Dissolved Oxygen (DO) and pH

Part 1: Dissolved Oxygen

Dissolved oxygen (DO) is an important measure of the quality of lakes, ponds, rivers and the ocean. Fish and plants cannot live without enough oxygen. When you breathe, you inhale air and your blood extracts the oxygen. When fish breathe, they force water through their gills and their blood extracts the oxygen. Plants produce oxygen during the day when the sun shines and photosynthesis is taking place, but they also use oxygen at night when there is no sun.

Sources of Dissolved Oxygen in Water

1 *Plant life:* Plants are the primary source of oxygen in water – as they are on land. When the sun shines on green plants, they undergo photosynthesis and produce oxygen. During photosynthesis, plants take in energy from sunlight and convert carbon dioxide and water into food (carbohydrates) and oxygen. At night, these plants consume oxygen and release carbon dioxide as a byproduct, just as humans do.

The tiniest plants, called *phytoplankton*, produce the bulk of the oxygen that exists both in the water and in the atmosphere. Phytoplankton is part of the mix of microscopic plants and animals we call *plankton*.

In addition to providing oxygen, phytoplankton serves two other important services. It is the bottom of the food chain, and it recycles the chemicals and nutrients in the water into forms that other plants and animals can use. A body of water without phytoplankton cannot support life, clean itself or provide oxygen for living creatures.

2 *Turbulence:* When water mixes with air, like in a waterfall or a rushing stream, it absorbs oxygen from the air. As a result, moving water usually has more oxygen than standing water. Fast-moving streams, waterfalls and ocean surf can contain a lot of oxygen. Likewise, water near the surface of a lake or pond has higher oxygen levels on windy days.

Factors That Affect the Oxygen Level of Water

1 *Temperature:* Warm water holds less oxygen than cool water. Thus, the same healthy stream will have lower DO levels in the summer than in the winter. Sometimes, high summer temperatures can reduce the oxygen level so much that fish suffocate. To make matters worse, fish metabolism usually increases in warmer temperatures, so fish need more oxygen just when there is less of it.

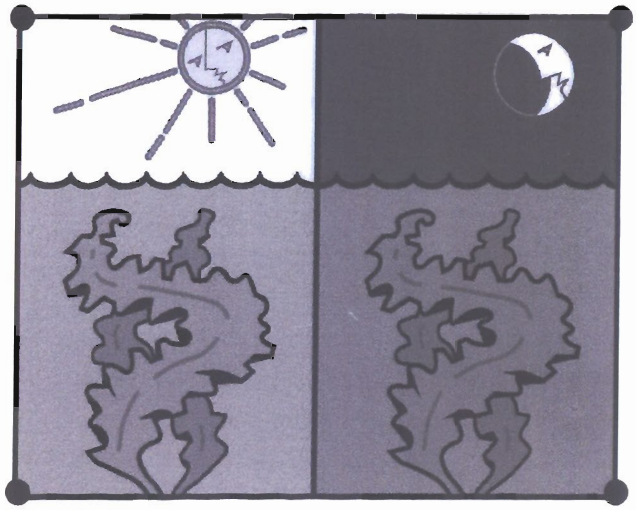
FISH KILLS

You may have seen pictures of a river bank covered with dead fish. People become quite alarmed when massive numbers of fish die. Aside from the unpleasant look and smell of the dead fish, fish kills usually mean bad news. The body of water might be terribly polluted, or the fish might be diseased. In either case, what is bad for the fish might also be bad for humans. Occasionally, however, a fish kill occurs in a healthy body of water to healthy fish during heat waves. The water simply becomes too warm to hold enough oxygen to support the fish.

2 *Organic material:* Organic materials include twigs, leaves, dead insects and animals, as well as sewage and animal waste. The bacteria that break down these materials into basic nutrients use oxygen. A healthy body of water must have enough oxygen to support these bacteria. It must also have enough oxygen left over for fish and other animals. If the water has too much organic material, bacteria can use more oxygen than plants produce during photosynthesis. The oxygen levels become too low to support higher forms of life. Such high levels of organic materials are generally caused by raw sewage or runoff containing animal waste.

3 *Mineral content:* Mineral-rich water, such as hard water, holds less oxygen than pure water or soft water. Sea water contains a high concentration of minerals, and under identical conditions, it can hold only about 80 percent as much oxygen as fresh water. (See Fact Sheet 3: Total Dissolved Solids and Salinity and Fact Sheet 4: Hardness.)

4 *Photosynthesis:* The level of dissolved oxygen is at its highest during sunlight hours in bodies of water containing phytoplankton, algae and other plants. It is at its lowest at night, when the plants are "respiring," or using oxygen and releasing carbon dioxide.



PHOTOSYNTHESIS: Oxygen production

RESPIRATION: Oxygen consumption, and release of carbon dioxide

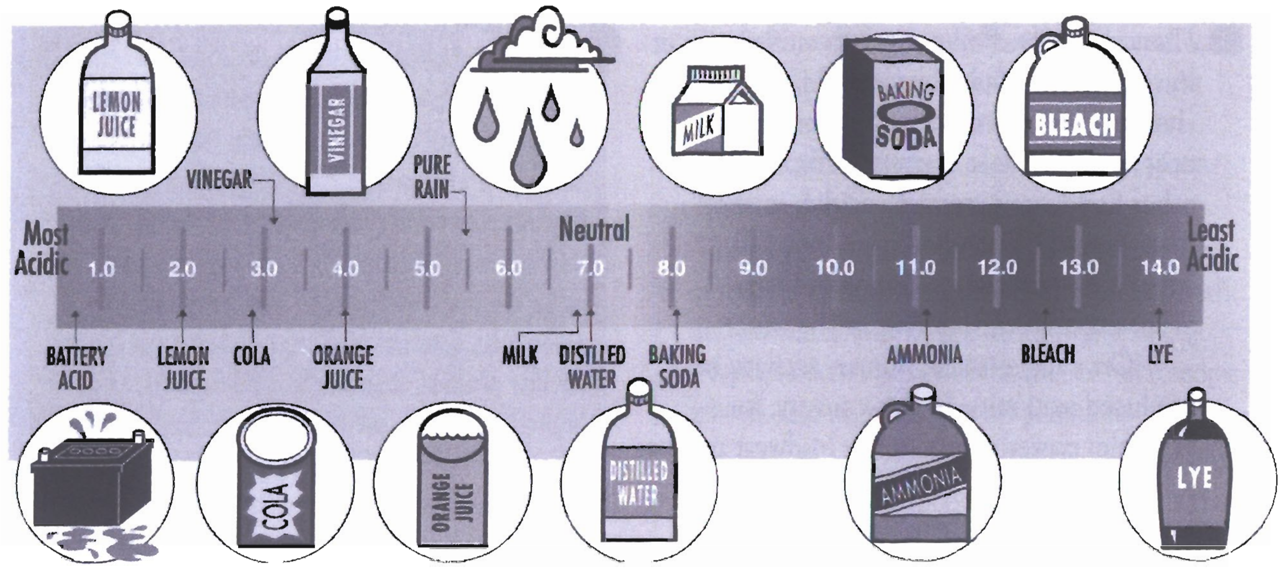
Part 2: pH

pH is another important factor that affects the health of water and determines what organisms can live in it. pH defines the level of acidity in the water. Technically, pH is a measure of the hydrogen ions present in a substance. "Acids" react with certain metals to give off hydrogen ions, so the more acidic a substance, the more free hydrogen ions there are. Acids turn litmus paper red, and acidic foods taste sour.

"Bases," on the other hand, are substances that absorb hydrogen ions. We call bases "alkaline" as opposed to acidic, and the more alkaline the substance, the fewer free hydrogen ions. Bases taste bitter and have a soapy feel. They turn litmus paper blue.

"Neutral" substances have a pH of 7, which defines the midrange between acid and alkaline. "Distilled water" is neutral, so it has pH 7.

pH is measured on a scale from 1 to 14, as shown on the chart on the next page. Anything with a pH below 7 is acidic (more hydrogen ions). A pH above 7 indicates alkalinity (fewer hydrogen ions).



The pH scale is "logarithmic," meaning that each unit along the scale is ten times greater or less than the next unit. A pH 6 is 10 times more acidic than a pH 7. pH 5 is 100 times as acidic as pH 7. Likewise, pH 8 is 10 times as alkaline as pH 7.

pH Below 7		pH Above 7	
↑ High acidity	↓ Low pH	↑ High alkalinity	↑ High pH

According to the chart at the top of this page, how much more acidic is lemon juice than distilled water? How much more alkaline is ammonia than lemon juice?

Factors That Affect the pH Level of a Body of Water

1 *Type of rocks and soils*. The nearby rocks and soils determine a body of water's pH level, as well as how much the pH changes each day. Some rocks, such as limestone, dissolve easily in water and are naturally alkaline. They keep the pH on the alkaline side of neutral. Very hard bedrock, such as granite, does not dissolve easily. As a result, the pH of the water is more easily influenced by other factors, such as air pollution or the type of plants growing nearby.

Some rocks and soil also contain metals, some of which are harmful to the health of people and animals. These metals dissolve more easily in acidic water than in alkaline water. Thus, acidic water can contain more harmful metals than neutral or alkaline water.

2 *Level of biological activity in the water*: Active plants and animals produce carbon dioxide when they breathe. Carbon dioxide dissolves in water to form carbonic acid. Thus, respiring plants and animals increase the acid content of the water and lower the pH level.

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

(Carbon dioxide) (Water) (Carbonic Acid)

THE "DIURNAL" CYCLE

The word "diurnal" means occurring during the 24-hour day. The diurnal cycle causes natural changes each day in the chemistry of a body of water. As the sun rises, photosynthesis starts, and plants start making oxygen. As the sun sets, the plants respire at a faster rate, meaning that they use oxygen and release carbon dioxide. In water, this carbon dioxide immediately forms carbonic acid, turning the water acidic.

3 *Human activity* Pollutants can either raise or lower the pH level. For example, pollutants that contain ammonia are alkaline, so they raise the pH levels. Battery acids, on the other hand, are extremely acidic, so they lower the pH. Such pollution may kill aquatic life, or it may change the type of species that can survive in the water.

On a larger scale, human activity has produced acid rain. In this country, for example, power plants in the Midwest release sulfur and nitrogen gases. These gases dissolve in the atmosphere's water vapor, making the vapor very acidic. The vapor blows toward the northeast and falls as acid rain. Most soil in the Northeast lies over granite bedrock, so it cannot neutralize the acid. Some lakes in the eastern U.S. are so acidic that they are completely dead, containing no plants or animals.

BALANCING pH IN WATER SUPPLY SYSTEMS

Balancing pH in drinking water systems helps protect the water pipes and human health. Water that is too acidic (low pH) corrodes metal pipes and plumbing fixtures. Corrosion causes poisonous metals, such as lead, to dissolve (leach) in the water. It can also make the pipes disintegrate. Alkaline water, on the other hand, does not leach metals, but it can cause another problem. It causes mineral deposits, which are called scale, to build up in the pipes. Over time, so much scale can build up in pipes that water cannot flow through them. To avoid these problems, water agencies treat their water to maintain a fairly neutral pH level.

Turbidity

A cup of water from a swimming pool may look clean enough to drink, but it's not. A cup of water from a stream, on the other hand, is probably full of floating particles. The term *turbidity* refers to the amount of these undissolved, suspended particles in water.

Most turbidity is caused by dirt, dust and organic material, such as plankton, algae and leaves. Until recently, water quality experts considered turbidity an "aesthetic" concern, meaning that it only affected the water's appearance. They thought that microscopic algae generally does not cause any harm as long as the water is disinfected to kill disease-causing germs.

Today, experts have changed their thinking about turbidity. Now they know that some microorganisms are hard to kill and that using extra disinfectant can be unhealthy. They also realize that algae and plankton in turbid water

Can you think of ways the surrounding environment may impact the turbidity of this river water?

provide a good habitat for these microorganisms. Turbid water simply is not high-quality drinking water. Water agencies now meet tougher standards for turbidity.

It is fairly easy to reduce turbidity using a combination of settling and filtration. Letting water sit in a clean, undisturbed environment allows solid materials to settle to the bottom. For example, a stream carries muddy water into a reservoir, but that muddy water takes months or years to move across the reservoir before it is used. In that time, gravity causes the suspended solids to settle to the bottom or float to the shore, so the water is clear. Filtering water reduces turbidity even more. Water agencies let water seep through charcoal filters, sand and gravel. This approach mimics the earth's natural filtration but works much faster. Groundwater is usually clearer than surface water, because it is filtered through sand and gravel as it seeps through the earth.

Total Dissolved Solids and Salinity

When rain falls to earth, the water starts to dissolve the minerals and salts in rocks and soil. These dissolved minerals are called *total dissolved solids* (TDS). In the western U.S., water usually contains dissolved minerals such as sodium, calcium, magnesium and potassium.

Since most of these minerals are "salts," measuring the TDS in water gives us a measure of its "salinity" or its saltiness. The amount of TDS in water determines whether the water is *fresh water, brackish water* or *salt water*. It also determines what type of plants and animals can live in a certain body of water. For example, different plants and animals live in brackish water than in fresh water.

These classifications also determine how we can use a body of water. For example, brackish water and salt water are seldom used as a source of drinking water, while they may be used for recreation, fishing or industrial cooling.

Measuring TDS

Chemically, dissolved mineral salts have atomic structures that make them good conductors of electricity. As a result, the TDS level of water affects its ability to conduct electricity! The more conductive it is, the higher its level of TDS.

HOW DID THE SEAS GET SALTY?

Where did the salt in the oceans come from? One theory explains it this way: As water runs across the earth, minerals dissolve in it. This water eventually runs into the oceans and then evaporates. As it evaporates, it leaves its dissolved salts behind. Over millions of years, the level of salinity in the ocean rises very, very slowly.

SOUTHERN CALIFORNIA'S WATER AND TDS

Southern California's water is a mixture of water from Northern California, the Colorado River and local underground aquifers. The water from the Colorado River flows from the western slope of the Colorado Rockies and across about 1,000 miles of the alkaline soil of the American West. Along the way, it picks up minerals. The TDS of your tap water, therefore, varies depending on the "mix" of water from different sources. Colorado River water has higher TDS, while water from the north usually has lower. The TDS of our water tends to be at its highest in August and September after the dry summer, and at its lowest in the spring, when the snowmelt dilutes the minerals.

SALT BUILDUP IN CALIFORNIA'S WATER SUPPLY: A PROBLEM OF THE 21ST CENTURY

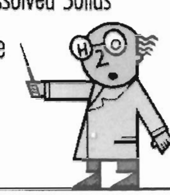
Water flowing into Southern California from the Colorado River tends to be naturally high in salts. The salt content of water from the State Water Project in Northern California varies from year to year depending on precipitation and drought. In addition, efficient water use practices, such as water conservation, water reuse and water recycling, tend to raise salt levels because they provide less opportunity for diluting salts. As a result, the TDS of Southern California's water supplies are slowly increasing. Eventually, these increasing levels may become problems for agriculture because salty water lowers the crop yield, for industry because it will increase the amount of scaling, and for homes because our water will be even harder than it already is. Limiting and controlling this salt buildup will be an important challenge to water specialists in the next century.

Hardness

Hard water has high levels of two minerals: calcium and magnesium. Calcium is the principal mineral in lime and limestone. You don't really need a lab to tell you if your water is hard. You can usually tell by the way it behaves when you shower or bathe.

DEFINITIONS

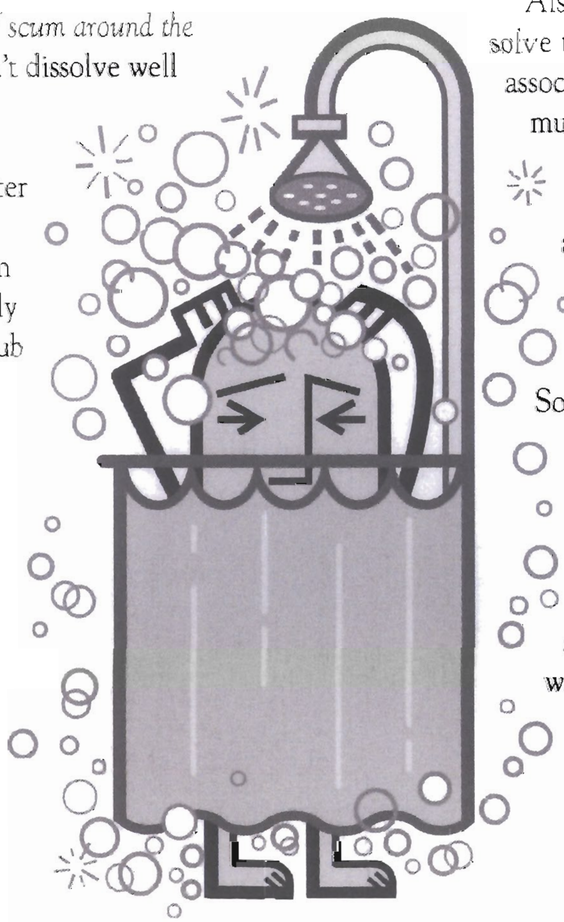
"Hard Water" refers to water with high amounts of the minerals calcium and magnesium. Total Dissolved Solids is a measure of all dissolved minerals, while hardness is a measure of just calcium and magnesium.



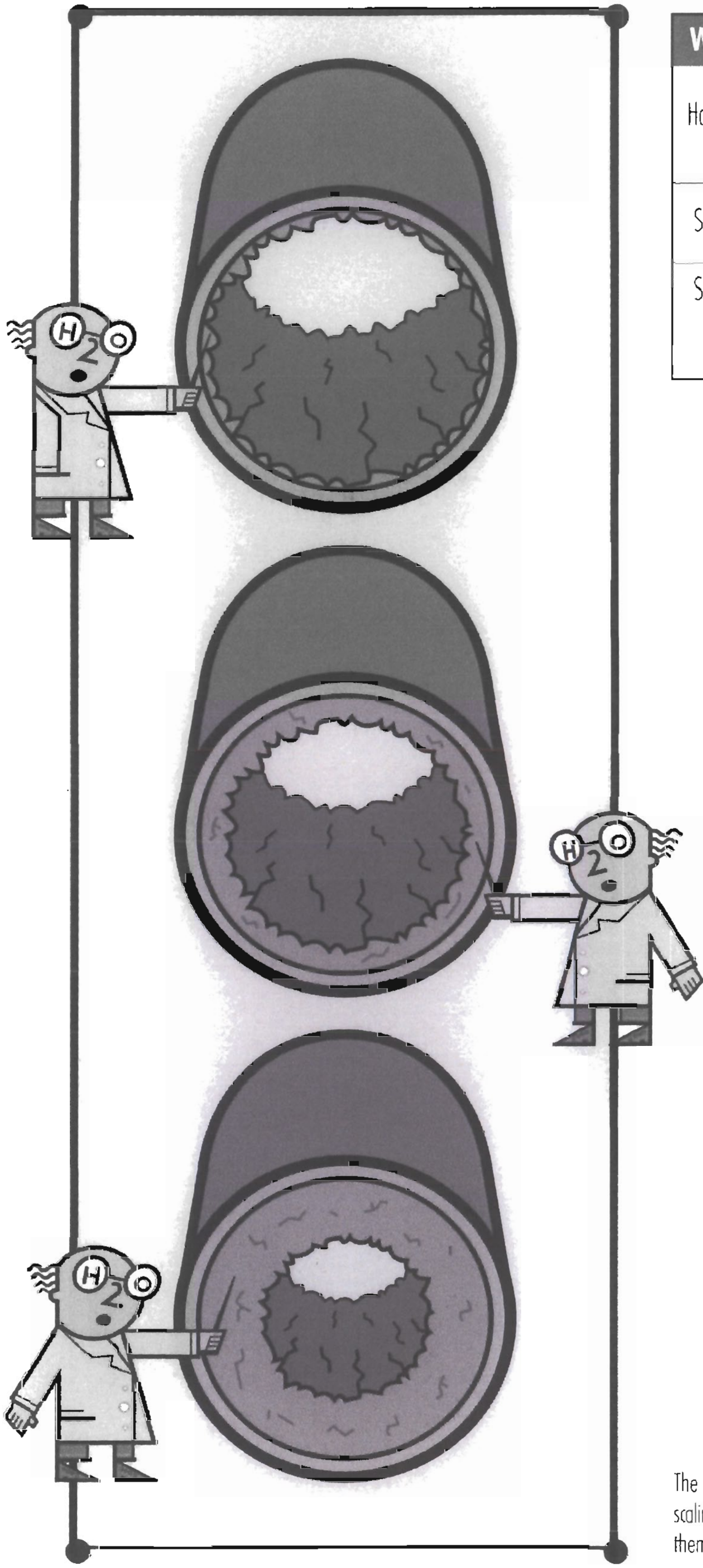
Hard Water and Soft Water

There are a few visible differences in hard and soft water.

1. *Soap or detergent does not lather very much in hard water.* Soap dissolves more easily in soft water than hard. As a result, soap may become very sudsy and bubbly in soft water, but it may not suds at all in hard water.
2. *Hard water leaves a ring of scum around the bathtub.* Since soap doesn't dissolve well in hard water, the minerals and soap settle out of the water. Thus, hard water leaves a ring around the tub after a bath and a film on shower doors. The only way to get rid of it is to scrub or use a special cleaning product that dissolves the minerals.
3. *Hard water causes scale to build up inside pipes.* The minerals in hard water can settle out when the water sits in pipes for a while. They build up as a "scale" inside plumbing pipes, eventually leaving no room for the water to flow. When that happens, the pipes need to be replaced. For that reason, many homes with hard water use water softeners, which replace calcium and magnesium with sodium.
4. *Preventing this buildup requires a trade-off.* Water softeners solve one problem but create another. They work by replacing the calcium and magnesium with sodium. The sodium, however, can be harmful to people on low-sodium/low-salt diets as well as to house plants. Also, while water softeners solve the plumbing problems associated with having too much scale, some scale can be good for your health. Scale covers the lead and copper found in many pipes and prevents them from leaching into the water. Soft water, on the other hand, can dissolve these metals, making the water potentially harmful to drink. Soft water can also corrode plumbing, sometimes making pipe walls so thin they can't hold water.



Water	Associated Problems
Hard Water	Scale in pipes, poor sudsing, rings around the tub
Softened Water	Added sodium can cause health problems
Soft Water	Corrodes pipes, leaches potentially harmful metals

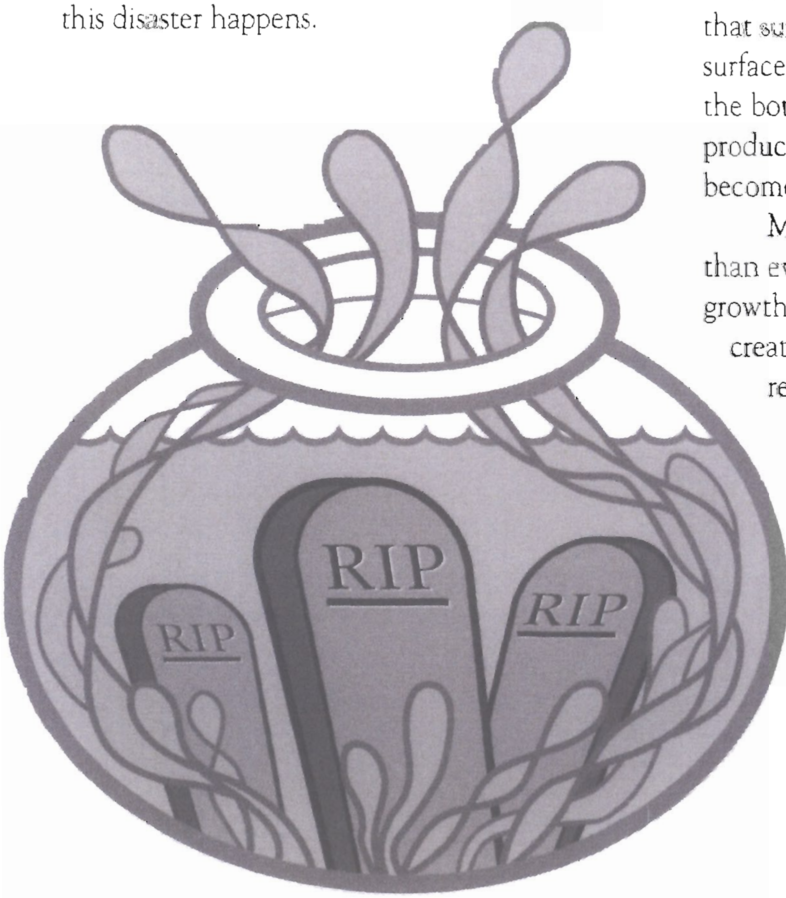


The minerals in hard water cause scaling in pipes, eventually clogging them completely.

Nutrients

In simple terms, nutrients are fertilizers. They include nitrates, phosphates and potassium. Plants need nutrients to grow and stay healthy. In nature, most nutrients come from animal wastes and decaying plants and animals. Human activity (such as fertilizing, septic tanks and sewage treatment plants) adds extra nutrients to the land and water.

A healthy ecosystem has a balance between the nutrients entering the water and those used by plants and animals. Too many nutrients in water can upset this balance. Excess nutrients cause so much plant growth that a body of water becomes choked and can even begin to "die." Here's how this disaster happens.



Too Many Nutrients: A Disaster in the Making

Let's start at the bottom of the food chain: plankton and algae. These small plants maintain the health of natural bodies of water. When the sun shines, they photosynthesize and produce oxygen. At night, they respire, consuming oxygen and producing carbon dioxide.

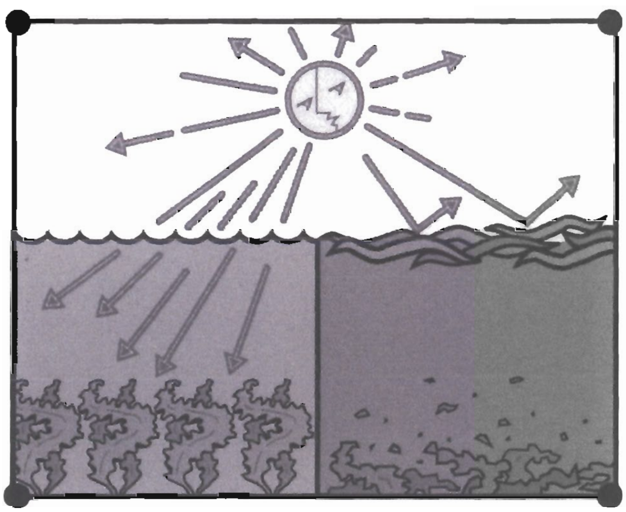
When too many nutrients enter the water, these plants grow more. At first, the effects seem good: fast plant growth produces lots of oxygen that fish and other animals need during the day.

However, several negative things begin to happen. An "algal bloom" appears on the water's surface. The plant growth becomes so thick that sunlight cannot reach the plants under the surface. The plants beneath the surface and on the bottom do not photosynthesize, so they don't produce oxygen. The water below the surface becomes starved for oxygen.

Meanwhile, the need for oxygen is greater than ever beneath the surface. The rapid plant growth on the surface attracts fish and other creatures. These creatures use oxygen, and they release waste products: scales, skin, food waste and feces. The bacteria that decompose the waste need a lot of oxygen, but the water where they do their work has very little oxygen left. This condition becomes even more severe at night when the plants respire.

Soon, the fish, bacteria and other organisms below the surface begin to die from lack of oxygen. There is now more waste material, but fewer bacteria. Over time, the water becomes "dead" from lack of oxygen.

Eventually the bacteria that require oxygen die off. These bacteria need oxygen to live, so they are called *aerobic*. As they die, the aerobic bacteria are replaced by bacteria that do not require oxygen in the water, called *anaerobic* bacteria. Anaerobic bacteria get oxygen by slowly breaking down the decaying organic material. For example, they break down the nitrate (NO_3) in organic material into nitrite (NO_2), and use the extra oxygen atom for themselves.



In healthy bodies of water, sunlight shines through the water, so plants at the bottom undergo photosynthesis and produce oxygen. In water high in nutrients, the surface stays green and oxygen-rich, but sunlight does not penetrate through the thick mat of plants. The water beneath the surface becomes starved for oxygen, and the plants and fish that live at the bottom begin to die.

In anaerobic environments, everything happens very slowly. It takes anaerobic bacteria years instead of days or weeks to decompose the dead material. Over the years, the body of water becomes clogged with more dead organic material. Eventually, it can fill up and become a swamp. In time, the swamp may dry up and become a meadow.

This "death-of-a-pond" process is called *eutrophication*, and it happens naturally to many water bodies over centuries. However, human activity is adding extra nutrients to the ecosystem through sewage, farming and fertilizing. Many ponds and lakes are dying prematurely because we are speeding up the eutrophication process and altering the natural biological balance of a body of water. As a result, healthy ponds become choked with plants and begin to die.

To prevent bodies of water from dying before their time, we need to protect them from sources of excess nutrients. You and your family can help keep excess nutrients out of the water by:

- ▲ Limiting the amount of fertilizer you use on your lawn and garden;
- ▲ Not fertilizing right before a rain, so less is washed away before it is used by the plants;
- ▲ Using organic fertilizers that release their nutrients slowly, so less is washed away and the plants receive a more steady diet of nutrients;
- ▲ If you have a septic tank, have it inspected to be sure it is not leaking, and maintain it regularly.

Taste and Odor

Taste and Odor

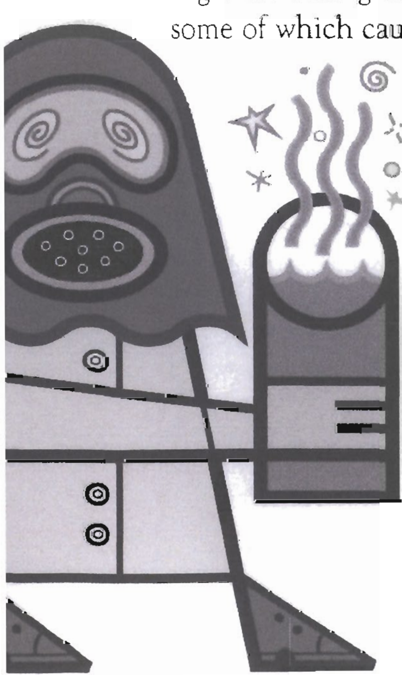
Have you ever thought the water from your tap smelled like freshly turned dirt in a garden? While such things do not happen often, they do happen now and then, and when they do, some people are more sensitive to them than others.

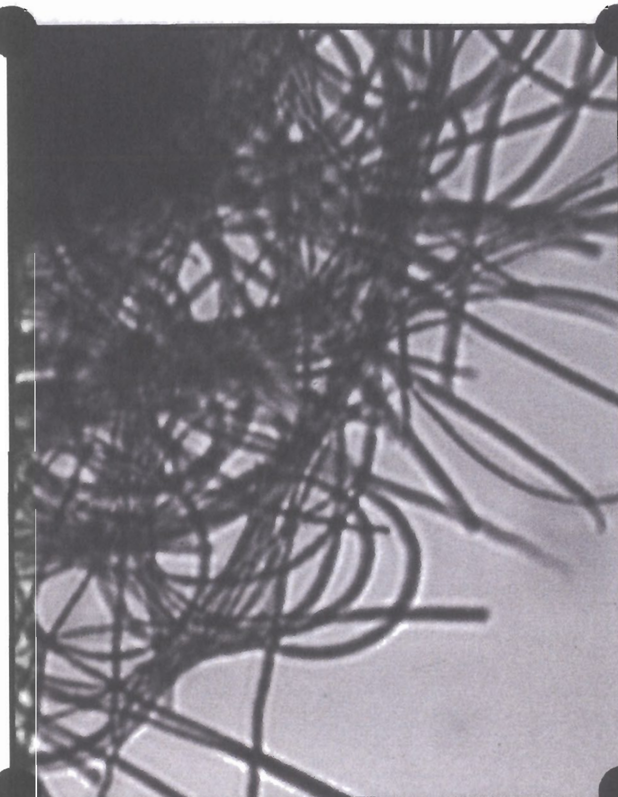
That smell generally results from algae. Some kinds of algae release a smelly chemical called methyl isoborneol, or MIB. It affects the taste of the water. Fortunately, the water stays safe to drink, but it tastes and smells bad.

As a result, many water agencies have "taste and odor panels" of experts who test the drinking water to make sure it meets their standards.

Algae

Algae are a large group of photosynthesizing aquatic organisms with a range of different qualities. Some are plants, while others belong to other kingdoms, such as "protista." Some are single-celled, while others are huge, like kelp. Among the smallest forms of algae are blue-green algae and diatoms, some of which cause water to smell bad. Diatoms cause a "fishy" odor, and blue-green algae cause a "fresh dirt" smell. Filtration can remove the algae, but it cannot remove the odor. As a result, odors must be treated at the reservoir where the algae grow.





These are some of the blue-green algae that affect the smell of water.

Treating the Algae that Cause Odors

In the past, water agencies have tried to prevent these odors by killing the algae that caused them. They did this by adding copper sulfate ($CuSO_4$) to the water supply. However, no one likes the idea of adding a compound containing metal to a water supply. As a result, scientists looked for other ways to keep the algae out of the reservoirs.

One method is to reduce the amount of algae that grows in the first place. Based on what you learned in Fact Sheet 5: Nutrients, can you think of one type of action that might help reduce algae? If you answered, "Reduce the nutrients that increase algae growth," then you are thinking like a water scientist. But such action requires the cooperation of many people in the surrounding watershed. Such cooperation can be hard to achieve, especially when the watershed includes different cities, counties or even states.

Limnology

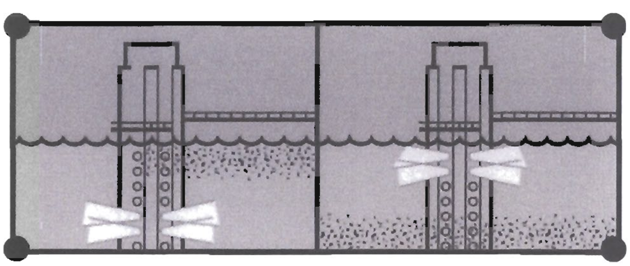
Scientists called "limnologists" have helped water agencies come up with another, safer method to keep the odor out of water. Limnologists study fresh water ecosystems. Limnologists have found that water supply reservoirs "stratify," or separate into layers. If you have ever been swimming in a lake and suddenly hit a cold spot, you've experienced stratification.

These layers have different temperatures, amounts of sunlight, nutrients and levels of dissolved oxygen. The layers are not always the same because of daily and seasonal temperature changes, as well as other variations.

Algae do not live evenly throughout a body of water. They live in the layer where there is the right mix of sunlight, temperature and nutrients. Water at one layer may be free of algae (and odor), while water from a higher or lower layer may have a lot.

Some water agencies take samples of water at different layers and locate the layer that has the least algae – and thus the least odor. Then they adjust the water intake pipes so the water treatment plant draws in algae-free water. The location of an algae-free layer may change from week to week and from season to season, so these water agencies have developed an adjustable system of intake pipes.

However, since not all reservoirs stratify, water agencies cannot always selectively withdraw algae-free water. Sometimes a water agency must still use chemicals to reduce foul-smelling algae in your drinking water.



This adjustable intake system allows water agencies to withdraw water from a layer of the reservoir that is free of odor-causing algae.

At the Metropolitan Water District, a small group of scientists make regular dives into the water supply reservoirs to observe and study the growth and movement of algae. This dive team includes biologists, chemists and limnologists.

AN ELECTRONIC SNIFFER?

In addition to MWD's taste and odor panel, the water agency also uses a Gas Chromatograph/Mass Spectrometer (GC/MS) to find the exact amounts of taste and odor compounds in water. These data help determine whether or not action needs to be taken to reduce unpleasant qualities in the water.

Microorganisms: Size, Scale and Filtration

Microorganisms and Health

Microorganisms are organisms too small to see with the naked eye. They include bacteria, viruses and protozoa. Many of these "microbes" live in water. Most are harmless to humans, but some can cause dangerous, even fatal, diseases. The harmful microorganisms in water cause serious public health problems worldwide. Each year, more than 3 million people die from diarrhea caused by waterborne diseases such as *cholera* and *dysentery*.

To protect the public's health, water agencies in the United States kill the microorganisms in drinking water. This process is called *disinfection*.

In addition, many water agencies also filter the water. While filtration may seem like a "low tech" process, it is extremely important since there are disadvantages to most disinfection processes.

Disinfecting water with chemicals creates a new set of problems. Some chemicals may form byproducts that create health concerns. As a result, it is becoming more and more important to filter the drinking water supply.

E. COLI: AN INDICATOR SPECIES

There might be hundreds of different pathogens in raw water, and identifying each one would be impractical. As a result, water scientists look for one easy-to-find microorganism – *Escherichia coli* (a form of coliform bacteria). *E. coli* is called an indicator species because it "indicates" that there are other microorganisms as well, some of which might be harmful to humans. As a result, water quality specialists adjust the level of disinfection according to the amount of *E. coli*.

Filtration

Filtering water can remove many of the microorganisms before disinfection. Doing this lessens the need to use harsh chemicals and reduces the related side effects. To catch and remove the microorganisms, however, the openings in the filter must be so small that the microscopic organisms cannot sneak through.

Microorganisms come in many different sizes. While they are all too tiny to see with the naked eye, the relative differences in the sizes are immense. For example, a common bacterium is 0.02 millimeters long. How tiny is that? Try dividing the millimeter marks on your ruler into hundredths! But a bacterium can be 10-times smaller than that, measuring two microns, or only 2 one-thousandths of a millimeter (0.002 mm). A virus can be 10-times smaller yet again, measuring only 0.2 microns or 2 ten-thousandths of a millimeter (0.0002 mm).

Numbers, Concentrations and Scientific Notation

Scientists use scientific notation for simplifying the communication of very large and very small numbers. Scientific notation is the number ten followed by an exponent sign (such as 10^2, 10^5, or 10^{-8}). The exponent sign indicates the number of zeros following the number one. So 10^1 is ten, and 10^6 is one million (1,000,000).

Negative exponents indicate fractions. They are the number of digits to the right of the decimal. So 10^{-1} is .1 (one-tenth), 10^{-2} is .01 (one one-hundredth), and 10^{-6} is .000001 (one one-millionth).

To indicate units between these factors of 10, scientists write a number and multiply it by the factor of 10. The number 50, therefore, would be 5×10^1, which is the same as 5×10. The number 3,600,000 would be written as 3.6×10^6.

Chart of Scientific Notation

Scientific Notation	Number	Word	Abbreviation
10^9	1,000,000,000	one billion	
10^8	100,000,000	one hundred million	
10^7	10,000,000	ten million	
10^6	1,000,000	one million	
10^5	100,000	one hundred thousand	
10^4	10,000	ten thousand	
10^3	1,000	one thousand	
10^2	100	one hundred	
10^1	10	ten	
10^0	1	one	
10^{-1}	.1	one one-tenth	
10^{-2}	.01	one one-hundredth	
10^{-3}	.001	one one-thousandth	
10^{-4}	.0001	one ten-thousandth	100 ppm
10^{-5}	.00001	one one-hundred-thousandth	10 ppm
10^{-6}	.000001	one one-millionth	1 ppm
10^{-7}	.0000001	one ten-millionth	100 ppb
10^{-8}	.00000001	one one hundred-millionth	10 ppb
10^{-9}	.000000001	one one-billionth	1 ppb

A COMMUNICATION CONFUSION

Scientists in different disciplines use the term "ppt" to mean two different things. Sometimes it means "parts per thousand," and other times it means "parts per trillion," a difference of 1 billion. Be careful!

The Universe by Factors of Ten

In round numbers, people are approximately 2 meters tall (even though very few of us really measure that). If we moved into and away from that person in steps of one factor of ten, here's what we would see:

2 X 10^{-9} meters	molecule of cholesterol	2 nanometers
2 X 10^{-8} meters	polio virus	.02 microns
2 X 10^{-7} meters	smallpox virus	.2 microns
2 X 10^{-6} meters	one *Cryptosporidium* oocyst	2 microns
2 X 10^{-5} meters	*E. coli* bacterium	.02 millimeters
2 X 10^{-4} meters	thickness of an index card	.2 millimeters
2 X 10^{-3} meters	width of a pencil "lead" from a wooden pencil	2 millimeters
2 X 10^{-2} meters	diameter of a penny	.02 meters
2 X 10^{-1} meters	one outstretched adult hand	.2 meters
2 X 10^{0} meters	person	2 meters
2 X 10^{1} meters	length of a large whale	20 meters
2 X 10^{2} meters	a city block	200 meters
2 X 10^{3} meters	slightly more than one mile	2 kilometers
2 X 10^{4} meters	the distance from downtown Los Angeles to Santa Monica	20 kilometers
2 X 10^{5} meters	distance from Los Angeles to San Diego	200 kilometers
2 X 10^{6} meters	distance from Los Angeles to Denver, Colorado	2,000 kilometers
2 X 10^{7} meters	one-half the circumference of the earth	20,000 kilometers
2 X 10^{8} meters	one-half the distance from the earth to the moon	200,000 kilometers
2 X 10^{9} meters	1.3% of the distance from the earth to the sun	2,000,000 kilometers

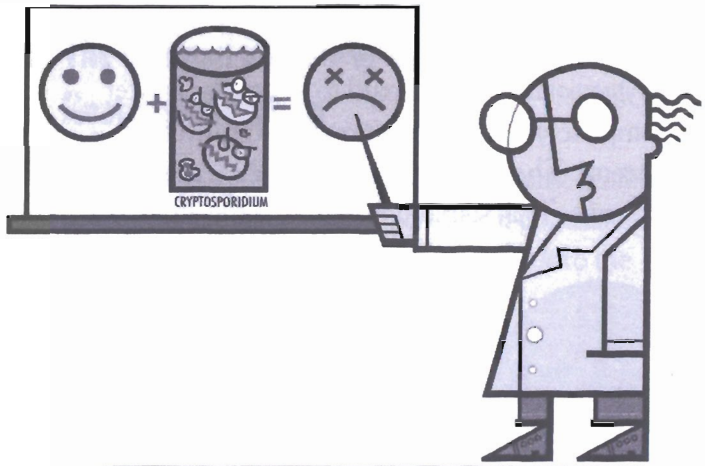
Chart of Scientific Notation

Scientific Notation	Number	Word	Abbreviation
10^9	1,000,000,000	one billion	
10^8	100,000,000	one hundred million	
10^7	10,000,000	ten million	
10^6	1,000,000	one million	
10^5	100,000	one hundred thousand	
10^4	10,000	ten thousand	
10^3	1,000	one thousand	
10^2	100	one hundred	
10^1	10	ten	
10^0	1	one	
10^{-1}	.1	one one-tenth	
10^{-2}	.01	one one-hundredth	
10^{-3}	.001	one one-thousandth	
10^{-4}	.0001	one ten-thousandth	100 ppm
10^{-5}	.00001	one one-hundred-thousandth	10 ppm
10^{-6}	.000001	one one-millionth	1 ppm
10^{-7}	.0000001	one ten-millionth	100 ppb
10^{-8}	.00000001	one one hundred-millionth	10 ppb
10^{-9}	.000000001	one one-billionth	1 ppb

A COMMUNICATION CONFUSION

Scientists in different disciplines use the term "ppt" to mean two different things. Sometimes it means "parts per thousand," and other times it means "parts per trillion," a difference of 1 billion. Be careful!

Cryptosporidium and Genetic Tests



Cryptosporidium: A New Shock to the Water Industry

Together, filtration and disinfection have saved countless lives and prevented billions of illnesses. In recent years, however, we have become aware of a tiny microorganism that can survive chlorine disinfection and can sneak through filters in very small numbers.

That microorganism is a tiny parasite called *Cryptosporidium parvum*. It causes a disease called "cryptosporidiosis." In a person with a healthy immune system, cryptosporidiosis can be highly unpleasant: severe diarrhea, nausea, vomiting and headaches, and it may last one or two weeks. Other than our own immune systems, there are no known cures for the disease. The disease is very serious for people with weakened immune systems, such as people with AIDS and other diseases, as well as for people undergoing chemotherapy treatment for cancer. These people may be sick for months or years, or they may die.

SOURCES OF *CRYPTOSPORIDIUM*

Humans can become infected with *Cryptosporidium* in several ways:

- ▲ Drinking water that has been contaminated with infected feces from humans or animals. The most common sources for this contamination are sewage and domesticated or wild animals.
- ▲ Eating food that has been contaminated by improper sanitation in food-handling warehouses, restaurants or private homes.
- ▲ Touching feces while using the toilet, changing diapers or handling animals, followed by failure to wash hands properly.

CONTROLLING *CRYPTOSPORIDIUM*

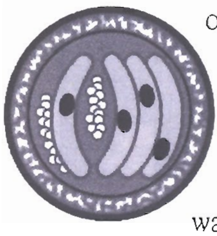
- ▲ If drinking water is contaminated with *Cryptosporidium*, the best protection is to boil water for at least one minute before drinking and cooking.
- ▲ Most other sources of infection can be prevented by thoroughly washing hands after using toilets, changing diapers and handling animals – and before handling food.

Hidden Spore

In Greek, the word *Cryptosporidium* means "hidden spore," and in many ways that is what it is. *Cryptosporidium* is a "parasitic oocyst" (pronounced "oh-oh-sist"). A parasite is an organism that depends on another "host" organism for food and cannot live independently. An oocyst is a protective shell within which protozoa develop. This shell allows the organism to survive for a long time outside the body of the host. *Cryptosporidium's* hosts include mammals, birds and fish, and it can be spread through the feces of an infected animal, or through water and food that has been contaminated with feces. Once swallowed, it may cause illness in two to 10 days.

Cryptosporidium's protective shell does more than allow it to survive a long time while waiting for a host. It also makes the organism difficult to kill with chlorine or chloramine. For these disinfectants to work, the organism must be in contact with them for a long time, and this would be impractical for water treatment.

In addition to being hard to kill, *Cryptosporidium* is also hard to filter out of water completely with conventional water filtering systems. These systems are about 99.9 percent effective. That sounds very good, but even so, one of every 1,000 oocysts sneaks through. It only takes a small number of oocysts to make a vulnerable person sick.



Fortunately, *Cryptosporidium* can be killed by boiling water for five to 10 minutes. Thus, when water agencies know their treated water might be contaminated, they alert the public and advise them to boil water before using it for drinking, cooking or feeding pets.

Finding *Cryptosporidium*

It is very hard to know when *Cryptosporidium* is actually present in a water supply. Conventional tests for *Cryptosporidium* are expensive and often inaccurate. A negative result, therefore, does not confirm that there are no *Cryptosporidium* in the water, only that they were not found!

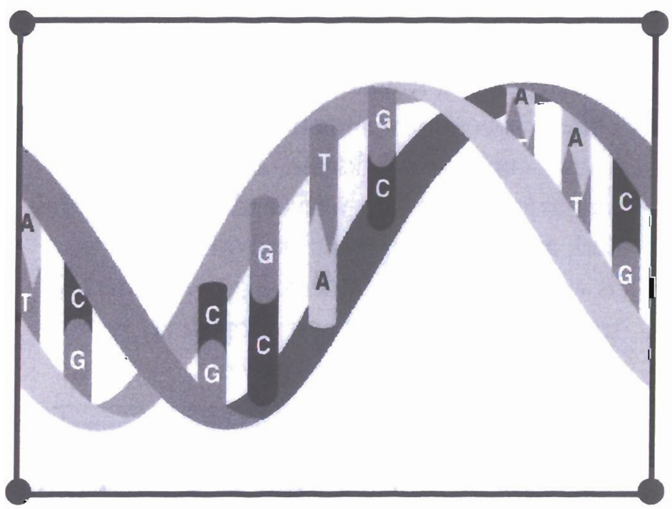
In addition, the tests for *Cryptosporidium* do not indicate if it is alive, or "viable." Only viable *Cryptosporidium* cause disease, so people do not have to boil water if the *Cryptosporidium* is dead. Further, there are several species of *Cryptosporidium*. Only the species *Cryptosporidium parvum* (abbreviated C. *parvum*) is known to cause disease in humans. But existing tests cannot distinguish between C. *parvum* and other species.

Clearly, scientists need better technology for identifying when *Cryptosporidium* poses a threat to human health. The Metropolitan Water District has developed a new test to identify the presence of viable *Cryptosporidium* using the tools of microbiology and genetics.

A Genetic Primer

DNA (deoxyribonucleic acid) is the molecule that makes up chromosomes and holds all the genetic information for an organism. The DNA molecule is a long double strand made up of only four chemical bases: adenine (A), cytosine (C), guanine (G) and thymine (T).

In forming the double strand, A and T always bind together and G and C always bind together. Thus, every time the base A appears on one strand, the base T appears on the other strand. These matches are called "complementary base pairs," because they are always exact complements of each other. If two strands become separated (as they sometimes do both within the cell and in the research lab), the complementary bases seek each other out and reattach. If the two strands are not perfect complements, they will not attach at all.



DNA consists of only four bases: adenine (A), thymine (T), guanine (G) and cytosine (C). A only binds with T, and C only binds with G. When the double strand of DNA is separated, the single strand will bind to its exact complement, and it will not bind to any other sequence of DNA.

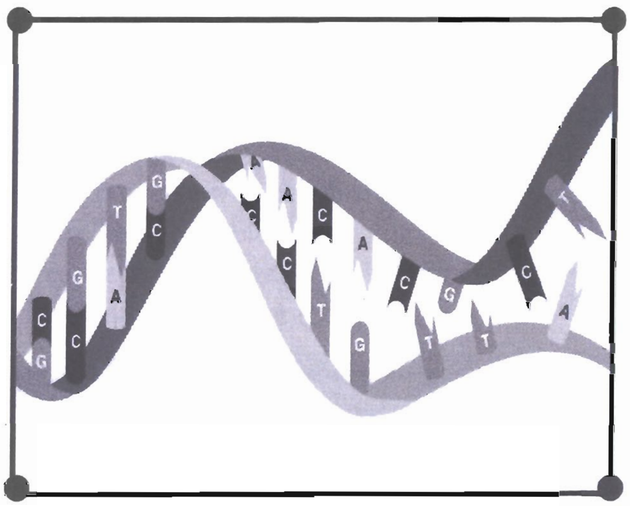
Probes: Genetic Tests

Gene "probes" can show whether a certain form of a gene is present in a sample of DNA. A DNA probe is the complement of part of the single strand of DNA. Thus, if the DNA sequence contains A-A-G-C-T, the complementary probe would be: T-T-C-G-A. If the probe finds its complement, it binds to the single DNA strand. If it doesn't find its complement, it doesn't bind and gets "washed away." When scientists create the probes, they attach a "tag" that will produce a signal, such as a fluorescent glow when the probe attaches to its match. If they see the signal, they know the probe attached to the DNA sample, and that tells them they have found their gene!

Write this sequence into your journal:

C - T - C - T - G - A - A - G

Imagine it is your probe. Write the sequence it will bind to.



The two sequences in this example cannot bind into a double strand of DNA because they are not exact complements. If the upper strand were a "probe", it would prove that the bottom strand is not from the gene it was seeking.

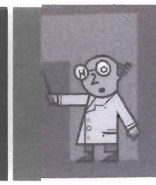
The Unusual Powers of *Cryptosporidium's* Heat Shock Protein

Because it is a parasite, *Cryptosporidium* must be able to respond to changes in temperature: it immediately shifts from the 21°C environment of water to the 37°C environment of a mammal host. In response to temperature changes, *Cryptosporidium* produces a heat shock protein that allows the organism to quickly adapt to the new temperature. Thus, the higher temperature of the host stimulates, or turns on, a heat shock gene.

A team of molecular biologists at the Metropolitan Water District used this information to develop genetic tests that can detect *Cryptosporidium* in water. They knew that if you expose a living *Cryptosporidium* to heat, its heat shock gene will turn on. So they searched for a DNA sequence in *Cryptosporidium parvum's* heat shock gene that they knew would be unique to that organism.

With help from genetic researchers at Kansas State University, who had mapped C. *parvum's* heat shock gene and posted their results on the Internet, Metropolitan's scientists isolated short, unique sequences. Then they used those short sequences to make a probe for detecting C. *parvum* in a sample of water. If the probe finds its complement, the researchers know with certainty that they found C. *parvum* in the water.

With a level of accuracy never before possible, Metropolitan's microbiologists will be able to inform customers in the Metropolitan Water District's entire service area if a health threat exists from the presence of *Cryptosporidium parvum* in the water supply!



Is This Water Clean Enough to Drink?

Describe the appearance and smell of the water samples. Then mark whether or not you would drink the sample.

SAMPLE 1 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 2 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 3 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 4 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 5 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 6 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 7 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 8 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

SAMPLE 9 Appearance ____________ ❍Yes ❍No
Smell ____________ ❍Yes ❍No

TASTE TEST WORKSHEET

Temperature	Rating Scale for Flavor Salty, Sweet, Bitter, Sour	Rating Scale for General Flavor
H = HOT	1 = NOT AT ALL	1 = EXCELLENT
RT = ROOM TEMPERATURE	2 = BARELY NOTICEABLE	2 = GOOD
C = COLD	3 = MODERATE	3 = NOT VERY GOOD
	4 = EXTREME	4 = VERY BAD

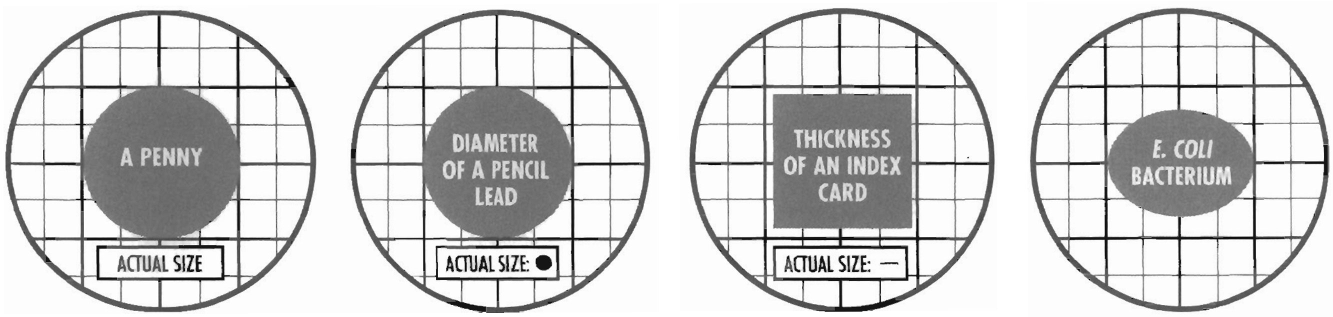
	TEMPERATURE	SALTY	SWEET	BITTER	SOUR	GENERAL FLAVOR
	(H, RT, C)	(1-4)	(1-4)	(1-4)	(1-4)	(1-4)
Sample A						
Sample B						
Sample C						
Sample D						
Sample E						
Sample F						
Sample G						
Sample H						
Sample I						
Sample J						
Sample K						
Sample L						
Sample M						
Sample N						
Sample O						

ODOR TEST WORKSHEET

	SMELLER #1	SMELLER #2	SMELLER #3	SMELLER #4	CONSENSUS
ODOR #1					
ODOR #2					
ODOR #3					
ODOR #4					
ODOR #5					
ODOR #6					
ODOR #7					
ODOR #8					
ODOR #9					
ODOR #10					

MICROORGANISMS: SIZE, SCALE AND FILTRATION WORKSHEET

Determine which filter at the bottom of the page will allow the objects at the top of the page to pass through.

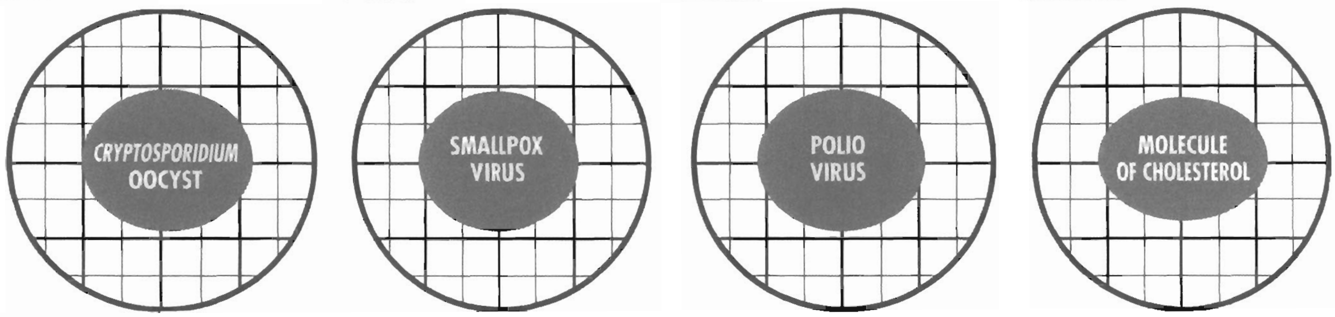


SCALE 1:1 1cm = 1cm

SCALE 1:10 1cm = 1mm

SCALE 1:100 1cm = .1mm

SCALE 1:1,000 1cm = .01mm

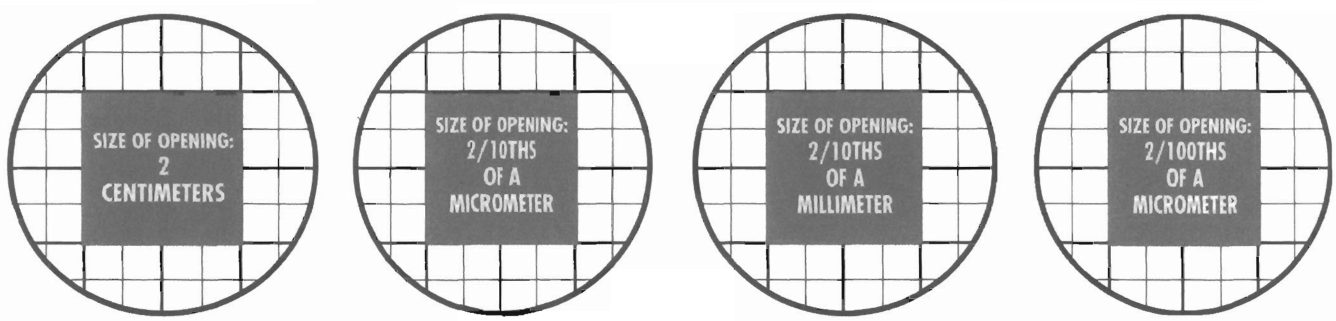


SCALE 1:10,000 1cm = 1μm

SCALE 1:100,000 1cm = .1μm

SCALE 1:1,000,000 1cm = .01μm

SCALE 1:10,000,000 1cm = 1nm



What will fit through this opening? ______________

What is the scale? ______________

What will fit through this opening? ______________

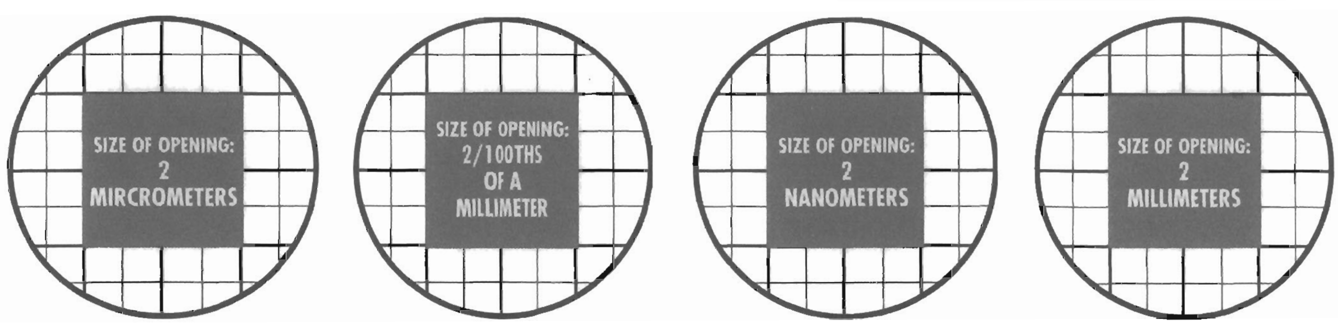
What is the scale? ______________

What will fit through this opening? ______________

What is the scale? ______________

What will fit through this opening? ______________

What is the scale? ______________



What will fit through this opening? ______________

What is the scale? ______________

What will fit through this opening? ______________

What is the scale? ______________

What will fit through this opening? ______________

What is the scale? ______________

What will fit through this opening? ______________

What is the scale? ______________

EPIDEMIOLOGY WORKSHEET 1

What Do You Think?

1 What is the average "background rate" of cryptosporidiosis among the HIV-infected population?

2 What are at least three reasons why the water supply does not appear to be the source of the cryptosporidiosis?

3 What is at least one reason why the water supply might be a source of *Crypto*?

4 What other potential causes could you investigate besides the water supply?

What Would You Want To Know?

1 Why do you think the CDC wanted to study the victims? ______

2 Why did they want to learn if cryptosporidiosis also affected the general population? ______

3 Suppose you were on the CDC team investigating this outbreak. What are some of the questions you would ask during this interview? Remember, you are trying to find out things the sick people shared but the well people did not share: ______

What Do You Conclude?

1 What seems to be the most common shared factor among people who have HIV or AIDS who contracted cryptosporidiosis? __________

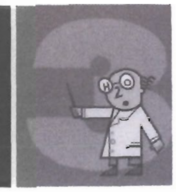
2 Do people in the community at large who reported diarrhea share this factor? __________

3 Do you have any evidence that this factor could be responsible for the outbreak? If so, what? __________

4 Is there any evidence (from other things you know about the case) that contradicts this conclusion, and if so, what is it? __________

5 What other information would you like to have that might help you understand the cause of the outbreak? __________

BODY CONTACT GROUP WORKSHEET



BODY CONTACT: DISCUSSING THE ISSUES

To prepare your group's presentation of its position at the town meeting, discuss these issues with your group and have one member record your responses:

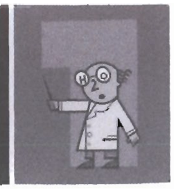
1. The role of our group is: ______________________________

2. From our perspective, the consequences of allowing swimming at the reservoir are: ______________________________

3. From our perspective, the consequences of banning swimming at the reservoir are: ______________________________

4. To support the role of our group, we have to support/oppose swimming in the reservoir because: ______________________________

5. The major weaknesses in the other positions are: ______________________________



Is This Water Clean Enough to Drink?

Describe the appearance and smell of the water samples. Then mark whether or not you would drink the sample.

SAMPLE 1	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 2	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 3	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 4	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 5	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 6	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 7	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 8	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No
SAMPLE 9	Appearance ____________	○Yes	○No
	Smell ____________	○Yes	○No

CRYPTOSPORIDIUM PRIVATE DECISION WORKSHEET

PRIVATE DECISION MAKING

1 In your own words, what is the trade-off between cost and control of *Cryptosporidium*? ____________

2 Describe the responsibility of your group as it relates to a safe water supply. ____________

3 Given this responsibility, which option will be best for the group? ____________

4 What are three reasons why this is the best option?

1. ____________
2. ____________
3. ____________

5 Which option is the worst for your group? ____________

6 What are three reasons why this is the worst option?

1. ____________
2. ____________
3. ____________

7 Which of the statements made at the pubic hearing do you agree with the most? ____________

8 List at least two reasons why you agree with this statement.

1. ____________
2. ____________

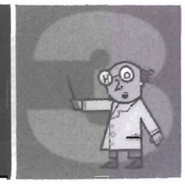
9 Which of the statements do you disagree with the most? ____________

10 List at least two reasons why you disagree with this statement.

1. ____________
2. ____________

11 "It is the responsibility of the community to protect the health of the most sensitive people in the population." Give at least two reasons why you agree or disagree with this statement.

1. ____________
2. ____________



MTBE WORKSHEET 1

Brainstorming on Stakeholders and their Perspectives

List who you think might be stakeholders in the MTBE issue.

Choose three stakeholder groups to focus on.

STAKEHOLDER GROUP #1:

Why is this group a stakeholder in the MTBE debate?

From this group's perspective, what are the most important public health issues? Why are they important and how important are they?

Does this group care if a gasoline additive is made from a petroleum product or an agricultural product? Why?

STAKEHOLDER GROUP #2:

Why is this group a stakeholder in the MTBE debate?

From this group's perspective, what are the most important public health issues? Why are they important and how important are they?

Does this group care if a gasoline additive is made from a petroleum product or an agricultural product? Why?

STAKEHOLDER GROUP #3:

Why is this group a stakeholder in the MTBE debate?

From this group's perspective, what are the most important public health issues? Why are they important and how important are they?

Does this group care if a gasoline additive is made from a petroleum product or an agricultural product? Why?

MTBE WORKSHEET 2

PART I: SOURCES OF INFORMATION

What sources will you use to gather information about the MTBE debate? ______

PART II: GUIDELINES FOR READING

What questions will you ask yourself as you read? ______

How will you assess whether the article is balanced or biased? ______