keep national waters fishable and swimmable.

Clean zone Any part of a stream upstream of the point of pollution entry.

Coagulants Chemicals that cause small particles to stick together to form larger particles.

- Coagulation** A chemical water treatment method that causes very small suspended particles to attract one another and form larger particles. This is accomplished by adding a coagulant that neutralizes the electrostatic charges on the particles that cause them to repel each other. The larger particles are easier to trap, filter, and remove.
- Coliform** A type of bacteria used to indicate possible human or animal contamination of water.
- Collectors or subcollectors** Collection system pipes that carry wastewater flow to trunk lines.
- Combined sewer** A collection system that carries both wastewater and storm water flows.
- Comminution** A process used to shred solids into smaller, less harmful particles.
- Community water system** A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.
- Composite sample** A combination of individual samples taken in proportion to flow.
- Contact time** The length of time the disinfecting agent and the wastewater remain in contact.
- Contaminant** A toxic material found as a residue in or on a substance where it is not wanted.
- Cross-connection** Any connection between safe drinking water and a nonpotable water or fluid.
- C × T value** The product of the residual disinfectant concentration C, in milligrams per liter, and the corresponding disinfectant contact time T, in minutes. Minimum C × T values are specified by the surface water treatment rule as a means of ensuring adequate kill or inactivation of pathogenic microorganisms in water.
- Daily discharge** The discharge of a pollutant measured during a calendar day or any 24 h period that reasonably represents a calendar day for the purposes of sampling. Limitations expressed as weight are total mass (weight) discharged over the day. Limitations expressed in other units are average measurements of the day.
- Daily maximum discharge** The highest allowable values for a daily discharge.
- Delayed inflow** Storm water that may require several days or more to drain through the sewer system. This category can include the discharge of sump pumps from cellar drainage as well as the slowed entry of surface water through manholes in ponded areas.
- Demand** The chemical reactions that must be satisfied before a residual or excess chemical will appear.
- Detention time** The theoretical time water remains in a tank at a given flow rate.

- Dewatering** The removal or separation of a portion of water present in a sludge or slurry.
- Direct flow** Those types of inflow that have a direct storm water runoff connection to the sanitary sewer and cause an almost immediate increase in wastewater flows. Possible sources are roof leaders, yard and areaway drains, manhole covers, cross-connections from storm drains and catch basins, and combined sewers.
- Direct potable reuse** The piped connection of water recovered from wastewater to a potable water supply distribution system or a water treatment plant, often implying the blending of reclaimed wastewater.
- Direct reuse** The use of reclaimed wastewater that has been transported from a wastewater reclamation point to the water reuse site, without intervening discharge to a natural body of water (e.g., agricultural and landscape irrigation).
- Discharge monitoring report (DMR)** The monthly report required by the treatment plant's NPDES discharge permit.
- Disinfect** To inactivate virtually all recognized pathogenic microorganisms but not necessarily all microbial life (cf. pasteurize or sterilize).
- Disinfectant** (1) Any oxidant, including but not limited to chlorine, chlorine dioxide, chloramine, and ozone added to water in any part of the treatment or distribution process, that is intended to kill or inactivate pathogenic microorganisms. (2) A chemical or physical process that kills pathogenic organisms in water. Chlorine is often used to disinfect sewage treatment effluent, water supplies, wells, and swimming pools.
- Disinfectant contact time (T in CT calculation)** The time (T) in minutes that it takes for water to move from the point of disinfectant application or the previous point of disinfection residual measurement to a point before or at the point where residual disinfectant concentration (C) is measured. Where only one C is measured, T is the time in minutes that it takes for water to move from the point of disinfectant application to a point before or at where residual disinfectant concentration (C) is measured.
- Disinfection** The addition of a substance (for example, chlorine, ozone, or hydrogen peroxide) that destroys or inactivates harmful microorganisms or inhibits their activity. Also, the selective destruction of disease-causing organisms. All the organisms are not destroyed during the process. This differentiates disinfection from sterilization, which is the destruction of all organisms.
- Disinfection by-products** Compounds formed by the reaction of a disinfectant such as chlorine with organic material in the water supply.
- Dissolved oxygen (DO)** Free or elemental oxygen that is dissolved in water.
- Dose** The amount of chemical being added in milligrams per liter.

Drinking water standards Water quality standards measured in terms of suspended solids, unpleasant taste, and microbes harmful to human health. Drinking water standards are included in state water quality rules.

Drinking water supply Any raw or finished water source that is or may be used as a public water system, or as drinking water by one or more individuals.

Drying hearth A solid surface in an incinerator upon which wet waste materials (or waste matter that may turn to liquid before burning) are placed to dry, or to burn with the help of hot combustion gases.

Effluent The flow leaving a tank, channel, or treatment process.

Effluent limitations Standards developed by the USEPA to define the levels of pollutants that can be discharged into surface waters, or any restriction imposed by the regulatory agency on quantities, discharge rates, or concentrations of pollutants that are discharged from point sources into state waters.

Electrodialysis Water using ion-selective membranes and an electric field to separate anions and cations in solution.

Estuaries Coastal bodies of water that are partly enclosed.

Evaporation The process by which water as liquid changes to water vapor.

Facultative Organisms that can survive and function in the presence or absence of free, elemental oxygen.

Facultative bacteria A type of anaerobic bacteria that can metabolize its food either aerobically or anaerobically.

Fecal coliform A type of bacteria found in the bodily discharges of warm-blooded animals. Used as an indicator organism.

Federal Water Pollution Control Act (1972) Under the act, the objective "to restore and maintain the chemical, physical, and biological integrity of the nation's waters" is outlined. This 1972 act and subsequent Clean Water Act Amendments are the most far-reaching water pollution control legislation ever enacted.

Feed rate The amount of chemical being added in pounds per day.

Filtrate The effluent or liquid portion of a biosolid removed by or discharged from a centrifuge.

Filtration A physical treatment method for removing solid (particulate) matter from water by passing the water through porous media such as sand or a man-made filter.

Flashpoint The lowest temperature at which evaporation of a substance produces sufficient vapor to form an ignitable mixture with air, near the surface of the liquid.

Floc Solids that join together to form larger particles that will settle better.

Flocculation The water treatment process following coagulation that uses gentle stirring to bring suspended particles together to form larger, more settleable clumps called floc.

Flume A flow rate measurement device.

Flushing Line clearing technique that adds large volumes of water to the sewer at low pressures to move debris through the collection system.

Food-to-microorganism ratio (F/M) An activated sludge process control calculation based upon the amount of food (BOD_5 or COD) available per pound of mixed-liquor volatile suspended solids.

Friction head The energy needed to overcome friction in the piping system. It is expressed in terms of the added system head required.

Grab sample An individual sample collected at a randomly selected time.

Grit Heavy inorganic solids such as sand, gravel, eggshells, or metal filings.

Groundwater The freshwater found under the earth's surface, usually in aquifers. Groundwater is a major source of drinking water, and concern is growing over areas where leaching agricultural or industrial pollutants or substances from leaking underground storage tanks are contaminating groundwater.

Head The equivalent distance water must be lifted to move from the supply tank or inlet to the discharge. Head can be divided into three components: *static head*, *friction head*, and *velocity head*.

Horizontal directional drilling (HDD) Technique used to drill or bore a tunnel through the soil and pull or push new pipe in behind the drill head.

Hydraulic line cleaning devices Devices for clearing built-up debris or blockages from sewer lines. These devices include hydraulic tools such as balls, kites, pigs, scooters, and bags. They work by partially plugging a flooded upstream main. The movement of the tool itself and the force of the water pressure from the partially blocked line work to loosen and flush away debris.

Hydrologic cycle Literally, the water-earth cycle: the movement of water in all three of its physical forms—water, vapor, and ice—through the various environmental mediums (air, water, biota, and soil).

Hygroscopic A substance that readily absorbs moisture.

Incineration An engineered process using controlled flame combustion to thermally degrade waste material.

Indirect potable reuse The potable reuse by incorporation of reclaimed wastewater into a raw water supply; the wastewater effluent is discharged to the water source, mixed and assimilated with it, with the intent of reusing the water instead of as a means of disposal. This type of potable reuse is becoming more common as water resources become less plentiful.

Indirect reuse The use of wastewater reclaimed indirectly by passing it through a natural body of water or use of groundwater that has been recharged with reclaimed wastewater. This type of potable reuse commonly occurs whenever an upstream water user

discharges wastewater effluent into a watercourse that serves as a water supply for a downstream user.

Industrial wastewater Wastes associated with industrial manufacturing processes.

Infiltration Water entering the collection system through cracks, joints, or breaks. Infiltration includes steady inflow, direct flow, total inflow, and delayed inflow.

Influent Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant.

Inorganic Mineral materials such as salt, ferric chloride, iron, sand, gravel, etc.

Interceptors Collection system pipes that carry wastewater flow to the treatment plant.

Jetting Line cleaning technique that cleans and flushes the line in a single operation, using a high-pressure hose and a variety of nozzles to combine the advantages of hydraulic cleaning with mechanical cleaning.

Junction boxes Collection system constructions that occur when individual lines meet and are connected.

Land application Discharge of wastewater onto the ground for treatment or reuse.

Lift stations Pump installations designed to pump wastes to a higher point through a force main, when gravity flow does not supply enough force to move the wastewater through the collection system.

Lime sludge Solids removed from water softening processes.

Line cleaning See hydraulic line cleaning and mechanical line cleaning.

Mains Collection system pipes that carry wastewater flow to collection sewers.

Manholes Collection system entry points that allow access into the sewerage system for inspection, preventive maintenance, and repair.

Maximum contaminant level (MCL) The maximum allowable concentration of a contaminant in drinking water, as established by state or federal regulations. Primary MCLs are health related and mandatory. Secondary MCLs are related to the water quality aesthetic considerations and are highly recommended, but not required.

Mean cell residence time (MRCT) The average length of time a mixed-liquor suspended solids particle remains in the activated sludge process. May also be known as sludge retention time.

Mechanical line cleaning Methods such as rodding or bucketing used to clean stoppages and blockages from sewer lines.

mg/L An expression of the weight of one substance contained within another. Commonly used to express weight of a substance within a given weight of water and wastewater, it is sometimes expressed as parts per million (ppm), which is equal to mg/L.

- Milligrams/liter (mg/L)** A measure of concentration equivalent to parts per million (ppm) (*see* mg/L).
- Mixed liquor** The combination of return activated sludge and wastewater in the aeration tank.
- Mixed-liquor suspended solids (MLSS)** The suspended solids concentration of the mixed liquor.
- Mixed-liquor volatile suspended solids (MLVSS)** The concentration of organic matter in the mixed-liquor suspended solids.
- Moisture content** The amount of water per unit weight of biosolids. The moisture content is expressed as a percentage of the total weight of the wet biosolids. This parameter is equal to 100 minus the percent solids concentration.
- National Pollutant Discharge Elimination System (NPDES)** A requirement of the CWA that discharges meet certain requirements prior to discharging waste to any water body. It sets the highest permissible effluent limits, by permit, prior to making any discharge.
- Near Coastal Water Initiative** Initiative developed in 1985 to provide for management of specific problems not dealt with in other programs for waters near coastlines.
- Nitrogenous oxygen demand (NOD)** A measure of the amount of oxygen required to biologically oxidize nitrogen compounds under specified conditions of time and temperature.
- Nonbiodegradable** A substance that does not break down easily in the environment.
- NPDES permit** The National Pollutant Discharge Elimination System permit that authorizes the discharge of treated wastes and specifies the condition that must be met for discharge.
- Nutrients** Substances required to support living organisms. Usually refers to nitrogen, phosphorus, iron, and other trace metals.
- Organic** Materials that consist of carbon, hydrogen, oxygen, sulfur, and nitrogen. Many organics are biologically degradable. All organic compounds can be converted to carbon dioxide and water when subjected to high temperatures.
- Osmosis** The natural tendency of water to migrate through semipermeable membranes from the weaker solution to the more concentrated solution, until hydrostatic pressure equalizes the chemical balance.
- Oxidation** When a substance gains oxygen, or loses hydrogen or electrons in a chemical reaction. One of the chemical treatment methods.
- Oxidizer** A substance that oxidizes another substance.
- Part per million** An alternative (but numerically equivalent) unit used in chemistry is milligrams per liter (mg/L).
- Pathogenic** Disease causing. A pathogenic organism is capable of causing illness.

- Physical treatment** Any process that does not produce a new substance (e.g., in wastewater treatment, screening, adsorption, aeration, sedimentation, and filtration).
- Pipe bursting** Trenchless technology method that destroys the old pipe while pulling the new pipe in behind.
- Planned reuse** The deliberate direct or indirect use of reclaimed wastewater without relinquishing control over the water during its delivery.
- Point source** Any discernible, defined, and discrete conveyance from which pollutants are or may be discharged.
- Pollutant** Any substance introduced into the environment that adversely affects the usefulness of the resource.
- Pollution** The presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as a man-made or man-induced alteration of the physical, biological, and radiological integrity of water.
- Potable water reuse** A direct or indirect augmentation of drinking water with reclaimed wastewater that is highly treated to protect public health.
- Precipitation** Atmospheric water that falls to earth as rain (a liquid) or snow, sleet, or hail (a solid).
- Pressure** The force exerted per square unit of surface area. May be expressed as pounds per square inch.
- Pretreatment** Any physical, chemical, or mechanical process used before the main water/wastewater treatment processes. It can include screening, presedimentation, and chemical addition. Also the practice of industry removing toxic pollutants from their wastewaters before they are discharged into a municipal wastewater treatment plant.
- Primary disinfection** Refers to the initial killing of *Giardia* cysts, bacteria, and viruses.
- Primary drinking water standards** Regulations on drinking water quality (under SWDA) that are considered essential for preservation of public health.
- Primary treatment** The first step of treatment at a municipal wastewater treatment plant. It typically involves screening and sedimentation to remove materials that float or settle.
- Publicly owned treatment works (POTW)** A waste treatment works owned by a state, local government unit, or Native American tribe, usually designed to treat domestic wastewaters.
- Receiving waters** A river, lake, ocean, stream, or other water source into which wastewater or treated effluent is discharged.
- Recharge** The process by which water is added to a zone of saturation, usually by percolation through the soil.

- Reclaimed wastewater** Wastewater that, as a result of wastewater reclamation, is suitable for a direct beneficial use or a controlled use that would not otherwise occur.
- Recovery zone** The point in a stream where, as the organic wastes decompose, the stream quality begins to return to more normal levels.
- Residual** The amount of disinfecting chemical remaining after the demand has been satisfied.
- Return activated sludge solids (RASS)** The concentration of suspended solids in the sludge flow being returned from the settling tank to the head of the aeration tank.
- Reverse osmosis (RO)** Solutions of differing ion concentration are separated by a semipermeable membrane. Typically, water flows from the chamber with lesser ion concentration into the chamber with the greater ion concentration, resulting in hydrostatic or osmotic pressure. In RO, enough external pressure is applied to overcome this hydrostatic pressure, thus reversing the flow of water. This results in the water on the other side of the membrane becoming depleted in ions and demineralized.
- Rodders** Mechanical method used to clear obstructions like heavy root accumulations or large soft obstructions from collection system lines to restore flow.
- Safe Drinking Water Act (SDWA)** Federal law passed in 1974 to establish federal standards for drinking water quality, protect underground sources of water, and set up a system of state and federal cooperation to ensure compliance with the law.
- Sanitary sewer** Collection system that carries human wastes in wastewater from residences, businesses, and some industry to the treatment facility.
- Sanitary wastewater** Wastes discharged from residences and from commercial, institutional, and similar facilities that include both sewage and industrial wastes.
- Screening** A pretreatment method that uses coarse screens to remove large debris from the water to prevent clogging of pipes or channels to the treatment plant.
- Scum** The mixture of floatable solids and water that is removed from the surface of the settling tank.
- Secondary disinfection** The maintenance of a disinfectant residual to prevent regrowth of microorganisms in the water distribution system.
- Secondary drinking water standards** Regulations developed under the Safe Drinking Water Act that established maximum levels of substances affecting the aesthetic characteristics (taste, color, or odor) of drinking water.
- Secondary treatment** The second step of treatment at a municipal wastewater treatment plant, which uses growing numbers of

microorganisms to digest organic matter and reduce the amount of organic waste.

Sedimentation Physical treatment method that reduces the velocity of water in basins so that the suspended material settles out by gravity.

Septic Wastewater with no dissolved oxygen present. Generally characterized by black color and rotten egg (hydrogen sulfide) odors.

Septic zone The point in a stream where pollution causes dissolved oxygen levels to sharply drop, affecting stream biota.

Settleability A process control test used to evaluate the settling characteristics of the activated sludge. Readings taken at 30 to 60 min are used to calculate the settled sludge volume (SSV) and the sludge volume index (SVI).

Settled sludge volume The volume in percent occupied by an activated sludge sample after 30 to 60 min of settling. Normally written as SSV with a subscript to indicate the time of the reading used for calculation (SSV₆₀) or SSV₃₀).

Sewage The waste and wastewater produced by residential and commercial establishments and discharged into sewers.

Slip lining Trenchless technology technique that slides a new, smaller-diameter, polyethylene pipe liner into an old damaged pipe.

Sludge The mixture of settleable solids and water removed from the bottom of the settling tank.

Sludge loading rate The weight of wet biosolids fed to the reactor per square foot of reactor bed area per hour (lb/ft²/h).

Sludge retention time (SRT) *See* mean cell residence time.

Sludge volume index (SVI) A process control calculation that is used to evaluate the settling quality of the activated sludge. Requires the SSV₃₀ and mixed-liquor suspended solids test results to calculate.

Solids concentration The weight of solids per unit weight of sludge.

Solids content (also called percent total solids) The weight of total solids in biosolids per unit total weight of biosolids expressed in percent. Water content plus solids content equals 100%. This includes all chemicals and other solids added to the biosolids.

Solids loading rate (drying beds) The weight of solids on a dry weight basis applied annually per square foot of drying bed area.

Solids recovery (centrifuge) The ratio of cake solids to feed solids for equal sampling times. It can be calculated with suspended solids and flow data, or with only suspended solids data. The centrate solids must be corrected if chemicals are fed to the centrifuge.

Static head The actual vertical distance from the system inlet to the highest discharge point.

Steady inflow Water discharged from cellar and foundation drains, cooling water discharges, and drains from springs and swampy areas.

This type of inflow is steady and is identified and measured along with infiltration.

Sterilization The removal of all living organisms.

Storm sewer A collection system designed to carry only storm water runoff.

Storm water Runoff resulting from rainfall and snowmelt.

Stream self-purification The innate ability of healthy streams (and their biota) to rid themselves of small amounts of pollution. Successful self-purification depends on the volume of water the stream carries, the amount of pollution, and the speed the stream travels.

Supernatant In a digester, the amber-colored liquid above the sludge.

Surface water All water naturally open to the atmosphere, and all springs, wells, or other collectors that are directly influenced by surface water.

Tertiary treatment The third step in wastewater treatment, sometimes employed at municipal wastewater treatment plants. It consists of advanced cleaning, which removes nutrients and most BOD.

Total dynamic head The total of the static head, friction head, and velocity head.

Total inflow The sum of the direct inflow at any point in the system, plus any flow discharged from the system upstream through overflows, pumping station bypasses, etc.

Total suspended solids (TSS) Solids present in wastewater.

Transpiration The process by which plants give off water to the atmosphere.

Trunk lines Collection system pipes that carry wastewater flow to interceptors.

Turbidity A measure of the cloudiness of water. Caused by the presence of suspended matter, turbidity shelters harmful microorganisms and reduces the effectiveness of disinfecting compounds.

Turbulence A state of high agitation. In turbulent fluid flow, the velocity of a given particle changes constantly in both magnitude and direction.

Urban water cycle A local subsystem of the water cycle created by human water use, also called an integrated water cycle. These artificial cycles involve surface water withdrawal, processing, and distribution; and wastewater collection, treatment, and disposal back to surface water by dilution and natural purification in a river. The cycle is repeated by communities downstream.

Velocity The speed of a liquid moving through a pipe, channel, or tank. May be expressed in feet per second.

Velocity head The energy needed to keep the liquid moving at a given velocity, expressed in terms of the added system head required.

Vents Collection system ventilation points that ensure that gases that build up within sewer systems from the wastes they carry are safely removed from the system.

- Waste activated sludge solids (WASS)** The concentration of suspended solids in sludge removed from the activated sludge process.
- Wastewater** The spent or used water from individual homes, communities, farms, or industries that contains dissolved or suspended matter.
- Wastewater collection system** Community sewerage system to collect and transport wastewater from (1) residents, commercial and industrial customers, and from (2) storm water runoff through storm sewers. Wastewater is transported through the sanitary sewer or a combination system to a treatment facility. Storm water is transported through a storm sewer system or a combined system to a treatment facility or approved discharge point.
- Wastewater reclamation** The treatment or processing of wastewater to make it reusable.
- Wastewater reuse** The beneficial use of treated wastewater, such as industrial cooling.
- Waterborne disease** Illness caused by pathogenic organisms in water.
- Water cycle** *See also* hydrogeologic cycle.
- Watershed** The land area that drains into a river, river system, or other body of water.
- Water softening** A chemical treatment method that uses either chemicals to precipitate or a zeolite to remove metal ions (typically Ca^{2+} , Mg^{2+} , Fe^{3+}) responsible for hard water from drinking water supplies. The waste by-product is lime sludge.
- Weir** A device used to measure wastewater flow.
- Wellhead protection** The protection of the surface and subsurface areas surrounding a water well or well field supplying a public water system that may be contaminated through human activity.
- Zone of recent pollution** The pollution discharge point, where the stream becomes turbid.
- Zoogleal slime** The biological slime that forms on fixed film treatment devices. It contains a wide variety of organisms essential to the treatment process.

Second Edition

Water and Wastewater Treatment

A Guide for the Nonengineering Professional

Lauded for its engaging, highly readable style, the best-selling first edition became the premier guide for nonengineers involved in water and wastewater treatment operations. ***Water and Wastewater Treatment: A Guide for the Nonengineering Professional, Second Edition*** continues to provide a simple, nonmathematical account of the unit processes used to treat both drinking water and wastewater.

Completely revised and expanded, this second edition adds new material on technological advances, regulatory requirements, and other current issues facing the water and wastewater industries. Using step-by-step, jargon-free language, the authors present all the basic unit processes involved in drinking water and wastewater treatment. They describe each unit process, the function of the process in water or wastewater treatment, and the basic equipment used in each process. They also explain how the processes fit together within a drinking water or wastewater treatment system and discuss the fundamental concepts that constitute water and wastewater treatment processes as a whole.

Avoiding mathematics, chemistry, and biology, the book includes numerous illustrations for easy comprehension of concepts and processes. It also contains chapter summaries and an extensive glossary of terms and abbreviations for quick reference.

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