CHAPTER 16. OUR WATER: HOW SAFE, HOW PURE?

CHEMICAL CONCEPTS USED IN THIS CHAPTER:

PHYSICAL PROPERTIES OF WATER

THE WATER CYCLE

AEROBIC PROCESSES FOR WATER PURIFICATION

EUTROPHICATION

CONTEMPORARY ISSUES ADDRESSED BY THIS CHAPTER:

WATER POLLUTION

WATER TREATMENT

Water: Our Planet's Essential Substance

If you were able to view the earth from space, the most striking feature of our planet would be its blue oceans, covering almost three-fourths of its surface. Partially obscuring the view of the planet's surface would be wispy white clouds made of water droplets and ice crystals. From this global perspective it would be strikingly obvious that one chemical compound, water or H_2O, dominates the planet's surface. Our own bodies are almost three-fourths water by weight, and each of our cells is bathed in an aqueous solution. From the time we develop within the water-filled amniotic sac until we die, we are dependent upon water for life. A loss of only 1% of body water can cause a painful degree of thirst; losing 5% can cause hallucinations; and losing 15% is fatal. Drinking water, however, accounts for only a very small fraction of our water use. The average American uses between 50 and 150 gallons of water every day, of which only 0.5% is actually used for drinking, and the rest used in the bathroom, kitchen, lawn and garden, laundry and swimming pool. In addition, the industrial and agricultural industries we depend upon use about 2000 gallons of water each day for each person in the U.S.

Agriculture's need for water is obvious, since plants and animals need water to survive, as we do. It takes about 120 gallons of water to produce one egg, and 3,500 gallons to produce one steak. The greatest use for water in the United States, however, is for industrial uses, which account for 58% of the total. Manufacturing a car, for example, requires about 30,000 gallons of water. The quality of water needed for industrial uses varies with the process involved. Water used for waste removal or to cool the effluent from nuclear power plants need not be of the same quality as drinking water. Water used in food processing must be at least of drinking-water quality, and water used to manufacture pharmaceuticals must be even purer than drinking water. Our economy is dependent upon water, and costs incurred in purifying water are passed along in increased product prices.

Since water is of such great importance to us, what is the status of the quantity and quality of our water? Should we be concerned? In a consumer's attitude survey conducted by the American Water Works Association in 1986, 87% of those surveyed considered their drinking water to be of average quality or better. More than 40%, however, said they were very concerned about encountering substances in their water in their lifetime that would lead to their death, with respondents in the Northeast being most concerned about drinking water contamination. Are these vague fears justified? What are the issues we face in water contamination? Before looking at specific water contaminants, the unwanted substances dissolved in water, we need some knowledge of the physical and chemical properties of water itself.

Properties of Water

Because water is such an important and familiar substance for us, we have been learning about its properties throughout our study of chemistry. Before we tackle issues of water pollution and purification, we need only to summarize what we know about water.

As we learned in Chapter 5, water is a covalently bonded compound of the elements oxygen and hydrogen. We have already learned the most important features of this molecule, its **shape** and its **intermolecular forces**. The electron dot formula for water we learned how to draw in Chapter 5 is useful in showing us that, in addition to the electron pair joining each hydrogen atom to the oxygen atom, there are two other, nonbonded electron pairs (Fig. 17-1). Thus, viewed in three dimensions, the shape of the water molecule, including the nonbonded electron pairs, is tetrahedral. Looking at the hydrogen and oxygen atoms alone, the resulting structure is bent, rather than having the hydrogens in a straight line on either side of the oxygen.

Fig. 17-1. *The shape of water is important in determining its properties. The "holes" apparent in the solid state of water, ice, are caused when the bent water molecules form hydrogen bonds*

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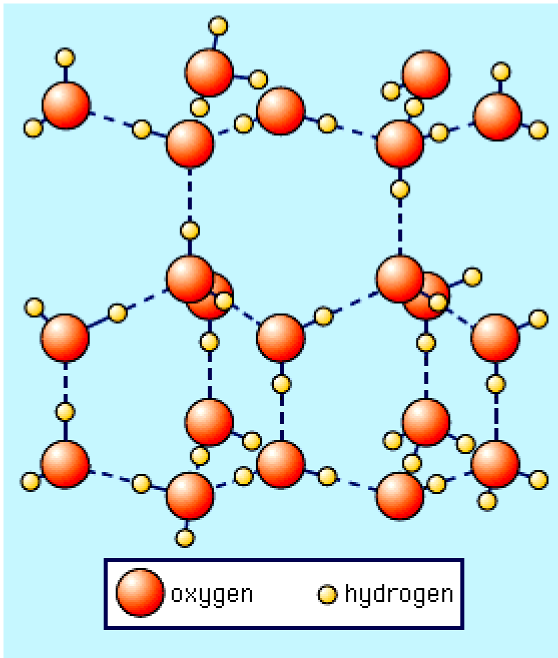


Some consequences of this shape we learned in Chapter 6: solid water, or ice, forms a lattice structure with hexagonal "holes" so that it is less dense than the less rigidly ordered liquid. The bonds within the water molecule are polar covalent, and, because the molecule has a bent rather than a linear shape these result in a polar molecule. The oxygen atom, being more electronegative than hydrogen, attracts the electron-pair bond more strongly toward itself. The result is a partial negative charge on the oxygen atom and partial positive charges on the two hydrogen atoms, especially powerful in the case of hydrogen because it has no inner electron levels to shield the effect of the positive charge of the nucleus. The forces binding one water molecule to another, then, are especially strong. These intermolecular forces, called **hydrogen bonding**, are responsible for some important properties of water, including its high heat capacity and its high heat of evaporation.

In Chapter 1 we were introduced to the idea of **heat capacity** by observing what happens when we use a Bunsen burner to heat a beaker of water supported on an iron ring in the laboratory. Sometimes it seems to take forever for the water to come to a boil; a finger inserted into the water several minutes after the heating process has begun may find the water only lukewarm. But touching the iron ring at the same time produces a nasty surprise and a bad burn. The iron has a lower heat capacity, so it warms up more quickly. Why does water have such a high heat capacity? In order to increase the temperature of the water by increasing the kinetic energy, or energy of movement, of the water molecules, the attractive forces between them must be partially overcome. The strong intermolecular attractive forces of hydrogen bonding result in the high heat capacity of water. Those who live near the ocean experience ongoing demonstrations of the effect of the high heat capacity of water. Springtime temperatures on Cape Cod, Massachusetts, which is almost surrounded by water, are typically lower on a given day than the temperatures in inland Massachusetts, because the ocean water's high heat capacity causes it to warm up slowly. The phenomenon works in the reverse in the fall, for the Cape, surrounded by warm ocean water, enjoys warmer days than the inland areas as the ocean water loses heat more slowly than the land.

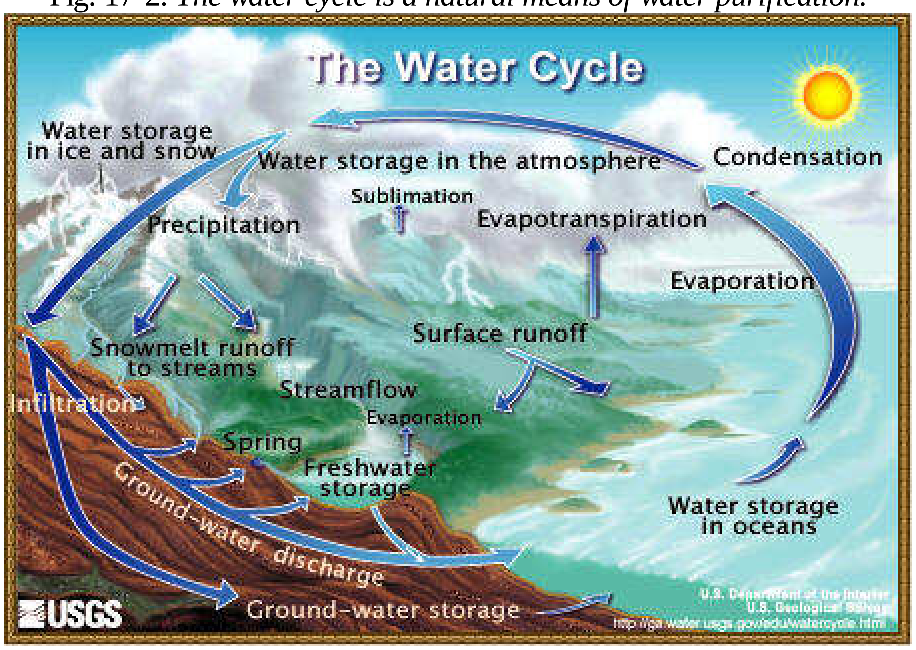
The **heat of vaporization** is the amount of heat needed to change a mole of a substance from the liquid state to the vapor state. The greater the intermolecular forces, the more energy will be required to break those forces and allow the molecules to escape into the vapor phase. Because of its hydrogen bonding, water has a high heat of vaporization. Just as with heat capacity effects, those who live on the seacoast or near large bodies of water experience the effects of the high heat of vaporization of water. The cool breezes from an ocean or lake show the effect of the heat absorbed from the air over the water as the water evaporates. Our bodies are designed to take advantage of this cooling effect, as well. When we sweat, the water evaporates from our skin, absorbing significant heat energy from our bodies because of the high heat of vaporization of water.

Because of its polarity, water has a mutual attraction for other polar substances and for ionic substances. It is this ability to serve as a good **solvent** for so many substances which has led to some our current problems with the pollution of our water. In the natural world as well, substances dissolve in the water supply, affecting its purity. The salt content of the ocean is caused by ionic substances dissolving into the rivers and building up in over time in sea water. Plants and animals decay, fouling the water. How does nature handle the problem of purifying polluted water?

The Water Cycle: Nature's Purification Mechanism

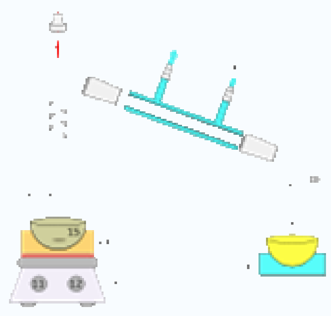
Through a series of natural processes called the **water cycle** purification of water constantly occurs. Fig. 17-2 depicts this cycling mechanism. A key step in the water cycle is **evaporation**. Water in the ocean or other bodies of water absorbs solar energy, enabling water molecules to escape into the gas phase. Dissolved impurities like salts and other solids are left behind. The vaporized water rises with the air that has ben warmed by the sun until it encounter cooler atmospheric temperatures and condenses as a cloud. Water droplets coalesce, finally falling as precipitation. In the natural state rainwater is normally quite pure, containing as dissolved materials only small amounts of those gases present in the air. For example, because of dissolved carbon dioxide which combines with the water to form the weak acid carbonic acid, H_2CO_3, rain water has a slightly acidic pH. Rainwater also contains dissolved nitrogen and oxygen from the atmosphere, and, as we have learned in our study of nitrogen fixation, lightning can result in small amounts of nitric acid in the rain as a result of the reaction of nitrogen and oxygen gases. In addition to these naturally occurring substances, as we have learned in Chapter 16, air pollution can introduce contaminants into the air, some of which can react with atmospheric water vapor. Precipitation carries these contaminants to earth. The formation of acid precipitation, containing sulfuric acid and nitric acid, is an example how water pollution can be formed as a direct result of air pollution. Acid rain may result in lakes and ponds with low pH levels harmful to wildlife. The extent to which this occurs is dependant on the amount of neutralizing substances present in the body of water. If acid rain causes a low pH in water where aluminum salts are present in the soil, the acid will cause the aluminum compounds to dissolve, leaching into the water so that the aluminum compound can be incorporated into the living systems of plants and animals with unhealthy effects. Other acid-soluble substances can be similarly dissolved into acidified water. Thus the water cycle, a natural purification mechanism, can be disrupted by man-made pollutants with far-reaching effects on the chemistry of air and water, plants and animals.

Fig. 17-2. *The water cycle is a natural means of water purification.*



Vaporizing water and condensing the pure vapors, as in the water cycle, has been used by people as a water purification means as well. In the laboratory the process is called **distillation**. Distilled water is among the purest forms of water available. A drawback to the widespread use of distillation as a means of water purification is the large amounts of energy required because of the high heat of vaporization of water. Some experimental projects imitate nature in using solar energy to provide the energy of vaporization. In Israel such projects are already used as a means of obtaining pure drinking water from salt water.

Fig. 17-3. Distillation is a process of boiling water and condensing the vapor. Dissolved materials are left behind, resulting in purified water.



1: Heat source

2: Still pot

3: Still head

4: Thermometer/Boiling point temperature

5: Condenser

6: Cooling water in

7: Cooling water out

8: Distillate/receiving flask

9: Vacuum/gas inlet

10: Still receiver

11: Heat control

12: Stirrer speed control

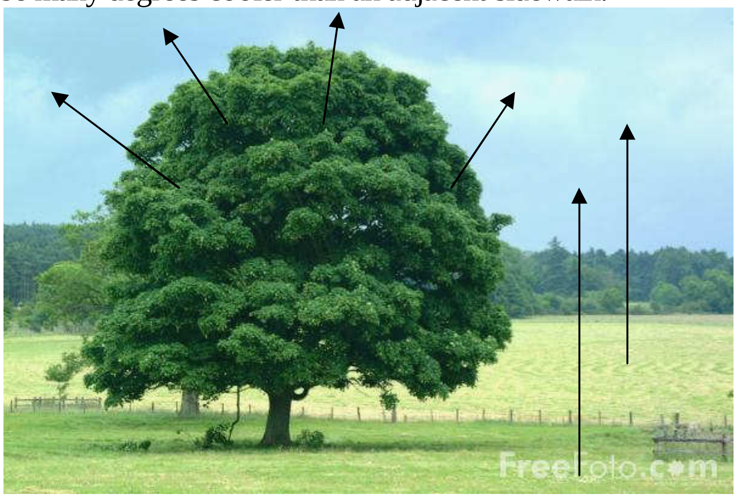
13: Stirrer/heat plate

14: Heating (Oil/sand) bath

15: Stirrer bar/anti-bumping granules

16: Cooling bath.

Another natural purification process involving the vaporization of water is **transpiration**, the loss of water vapor from the leaves of plants. About 99% of the water taken up by plants from the soil is lost through transpiration, with only 1% being consumed in the photosynthesis process. Like the water vapor formed from evaporation, the water vapor from transpiration is in a pure state. Like evaporation, transpiration is an energy- absorbing process, accounting for the fact that the temperature of a grassy lawn will be many degrees cooler than an adjacent sidewalk.



Transpiration from trees and grass cools the atmosphere as heat energy is absorbed to break the hydrogen bonds between water molecules, and they are released as water vapor, a gas.

In the water cycle, much of the water falling as rain flows as **runoff** into small streams which act as tributaries for rivers. Throughout this process the water is in contact with underlying soil, from which ionic compounds are dissolved in the water. Ionic concentration gradually increases until the water reaches the oceans, at which point it is once more purified of dissolved material in the evaporation step of the water cycle. Plant and animal material also finds its way into streams and rivers. Natural purification occurs at the same time, however, in oxidation reactions that involve dissolved oxygen gas and occur with the help of microorganisms called **aerobic bacteria**. In these processes carbon compounds are oxidized to form carbon dioxide. Nitrogen compounds are oxidized to form nitrates and phosphorous compounds to form phosphates, both of which serve as fertilizers for plant life. Sulfur compounds are oxidized to the sulfate form. The faster a stream or river flows, the more readily it incorporates oxygen. A well-oxygenated stream supports a healthy rate of cleansing oxidative processes, and releases waste gases readily into the air.

Not all precipitation ends up as runoff from the surface of the ground; it may soak into the ground in the process called **infiltration**. Some infiltrating water is held in the soil, and some is pulled downward by gravity, percolating through the soil and gravelly subsoil until it reaches an impervious layer of rock or dense clay, where it accumulates, becoming **groundwater**. In the process of **percolation**, microorganisms and particulate impurities are filtered out, giving a clear, purified water. Dissolved materials like ionic compounds, however, are not removed through percolation. Groundwater instead is more likely to pick up an increased concentration of dissolved ionic materials from the soil with which it comes into contact. Dissolved calcium, magnesium, and iron ions are common in groundwater; water containing any or all of these dissolved minerals is called **hard water**. Groundwater accumulations can move slowly like great underground rivers through porous layers called **aquifers**. Frequently water, drawn by gravity through an aquifer, will find its way to a surface opening and appear as a spring, thus re-entering the water cycle as surface water.

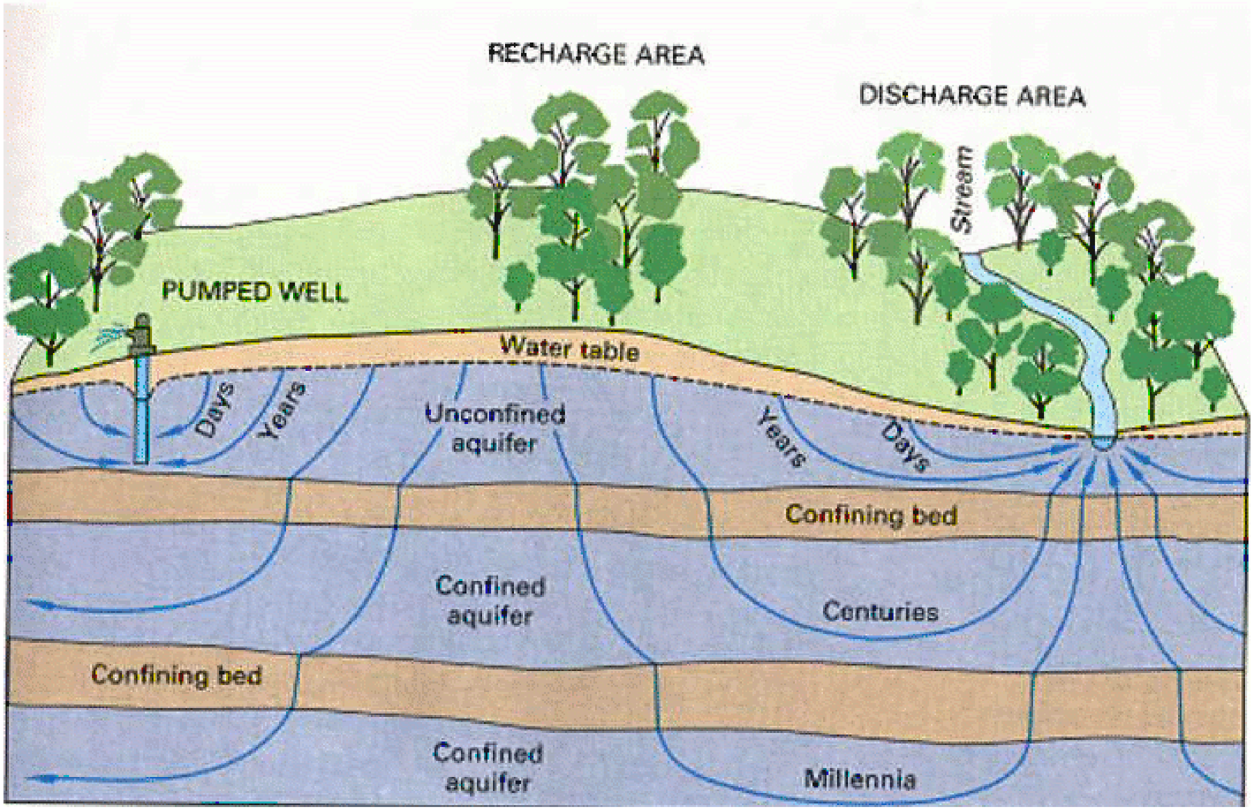


Fig. 17-4. Groundwater is water that accumulates above an impervious layer of the soil, saturating the pore spaces in the soil. The upper surface of groundwater is called the water table. Water percolates down through porous layers into the groundwater, and is purified by this filtration process.

Groundwater pollution is more difficult to remedy than runoff pollution because the period which water remains in the aquifers is much longer, and because they are inaccessible. Pollution of aquifers by industrial waste or leaking underground storage tanks from gasoline stations can do irremediable long-term damage to underground water supplies. Less dramatic in impact, but equally important in long-range consequences is the effect that land development produces in the aquifer. When natural forested soil is replaced by pavement and rooftops for receiving precipitation, infiltration of water into the ground is replaced by runoff, and the aquifer is no longer replenished with water. Hence the same development that greatly increases the withdrawal of water from the aquifer is accompanied by a process which affects the natural water cycle and limits aquifer water replacement.

Land development increases runoff and decreases filtration as land is paved over and covered with buildings. Groundwater is no longer recharged and filtered as in a natural system.

Impervious surfaces and urbanization affect runoff characteristics in the metro Atlanta, Georgia area.

Using our knowledge of the properties of pure water and of the natural processes through which water is purified in the environment, we can now explore some contemporary issues in water pollution and purification:

What are the most important types of water pollution we are likely to encounter? How hazardous are they to our health?

How does pollution enter the water system?

How can polluted water be purified?

Eutrophication: Water Pollution by Overfertilization

A "healthy" lake or other body of water is a balanced ecosystem. Aquatic plants growing from the bottom, generating oxygen in the photosynthesis process described in Chapter 14. Other plant life called **phytoplankton** (from *phyto* for "plant" and *plankton*, meaning "floating") may float on the surface, microscopic, single-celled, or as threadlike groups of cells. Animal life is present in the form of fish and shellfish which need oxygen supplied by the plants in order to survive. Thus, in the water environment as on land, the chemical reactions of plant and animal life are interdependent. Aqueous ecosystems participate in the carbon cycle, the nitrogen cycle, and the phosphorous cycle as described in Chapter 14. Activities which affect these cycles can unbalance an ecosystem, with consequences for its plant and animal species.

Algal bloom in Orielton Lagoon, Australia, 1994. (Photo by Geoff Prestedge)
From the Encyclopedia of Earth www.eoearth.org

Compounds of nitrogen and phosphorous, present in runoff water as the byproduct of human activities, act as fertilizer for the plant species. When the phytoplankton population increases, it blocks the light from the bottom-growing plants, which need sunlight as an energy source for photosynthesis. Phytoplankton has a high **turnover rate**, meaning that its increased growth rate is balanced by an accelerated dieoff, with a resulting accumulation of dead material throughout the system. The resulting detritus consumes oxygen in its decomposition reactions, while further making the water turbid and blocking out sunlight. Thus, high concentrations of nitrogen and phosphorous favor the growth of the top-growing phytoplankton at the expense of bottom-growing plants. The concentration of dissolved oxygen decreases except in the very top layer of water, as the phytoplankton become the only source of photosynthesis.

Fish kill in the Salton Sea as a result of eutrophication.
Eoearth.org

Oxygen-dependent animal species die out except for a limited number of species which inhabit the upper layers of water; the rest of the system is dead, a soupy mix of decaying material. If oxygen levels fall too low to support the aerobic bacteria necessary for aerobic decomposition reactions, **anaerobic decay** processes occur through anaerobic bacteria. The chemical products of anaerobic decay are different from those of aerobic decay. Nitrogen compounds, instead of being oxidized to nitrates, form ammonia instead. Sulfur compounds, instead of being oxidized to sulfates, form hydrogen sulfide, the compound responsible for the odor of rotten eggs. The term for this unappealing process in which overfertilization of a body of water affects its matter cycles, with these consequent changes in the ecosystem, is **eutrophication**.

Eutrophic lakes are not desirable recreation places, and the algae they contain make them undesirable sources of drinking water as well, clogging filter systems and sometimes causing a foul odor. Chemical treatments to kill the unwanted phytoplankton are not usually successful. Widespread application of herbicides in the 1960's and 1970's showed that planktonic algae are especially resistant to herbicides, requiring such heavy applications that all other plant species are killed as well. When herbicide application is discontinued, the algae returns, fed by the high nutrient level that caused eutrophication in the first place. Current treatment of algae-containing water supplies uses copper sulfate, a highly toxic substance. Clearly, a better solution for eutrophication would be to prevent the water pollution by excess nutrients that is causing the eutrophication to occur. What are these nutrients, and where do they come from?

The possible sources of eutrophication-causing nutrients are many. Which is most important for a given body of water will depend on the nature of the area from which it receives its runoff. Rural, suburban, and urban areas all produce characteristic wastes which can contribute to the problem. In rural areas, runoff from crop areas contains fertilizer leached from the fields, containing both nitrogen and phosphorous as well as other plant nutrients. Animal waste can also be a rich source of plant nutrients, especially nitrogen. Urban areas produce huge amounts of human waste. Even after treatment in sewage plants, the nutrient content of human sewage remains. Suburbs can contribute all these forms of nutrient load to the environment: fertilizer runoff from lawns and gardens, human waste, and animal waste from pets.

In many aquatic ecosystems phosphate is the limiting nutrient, the one in shortest supply for promoting plant growth. It is significant to note, then, that about sixty percent of the phosphate in waste water is from detergents. Phosphate is present as a "builder" in many detergents because of its ability to suspend grease in water, making it easy to rinse away. This is a particularly useful property in hard water, which contains ions of calcium, magnesium and iron which form an insoluble, gummy precipitate with soap. Substitutes for phosphate have been developed, and in watershed areas in which phosphate is the limiting nutrient, these are advisable and sometimes required by law.

The nitric acid, HNO_3, present in acid rain can be a significant source of nitrate ion. NO_3^-. A 1988 study of Chesapeake Bay by the Environmental Defense Fund showed that acid precipitation contributed up to one-fourth its nitrate concentration.

Water Pollution: A Threat to Our Health?

Though unpleasant to sight and smell and unlivable to most fish, a eutrophic lake may not be a threat to human health. The algae that impart a foul odor to drinking water may be less toxic to human health than the chemicals used to kill the offending algae. Health hazards do threaten many of our water supplies, however. The possible kinds of hazardous water pollutants are numerous. Among those known to be of concern in water systems in the United States are microbial hazards, organics, heavy metals, and nitrate.

Microbial Contaminants in Drinking Water

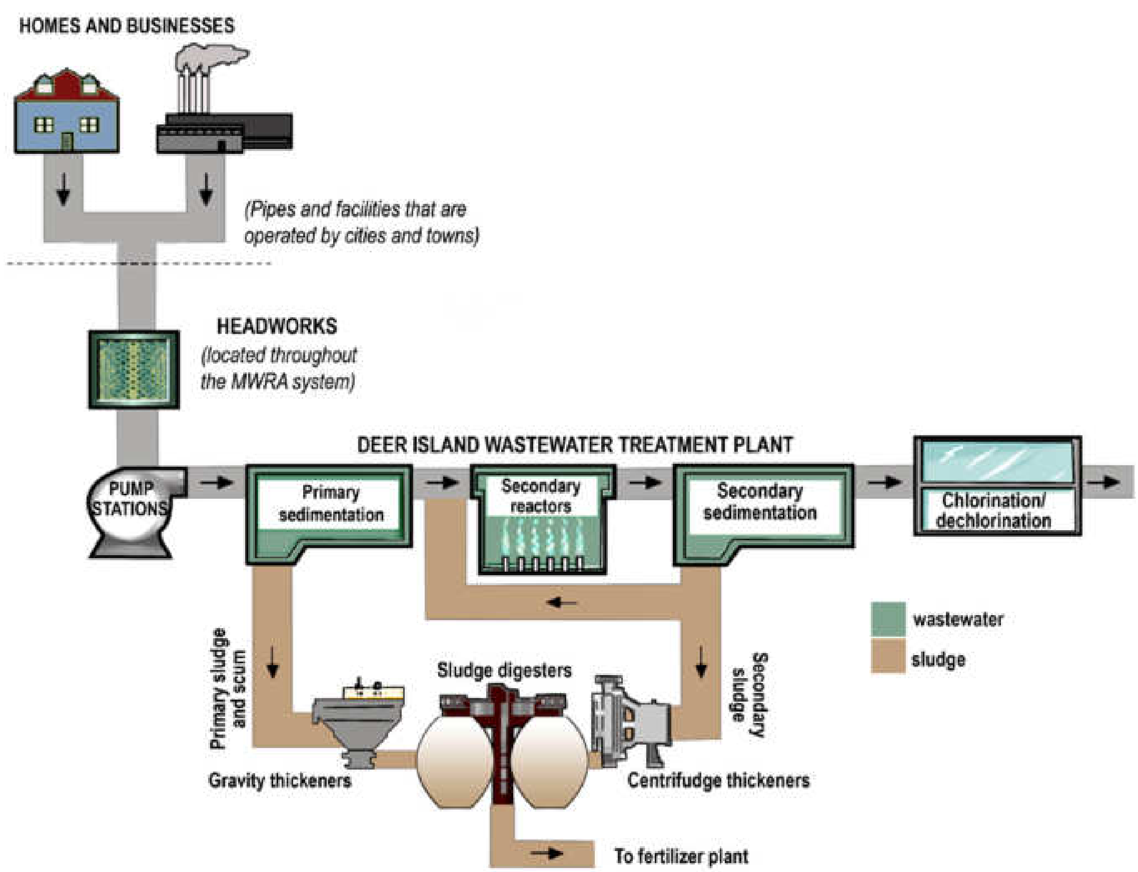
Historically, **microbes**, or microscopic organisms, primarily bacteria, viruses, and protozoans, have constituted the most serious threat to human health in drinking water. Waterborne epidemics of cholera, typhoid, and hepatitis were common before modern water treatment practices. In Albany, New York, the death rate from typhoid fever in 1899 was about 100 cases per 100,000 population. A cholera epidemic in London in 1854 caused about 100 deaths per day. Filtration and disinfection have greatly decreased the danger from waterborne diseases. The health threat from microbial contamination has not, however, been eliminated. In Oregon, for example, more of 10% of the state's water systems are not monitored for bacteria contamination, resulting in a rate of waterborne disease three times greater than the national average. Most water systems in the U.S. test for contamination by bacteria by testing for **coliform bacteria**. These bacteria are present in the gut of mammals, and are therefore present in fecal material. Their presence in water is taken as evidence of fecal contamination, and hence of possible disease-bearing, or **pathogenic**, bacteria. The coliform bacteria themselves do not cause disease, but they are easy to analyze for and serve as **indicator organisms** which indicate the possible presence of other, more dangerous forms of bacteria. Though not perfect, the coliform test has proven to be a useful tool for water testing, resulting in a waterborne disease rate in the U.S. that is among the lowest in the world.

Even when standard water treatment methods are applied, microbial contamination can occur. A relatively recent cause of disease outbreaks has been the protozoan called *Giardia lambia*. **Protozoans** are one-celled animals; parasitic protozoans like *Giardia* need a host like the human gut in which to replicate. In the U.S., from about 1.5% to 20% of the population may carry *Giardia*, though most may show no clinical symptoms. Symptoms usually appear 1 to 4 weeks after infection, and include diarrhea, weight loss, and chronic fatigue. If untreated, *Giardia* and its accompanying symptoms can last for months and even years. An antibiotic called Flagyl has been used to treat *Giardia*, but its side effects include effects upon liver function and a possible association with cancer. Campers, hikers, and fishermen who drink untreated surface water are frequently at risk from *Giardia*. Municipal water supplies have been sources of outbreaks as well. Twenty giardiasis outbreaks were recorded in the U.S. between 1971 and 1977. Most of these were in towns where the only water treatment was disinfection. *Giardia* organisms are more resistant than bacteria to disinfection by chlorination. If chlorination is combined with filtration, protozoan levels in the water can be greatly decreased. Nevertheless, giardiasis outbreaks continue to occur. One episode in 1985 in Pittsfield, Massachusetts affected about 500 of the town's population of 50,000. The protozoan is difficult to detect in the laboratory, and currently there are no federal standards for protozoans in drinking water.

Viruses are also difficult to detect in water supplies and are not currently subject to Federal standards for water quality. The structure of a virus consists only of an outer protein layer and an inner packet of genetic material that enables the virus to reproduce itself after it enters a host cell. Viruses generally can survive in the environment longer than bacteria, and they are more resistant to chlorination. Diseases caused by viruses include polio, hepatitis, and meningitis. It is believed that viral concentrations in water are low compared with bacteria. Some viruses are known to have caused outbreaks of gastrointestinal disorders. A virus called the Norwalk virus, first identified in the early 1970's by an NIH (National Institutes of Health) study of a gastroenteritis outbreak in Norwalk, Ohio, has been implicated in 40% of nonbacterial gastroenteritis outbreak between 1976 and 1980, according to the CDC. Another common virus called rotavirus has caused gastroenteritis outbreaks all over the world. In one episode in Eagle-Vail, Colorado, 30% of the population, some 1500 people, were affected. In this episode it was found that both the filtration plant and the chlorinator for the town's water system were inoperable at the time.

Modern water-treatment plants are designed foremost to protect the public health by removing bacteria and viruses. The Deer Island sewage plant in Boston Harbor is an example of a modern sewage treatment plant. Solid sludge is treated for use as fertilizer, and purifies water is discharged into Boston Harbor.

MWRA Wastewater Collection and Treatment Process



Organic Contaminants

As we have learned in Chapter 10, any compound containing carbon atoms can be classified as organic, and, given the large number of carbon-containing compounds, most of the chemical compounds in the world fall into this classification. Surface water, being in close contact with living organisms, tends to contain considerable organic matter, in dissolved or suspended form. Perhaps the most common type of organic material found in surface water is the **humic acids**, a type of compound also found in humus, the rich soil formed by the decomposition of animal and vegetable matter. Actually, there are many types of humic acids, and the chemical structures of the humic acids have not all been determined. If the water in a pond or river appears brown, the color is probably due to humic acids from organic material that has been washed from the soil or decayed in the water. Though less appealing than crystal-clear water for a swim or as drinking water, this brownish water is not necessarily unhealthy for recreation or consumption, since no known health risks are associated with moderate exposure to the humic acids. Natural filtration mechanisms tend to remove humic acids, so that, unlike surface water, ground water is not likely to contain much organic matter from natural sources.

Dumping or leaching of organic chemicals from man-made sources, however, has added organic contaminants to both ground water and surface water in many communities, and these organic compounds, usually synthetic in origin, can constitute serious health hazards. In one of the more notorious cases of water pollution with organics, in 1975 the James River in Virginia downstream from Life Sciences Products (Allied Chemical) was found to be heavily loaded with Kepone, a pesticide used to control ants and roaches. Estimates of the amount of Kepone in the river sediment have ranged from 22,000 pounds to over 60,000 pounds, and cleanup costs for removing the compound from the river would be at least $3 billion. The Kepone was incorporated into the food chain of the river, and found in marine animals and plants of all sizes. Shellfish harvesting was prohibited in the area, but humans had already been exposed to Kepone-contaminated products of the river and incorporated the substance into their bodies. Recent tests have found decreased Kepone levels in the river sludge, but this may mean only that the material lies buried under new layers of sediment, waiting to be stirred up by a major storm.

The Kepone incident is not an isolated case; industrial dumping has probably been widespread until recently, although few systematic studies have been performed to identify types and sources of dumping. In a study conducted in 1985 an environmental research group named INFORM performed an inventory of toxic chemicals discharged into the Hudson River. Even before the INFORM study it was known that the Hudson, the source of drinking water for over 600,000 people, was contaminated with toxic PCB's (polychlorinated biphenyls), an type of industrial organic chemical used in electrical transformers. Over a period of two decades, 1.2 million pounds of PCB's had been dumped into the Hudson by one company. In addition to the PCB's, INFORM found from discharge permits that in 1982 a total of 22,867 pounds of toxic chemicals had been dumped into the river, and that an additional 771, 000 pounds of oil and grease had been dumped. These quantities probably underestimate the total amount, since only 15% of forms were filled out completely enough for quantities to be estimated. Organics in this total included toluene and the carcinogens chloroform and benzene. Inorganics included lead, cyanide, chromium, and cadmium. In this study based on discharge permits it was found that 66 plants in 49 cities were discharging chemicals into the water. In addition, at least 224 waste discharge streams without permits were identified, and 132 of these involved known or suspect carcinogens. Pesticide runoff from farmland probably contaminated the river as well, since a 1981 report from the Council on Environmental Quality has stated that such sources probably account for over half of all pollution entering U.S. waters. However, quantities from such nonpoint sources is even more difficult to quantify than industrial dumping.

Organics in groundwater are particularly troublesome, since once groundwater is contaminated it remains so for a long time. Numerous groundwater wells that serve as the water supplies for cities all over the U.S. have had to be closed because of contamination from a variety of organics: ethylene dibromide, dioxane, tetrachloroethylene, and trichloroethylene are among the substances that have been found in drinking water supplies at levels far above acceptable limits. Trichloroethylene, a suspect carcinogen which affects the central nervous system, the liver, and kidneys, is used to clean out septic tanks and is a major contaminant of groundwater. Probably the greatest threat to groundwater safety is gasoline from leaking underground storage tanks. One leak of a gallon per day can ruin a water supply for 50,000 people, and an EPA estimate in 1983 gave a figure of 11 million gallons of gasoline leaking into U.S. aquifers each year, carrying benzene and ethylene dibromide along with its hydrocarbon mixture.

Table 17.1 Some Organic Contaminants in Tap Water and Associated Health Risks

Compound	**Industrial Uses**	**Associated Health Risks**
Polychlorinated biphenyls(PCBs)	Plasticizer(banned), insulating material in electrical apparatus,heat transfer medium	Birth defects; liver toxin, skin irritant; probable carcinogen
Benzene	Plastics intermediate Gasoline additive Petroleum refining byproduct	Carcinogen
Carbon tetrachloride	Fire extinguishers, solvents, cleaning agents, grain fumigant	Liver carcinogen
Chloroform	Solvent; byproduct of chlorine disinfection	Carcinogen
p-Dichlorobenzene		Kidney and liver damage
1,2-dichloroethane	Solvent; insecticidal fumigant;paint remover;used in manufacture of vinyl chloride	Irritant; CNS depressant; carcinogen

1,1-Dichloroethylene	Plastics intermediate	Liver and kidney damage
1,2-Dichloroethylene	Degradation byproduct of trichloroethylene and tetrachloroethylene	Anesthetic; liver and kidney toxin
Tetrachloroethylene	Dry cleaning, textile dyeing, metal degreasing, Freon production; pipe liner	Carcinogen
Toluene	Synthesis of other organics; gasoline additive	Affects liver, kidneys, central nervous system
1,1,1-Trichloroethane	Solvent, degreaser, spot remover	Central nervous system depressant
Trichloroethylene (TCE)	Solvent in household products (spot removers, rug cleaners, air fresheners); dry cleaning; septic system cleaner; metal polish	Potential human carcinogen; CNS depressant; anesthetic; can cause liver disfunction at high doses
Vinyl chloride	Monomer of PVC	Carcinogen; mutagen; affects central nervous system, lungs, kidneys, liver, cardiovascular system

Chlorination: the Negative Side

Since chloroform in high doses is known to cause cancer in laboratory animals, its presence in water supplies, or the presence of any of the trihalomethanes (THMs) like bromodichloromethane, dibromochloromethane, or bromoform, is cause for concern. First identified in the water supply of New Orleans in the early 1970's, THMs began to be detected in other water supplies as well. New Orleans water, obtained from the lower Mississippi, which like many rivers is subject to dumping of organics, contains a number of undesirable organics. Only after considerable study was the THM content of New Orleans water and that of other cities linked to chlorination of the water supply.

Without chlorination to disinfect the water supply , we would be subject to plagues of disease caused by infectious microorganisms. About 80% of the U.S. population drinks chlorinated water. Yet studies have shown that the chlorine used to disinfect the water reacts with organics in the water to form THMs and other chlorinated compounds. A typical water treatment plant is depicted in Fig. 17- , showing the various steps at which chlorine is added. The chloroform concentrations measured at each step show that chloroform rises most sharply in the earlier stages of purification when chlorine is added. Chlorination at the final step, after filtration, results in a relatively small increase in chloroform levels. At this point the organics have been reduced, so that the potential for chloroform formation by reacting chlorine with organics is slight. This important insight into the mechanism of chloroform formation is useful. Even a pure, natural surface water supply contains humic acids, harmless in themselves, but capable like other organics of reacting with chlorine to form THMs and other chlorinated organic compounds. One means, then, of reducing THM formation is to control the point at which chlorine is introduced into the treatment process. Other suggested changes in chlorination treatment which have been implemented in a few communities are adding ammonia at the same time chlorine is added. or adding a final charcoal filter at the end of the treatment process to remove THM's. Alternative compounds for disinfection have been proposed: ozone and chlorine dioxide are being used in some treatment plants, though critics charge that little is known about the possible negative effects of these disinfectants when used on a large scale.

Extensive studies on the residents of New Orleans and of other cities with high THM levels have shown a slight but definite link of THMs in drinking water with cancer, especially bladder cancer. Nevertheless, chlorination remains the water treatment for most water supplies which is seen as the least of evils which is currently available to protect public water supplies.

Nitrate

We have already seen that nitrate from human waste, animal waste, and fertilizer runoff can lead to eutrophication of water systems as the nitrate serves as a plant fertilizer. Since water treatment systems do not remove nitrate from the water, nitrate appears in tap water as well, from both surface water and groundwater. The nitrate levels in groundwater increase more slowly than in surface water, but, as with other contaminants, nitrate remains high once it has reached groundwater, and it is very difficult to remove from groundwater. In Iowa, nitrate levels in wells less than 90 feet deep increased 44% from 1950 to 1980, though wells deeper than 90 feet remained unaffected.

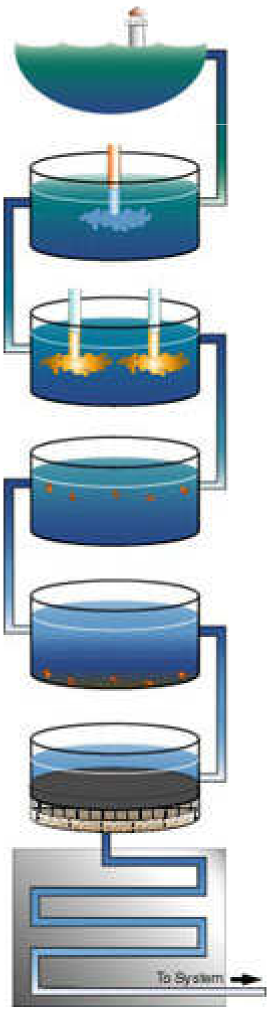
The most serious public health issue from high levels of nitrate may be the risk to infants, which develop a condition called methemoglobinemia ("blue baby syndrome"). Bacteria present in the stomachs of infants can change the nitrate ion to nitrite ion. The nitrite ion can oxidize the Fe(II) ion in the hemoglobin molecule to Fe(III); in this form it cannot take up oxygen. In 1986, an infant in South Dakota died after ingesting formula made from well water with high nitrate levels. Stomach acidity is high enough in adult to inhibit the conversion of nitrate to nitrite, so methemoglomenemia is seldom is problem for adults.

it has been shown, however, that in the conditions present in adult stomachs a small amount of nitrite is formed, a small amount of nitrate ion is changed to nitrite ion, which then goes on to form compounds called **nitrosamines**. Nitrosamines have been shown to be carcinogens. The role of nitrates in drinking water as a cause of cancer is a matter of debate. Since nitrate ions are present in foods, especially vegetables and processed meats, in most areas the water supply is not the major source of nitrates. The current Federal standard for nitrate in water is 10 parts per million. One fourth of private wells in Iowa, Kansas, Minnesota, Nebraska, and South Dakota exceed this level.

Our Drinking Water

So, when we decide how safe or drinking water is, we must first ask where it comes from, what contaminants may be present, and how the water has been treated to remove these contaminants. The Sweetwater Authority of Chula Vista, Californis, shares this information with its customers in an easy-to-understand format:
http://www.sweetwater.org/our_water/treatment_process.html

Robert A. Perdue Water Treatment Plant (traditional treatment)



Sweetwater Reservoir

Disinfection

Coagulation

Flocculation

Sedimentation

Filtration

Clear well

Boston tap water comes from a very pure source in central Massachusetts, and instead of chlorine uses ozone to purify the water without adding halogens. http://www.mwra.state.ma.us/04water/html/watsys.htm But New Orleans must draw its tap water from the Mississippi River, vulnerable to agricultural and industrial runoff , and chlorination of the organic compounds it contains produces carcinogenic halomethanes.

Lead in Tap Water

Heavy metals that can appear in drinking water supplies include lead, mercury, cadmium, tin, zinc, chromium, nickel, iron, copper, and barium. Generally, the action of heavy metals in the body involves interactions with enzymes. Since only a small amount of metal can effect enzyme activity, low concentrations of heavy metals can have a serious health effect. The most widespread type of heavy metal contamination of water is lead.

Lead concentrations in surface water are usually low, ranging from 1 to 10 parts per billion. However, lead is leached out of the solder used for connection in copper pipes and, in very old homes, pipes themselves may be made of lead. Lead is most likely to dissolve from pipes and when the water is soft and acidic; newly solder is more likely to leach lead than old solder. New England cities like Boston, Providence, R.I., and Manchester, N.H. have high lead levels in tap water because the water is soft and acidic. In areas of rapid growth like southern Florida, Colorado, and North Carolina, lead levels are high because the plumbing and solder are relatively recent. A change from the former standard of 50% tin/50% lead solder to 95% tin\5% antimony has been made in the plumbing industry, so that newly installed pipes need not contain lead. Lead concentrations are highest when water has ben sitting in the pipes for several hours. For that reason, the first water drawn in the morning from plumbing systems that contain lead should never be used as drinking or cooking water.

In humans, blood levels of lead greater than 100 ppb can inhibit the enzymes used to synthesize hemoglobin. Levels of 140 to 400 ppb can affect response of peripheral nerves (Peripheral neuropathy), and levels of 400 to 500 ppb have been shown to increase blood pressure in white males. Above 1000 ppb, brain damage occurs in adults. Childrens' brains are more sensitive to lead damage, with low-level exposure linked to learning disabilities and behavioral disorders. Water is only one of many sources of lead exposure. In urban environments air, dust, soil, and paint chips are sources of exposure, especially in children. One in six children under 6 years of age has elevated levels of lead in the blood, about 40% of which is estimated to come from water. A 1986 EPA survey estimated that water with elevated lead levels is a source of lead exposure for more than 40 million Americans. Current EPA regulations allow communities up to 20 years to comply with lead standards by removing old pipes. First, communities may attempt to lower lead levels in water by adding basic materials like sodium bicarbonate and lime to neutralize the acidity of the water. If this method fails, they are allowed 15 years to replace the pipes. Meanwhile, consumers cannot be assured that lead levels in their water are within safe limits.

Name___________________________ ***Date ______________***

CHAPTER 17 PROBLEMS

1. What is distillation?

2. What is transpiration?

3. What is eutrophication?

4. What is the most important purifying step in the water cycle? How does it work?

5. What is an aquifer?

6. What is groundwater?

7. Why does groundwater usually contain few organic contaminants (what is its natural purification mechanism?)

8. Why does groundwater usually contain dissolved in organic compounds?

9. Is hard water hazardous to your health? What is hard water?

10. How can a household's choice of laundry detergent affect eutrophication of a nearby lake?

11. In which type of water supply do you think nutrient runoff could lead to the most serious causes of eutrophication?

a) ocean

b) fast-flowing river

c) small pond

12. All thes compounds have been implicated as carcinogens that can appear in a water supply: carbon tetrachloride,
In the compounds above, what functional group do they all have in common?

14. What is *Giardia lambia*, and what is its effect on public health?

15. Why is chlorination an important step in water treatment?

16. Why is filtration an important step in water filtration?

17. Is lead usually present at high levels in ground water? in surface water?

18. How does lead enter the drinking water supply?

19. What can a community water supplier do reduce lead content in tap water?

20. What can a home owner do to reduce lead in tap water?

21. What are the conditions necessary for the action of aerobic bacteria?

22. Name some products of decomposition by anaerobic bacteria.