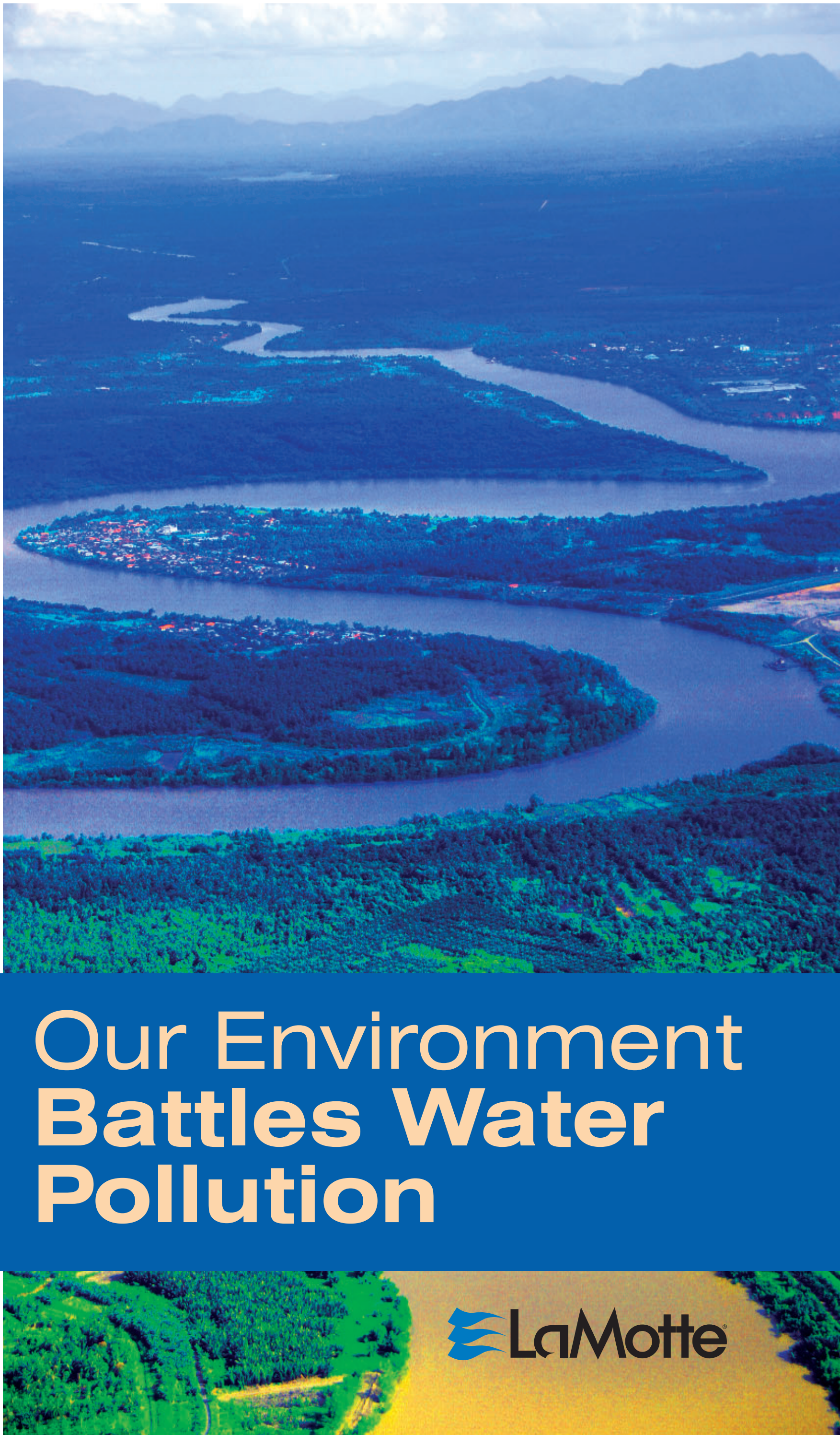

Our Environment **Battles Water Pollution**

LaMotte

ABOUT THE AUTHOR

This original text was prepared by Dr. Charles E. Renn, Professor Emeritus of Environmental Engineering Science, Johns Hopkins University. Dr. Renn held a B.S. Degree in science education from Columbia University, an M.S. Degree in science education from New York University, and a Ph.D. in soil microbiology from Rutgers University.

Dr. Renn was at the forefront of investgating various biological problems of water supply and wastewater engineering, and worked with most of the larger chemical industries. Of special interest to Dr. Renn, were the changes in water quality due to biological processes. He was a member of a number of professional societies including the American Water Works Association, The American Geophysical Union, and the Society of Limnology and Oceanography. He was also active in the teaching of elementary science and the development of equipment for teaching about water.

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Our Environment **Battles Water Pollution**

Dr. Charles E. Renn

THE PURPOSE OF THIS BOOK

Polluted water is water that has been used so that it has lost its usefulness. This is a good working description of what water pollution really means to us. Water is valuable because it is necessary for so many things, and when it isn't fit for the use that we have at hand, we are concerned. Activities that depend upon the right kinds of water are restricted and values are lost. Saying that water has been made useless by earlier uses shows the great variety of needs that we have for water – drinking, crops and animals, washing, cooling, transportation, waste removal, manufacturing, recreation, and hundreds of other necessary activities. The kind of water that is best for any single use may be very different from the kind needed for another, so that changes in water quality can be very important in a region where there are a number of large uses.

Water is valuable because it's necessary for all living things.

This is the reason that so much attention is being given to the control and treatment of waste waters – avoiding pollution. With increasing populations and rising demands for useful water, there must be more reuse of the existing water sources. It's not that we are running out of water, we simply have to use water sources more wisely so that new needs can be met.

There are many natural processes and engineered systems for improving waters that carry wastes. This is most fortunate. Waters can be restored to usefulness by taking advantage of biological and chemical processes that go on in nature and by applying similar processes in waste treatment and water purification systems.

This handbook will describe the changes that go on when waters are polluted. It will also describe the processes that restore their usefulness.

WATER POLLUTION AND DISEASE

To most people, "water pollution" means disease and sickness. Historically, our earliest concern with water pollution was with the transmission of water borne intestinal diseases – typhoid, cholera, and the dysenteries, and later with the control of parasitic organisms involving host organisms that lived in waste bearing water and maintained the cycle of infection among people using these waters. Intensive public health programs and extensive public works were established to make people aware of the causes and to secure their cooperation in accepting the necessary changes in distributing, treating and handling water and in disposing of human wastes. Water borne intestinal disease was common and often catastrophically epidemic, however, incidents of water borne disease have become infrequent and this good fortune is taken for granted.

Polluted water is water that has been used in such a way, so that it has lost its usefulness.

Many conditions operate together to produce and maintain the safety of drinking waters. First, our aesthetic preferences are on the right side. We prefer clear, colorless, odor free waters. Such waters are not necessarily free of troublesome organisms, but they can be treated more reliably than turbid, colored, and smelly waters. So there is a valuable indirect benefit. Second, the number of carriers of intestinal disease – particularly typhoid – has dropped sharply. Third, a larger proportion of the population receives potable water from controlled treatment and disinfection systems, and there is much more attention given to the design of smaller individual water supplies.

Most important is the fact that the organisms that transmit water borne disease do not multiply in natural waters or even in heavily polluted waters. Water and waste waters are not good media for their growth. Some of the higher parasitic organisms do divide in water, but they have short periods of activity. Some viruses are known to persist for very long periods, but they do not multiply in water. Water serves primarily as a mechanical medium for transmission of disease organisms, and most of the natural processes that go on in water decrease the likelihood of transmittance. Water borne outbreaks are associated with recent, gross pollution.

This is the reason that so much attention is paid to the actual machinery of supplying water – to household and institutional plumbing, distribution systems, storage, pressure and flow patterns, and other elements of our increasingly complex common water supplies.

Since water borne disease is caused by microorganisms in water, it would seem most reasonable to judge the safety of water by searching for and identifying the bacteria, viruses, amoebae, schistosomes, and other microbiological bits in water. If the troublesome organisms are very numerous, this can be done. But even in water that we regard as highly polluted, the search is complicated by the presence of much more numerous, more active, and often antagonistic organisms that make identification difficult. There may be hundreds of millions of harmless soil bacteria in water for every active pathogenic organism. The organisms that cause disease in water supplies do not wear distinctive beards, fangs, or antennae that can be indentified under a microscope. Their presence must be "presumed" by other signs and characteristics of the water that are added by sewage or other wastes bearing pathogenic organisms.

Practically, public health engineers examine the physical system first. If there appears to be any possibility that human wastes may enter the supply and may evade treatment or enter the water handling system after treatment, the system is suspect, and more elaborate searches are made.

THE NITROGEN CYCLE AND WATER POLLUTION

Tests for ammonia were widely used in early studies because ammonia could be traced in very low concentrations by relatively simple colorimetric methods that could be applied in the field. Clean, natural waters rarely contain more that a tenth of a milligram of ammonia nitrogen per liter (0.1ppm NH_3-N) while community sewages commonly contain fifteen to fifty milligrams of ammonia nitrogen per liter. Most of this ammonia rises from the hydrolysis of urea in urine, but additional ammonia is generated by the decomposition of other nitrogenous materials in sewage. Sudden increases in the concentrations of ammonia found in streams indicate that sewage, barnyard wastes, or other high nitrogen additions were present.

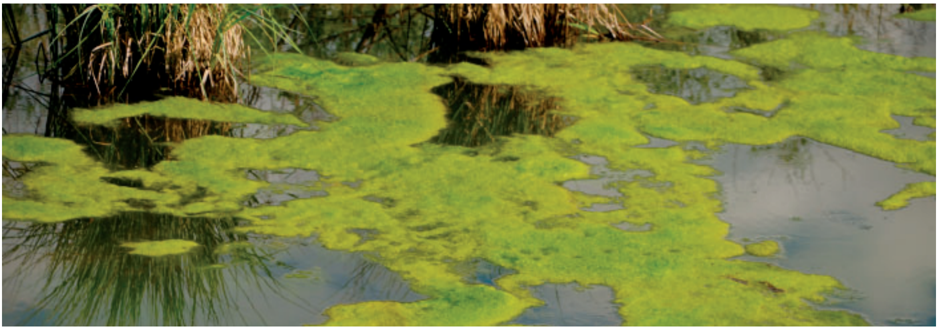
One of the first tests used to determine the possible pollution of water by sewage was the examination for organic nitrogen compounds; ammonia, nitrite, and nitrate.

Other changes commonly accompanied added nitrogen from sewage – slime growth of shallow surfaces of the stream bottom, heavy algal blooms, turbidity due to bacteria and colloids, and sewage odors – would be noticed when pollution was heavy. Ammonia nitrogen measurements were used because they afforded a rough quantitative measurement of the relative concentration of sewage in the water; the measurements were simple and very low levels of pollution could be detected.

Later, ammonia analyses were replaced or supplemented by other tests designed to give information on the degree of treatment required to improve waste bearing waters, but the determination of ammonia in waste waters and receiving streams remains a very useful and sometimes critical measurement of water quality.

AMMONIA COMBINES WITH OXYGEN

There was a second reason for the early popularity of ammonia nitrogen measurements in pollution studies. Ammonia is rapidly oxidized in natural water systems by special bacterial groups that produce nitrite and nitrate. This oxidation requires that dissolved oxygen be available in the water. Time is required for the change. In a flowing stream, the presence of ammonia in high concentrations indicated recent pollution, that sewage was entering the water somewhere in the vicinity. The disappearance of ammonia and the appearance of roughly equivalent concentrations of nitrite and nitrate indicated older waste, pollution further up stream; it also indicated that the water contained dissolved oxygen, that oxygen consuming organics existed in low concentrations. The replacement of ammonia and nitrite by nitrate indicated a polluted water well on its way to "recovery."



Blue green algae frequently develop and dominate waters that receive steady additions of ammonia wastes.

Nitrite and nitrate determinations can be made by colorimetric methods in the field. The methods are extremely sensitive.

Nitrite and nitrate analyses were widely used in sewage treatment control before the more generally useful dissolved oxygen and biological oxygen demand methods were developed. The presence of nitrite in the effluents and filters used for treating domestic sewage indicated that oxygen was present through the bed and that the system was operating within the designed capacity. The disappearance of nitrite and the appearance of ammonia indicated overloading of the beds.

Nitrogen changes are not so widely used in modern high rate trickling filter or activated sludge treatment as control measurements. More direct methods have replaced them.

Ammonia, nitrite, and nitrate enter water from sources other than sewage, of course. A variety of industrial wastes, fertilizers washed from the land, and even rainwater falling through industrial atmospheres carry nitrogenous materials that produce ammonia and, eventually, nitrite and nitrate. At present, two changes in water quality are recognized when ammonia concentrations are increased – high levels may kill fish; lower levels may produce heavy growths of blue green algae.

WEEDS OF THE WATER

History repeats itself. When producer gas was a major source of power for many communities and industries, ammonia discharged from large gas works killed fish in the area. Today, ammonia from concentrated fertilizers, from organic ammonia materials used in industry, and other sources, kill fish when they enter waters in sufficient concentrations. The principal difference is that we make ammonia analyses infrequently now, so we know less about its action in polluted waters. The point that is important is that infrequent analyses of water quality have little value – a continuing record over long periods is required to establish the normal range of change and the conditions that produce water pollution.

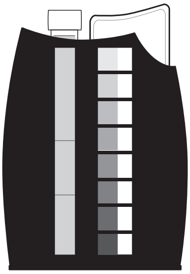
Ammonia nitrogen is available to many aquatic plants. But blue green algae very frequently develop and dominate waters that receive steady additions of ammonia wastes. These coppery slimes repress the growth of other organisms; they are poor food for microscopic animals and insect larvae. They are true weeds of the water. Antibiotic action appears to be a normal action in the plant world, and blue green algae display a notable integrity. In polluted streams and lakes where they appear, little else grows.

THE CARBON CYCLE IN WATER POLLUTION

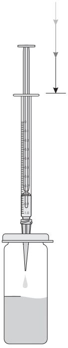
As populations of cities increased, and as industries grew, more attention was given to organized water supplies. Water treatment improved, and water borne intestinal disease in communities supplied by controlled water systems became a rarity. New techniques for distinguishing intestinal bacteria in water were developed, and less attention was given to nitrogen compounds and their analyses as devices for determining the fitness of water for municipal supply.

At the same time, the increased concentrations of organic materials entering waters bordering cities and industries began to produce new problems. Most of these were related to biological consumption of oxygen by microorganisms that grew on the waste materials. Fish died and the waters turned black and septic. The water was still useful for some things, but it was not pleasant, and most felt that is was poisonous or bad for health. It was simply out of oxygen – the other changes followed.

A great deal depends upon making measurements. Testing and measuring are not popular sports. They take time, patience, and care and the end of the game is numbers. But measurements are important in water and the progress that we have been able to make is due to improvements in our methods of making measurements – particularly, dissolved oxygen. Years ago, determining the dissolved oxygen content of water was a major effort for a research laboratory. Now it could be done in any high school laboratory with normal equipment and reagents. It can be done with many types of field kits, electrode and meter combinations, and continuous recorders. The important principle is that if the measurement can be made conveniently, it will be made. If it is tedious and difficult, it will be avoided.



The Octa-Slide 2 viewer provides standards of known value for evaluating the results of colorimetric tests.



A titration procedure requires the accurate measurement of the amount of titration solution needed to bring about a color change in the sample.

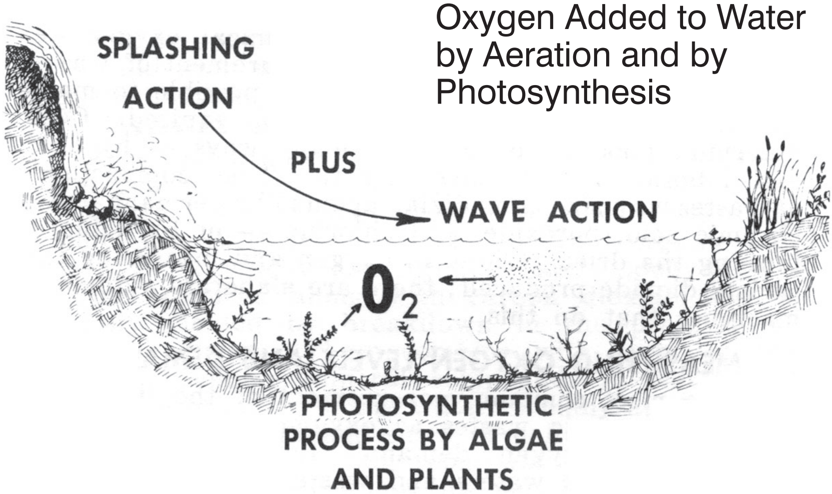
OXYGEN DISSOLVES IN WATER

We have come to know a great deal about oxygen in water and the effects of water pollution on the oxygen carried by water. This is a piece of good fortune, because oxygen concentrations fix the kinds of living activities that can go on in water. Another advantage that came with being able to measure concentrations was the ability to make more accurate estimates of the requirements for treating or removing the waste. This was not practical before, but with oxygen measurements from the waters receiving wastes and with information on the rates at which wastes consumed oxygen, it became possible to accurately design waste treatment plansts and to predict their performance under changing conditions.

It is an interesting fact that the waters that we enjoy most – cool, clear waters – are infertile waters. They contain relatively few fish and other organisms, but they will support many kinds of living things; cold, oxygen rich waters provide the conditions needed for the livelier, more competitive fish that sportsmen like. When organic materials in waters reduce the dissolved oxygen, unfavorable conditions develop for these diverse and specialized organisms; they may be replaced by more tolerant types, usually not as interesting to sportsmen, but there are likely to be more organisms altogether.

When oxygen is completely exhausted by the decomposition of organic wastes in water, a number of changes occur that are very obvious. All of the organisms that depend upon dissolved oxygen will die off and disappear. The sudden disappearance of oxygen due to slugs of pollution produces striking fish mortalities, but other smaller organisms, not so noticeable, may also be wiped out. If pollution persists and there is not dissolved oxygen, many of the bacteria that normally use dissolved oxygen will extract it from a variety of compounds in the water – for example, nitrite and nitrate, or sulfate, in that order. Nitrite and nitrate will be reduced to nitrogen gas which may show as bubbles, if there is sufficient nitrate to reduce. And the sulfate will be reduced to hydrogen sulfide, which announces itself as a well known rotten egg odor. Sulfides react with metal

Oxygen Added to Water by Aeration and by Photosynthesis



This cross section of a pond shows the two major sources of oxygen in limnological water supplies.

compounds in many waters to give fine black suspensions that darken polluted pools and streams.

In addition, some metals may be reduced, for example ferric compounds may be reduced to ferrous compounds, and manganic compounds to manganous compounds. Since ferric and manganic carbonates and oxides in silts and muds are relatively insoluble, and the ferrous salts are much more soluble, the decomposition of organic materials in waters without oxygen may greatly increase the iron and manganese content of the water and limit its usefulness for many industrial and domestic purposes.

WASTES CONSUME DISSOLVED OXYGEN

A second group of complications that rises when waste-bearing waters run out of oxygen comes from the fact that the decomposition of organics tends to be incomplete. A variety of partly oxidized organic materials – organic acids, alcohols, and aldehydes – will be produced along with carbon dioxide that is normally yielded by breakdown in the presence of adequate oxygen. These combine with many of the normally insoluble mineral compounds in water and change the behavior of the water in many applications.

The dark color and smell of polluted water without oxygen – that is, “anaerobic” water – is a warning of the great range of changes that may have taken place. But such waters may still be useful – for industrial cooling and transportation, for example. They are not pleasant. And converting them to useful water by treatment is relatively expensive, though it can be done as it has been done many times through necessity.

It is recognized that oxygen must be maintained in most waters to make them generally useful and acceptable. For the most part, this is determined by the concentrations of decomposable organic materials that are allowed to enter.

Although the “allowable loading” of organics is a critical determination, many conditions work together to determine the oxygen concentration in real streams and lakes.

OXYGEN REQUIREMENTS OF ORGANIC WASTES

The oxygen required to convert organic waste materials to stable, inoffensive, and harmless compounds – ultimately to carbon dioxide and water – is related to the content of carbon, hydrogen, and oxygen in the waste. Some wastes containing sulfur and nitrogen compounds will take up oxygen in amounts required to produce sulfate, nitrate, or other stable sulfur and nitrogen bearing materials. The requirement may be calculated from simple chemical formulations as though the materials were being burned in air.

But this would not represent the changes that go on in water, because the “rates” and “degrees” of oxidation in burning are much more rapid and more complete than those that go on during “biological burning” in the fermentation of organics by bacteria and other microorganisms in water. The “chemical oxygen demand” or COD, is a very useful measurement of wastewaters and polluted waters, and it is possible to make working estimates of degrees of control required. COD determinations can be made in many ways – by field and

The dark color and smell of polluted water without oxygen is a warning of the great range of changes that may have taken place.

laboratory tests involving the "wet combustion" of wastes with strong oxidizing agents like permanganate, chromic acid, peroxide, and chlorine – or by actually burning the dried residue in oxygen and measuring the carbon dioxide produced; there is elaborate automatic equipment that does this.

MEASURING OXYGEN LEVELS AND DEMANDS

The most common measurement of the likely behavior of organic wastes as oxygen consumers is the "biochemical oxygen demand" or BOD test. This involves placing standard waters and waste water mixtures in closed bottles and measuring the amount of oxygen lost after storage at fixed temperatures and times – usually 20°C over 5 days. There are other ways of getting this sort of information – in respirometers, fermenters, and specialized apparatus that measure the oxygen uptake of fixed or flowing volumes of waste. But so much information on wastes has been related to the standard "bottle" test, and engineers have become so accustomed to using this information that it is still widely used despite a number of recognized limitations. The principal drawback to the test is the length of time required to get measurements. Most wastes and polluted waters require several trials before trustworthy information can be developed, and this may require some weeks or months. That is why there is so much interest in chemical and physical tests that can give quicker results.

In the end, however, it is necessary to know with some precision what the biological requirements for oxygen will be in a polluted stream, river, or lake. Living organisms are doing the work, and their rates of oxidation determine the rates of oxygen uptake. One way of getting this information is to study the pattern of oxygen uptake in the water itself – this may involve many oxygen measurements (along with BOD and COD measurements) over the seasons, and at various points in the river or lake. This is the way that surveys of major waters are set up. The oxygen content of a body of water is determined by the rate at which the oxygen is being used up, and the rate at which it is being supplied.

The concentration of oxygen that can exist in water is determined by its temperature (it holds more oxygen at lower temperatures), its salinity (salt water holds less oxygen than fresh water), pressure (the oxygen content may be increased by increased pressures) and the composition of the atmosphere in contact with the water (the oxygen content of earth's atmosphere varies slightly with altitude).

Now, when biological oxygen consuming processes enter the picture, the oxygen concentration adjusts to fit a lot of shifting changes in the rates of consumption and replacement. For example, as temperatures rise, the concentration of oxygen that is normally held in water will decline, at the same time, rising temperatures will increase the rates of biological consumption. Again, fish become more active and require more oxygen. That is why summer time may be critical in polluted rivers – the flows decline so that the concentration of waste is greater, the normal oxygen content drops, the fish need more, and the microorganisms that consume the waste organics use oxygen faster. In this competition, the fish may lose. So waste engineers commonly design waste reduction systems to meet the conditions of summertime low flows.

Fresh oxygen can enter polluted waters from two sources – from the atmosphere, and from photosynthetic processes of algae and aquatic plants. The rates at which it can be supplied from the atmosphere depend upon the areas of water surface exposed, temperature, stirring, the presence or absence of surface films, salinity and the concentration of oxygen already in the water.

Melting snow feeds a mountain brook, adding particulate matter and gases filtered from the atmosphere by the falling snow. It pleases us to look upon cool, clear water that has been purified by nature's processes.

A RIVER BEGINS

All of the many conditions that come into play to determine the oxygen content of polluted waters can be illustrated in our major coastal rivers. We'll choose a nameless river, but it is a real river and it has its problems and hopes. The river begins with the joining of a number of mountain streams high in the hills, more than two hundred miles from the coast. These are cold, rapid streams. Some dry up in the summer, others flood and scour boulders from the hills during the spring thaws. But they are clean streams with many pools where a few fishermen go. The waters are always cold and well aerated by tumbling rapids and falls. The insect larvae that grow on the hard bottoms covered with light algae films, and the adult insects that fall into the water, furnish food for minnows and game fish. There is lively sport for a few fishermen who are willing to walk through the scrub and rocks to get to the pool areas.

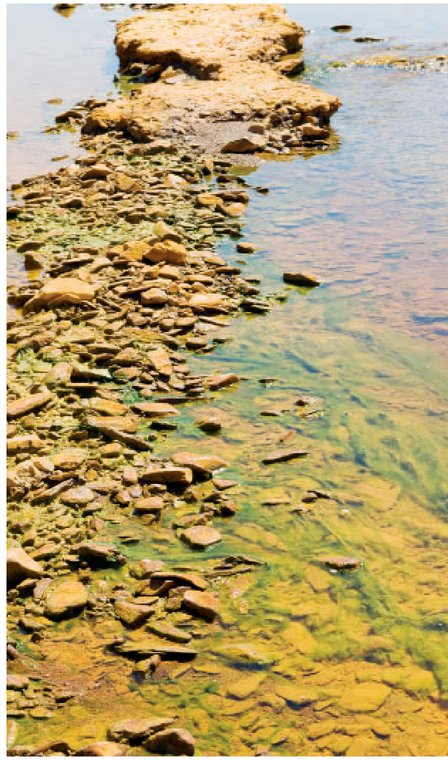
The splashing action of mountain streams add valuable oxygen to the water.

The streams join to form a good sized river, still rapid and cool, and at a high elevation. It is a pleasant river, the fishing is good, but fish have to be stocked to meet the increasing demands of the sportsmen who reach the area by cars; there is a limited time for fishing and the sportsmen are busy people with work to do. A mile or two below the major junction there is a shallow dam to supply water for a small town and

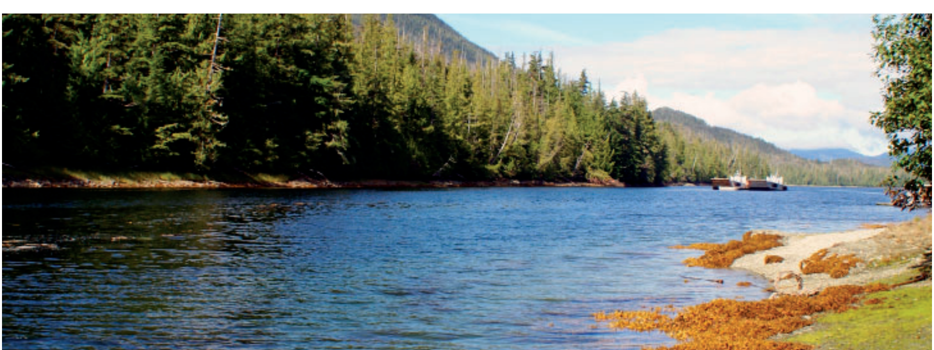
for a paper mill. This water is clean, cool, and the small lake is attractive. Boating and fishing are permitted, and people would like to swim, but because the water is used for the town supply there is strong public sentiment against it, particularly because swimming would draw visitors from a distance and would require expensive maintenance. The water is a little warmer than those of the headwaters, particularly in the summer, and the oxygen content is a little less, though more than enough for fish. But the quieter waters do not support as much bottom fish food and some species that live directly on the bottom organisms have replaced the livelier aggressive headwater game fish. It's good fishing, but there are too many fishermen, so stocking is carried out when there is a strong demand.

ADDED VOLUME – ADDED PROBLEMS

Below the dam, the river continues as a swift, wide, shallow stream for ten or fifteen miles. It is still high in the hills, with cold winters, and cold nights.

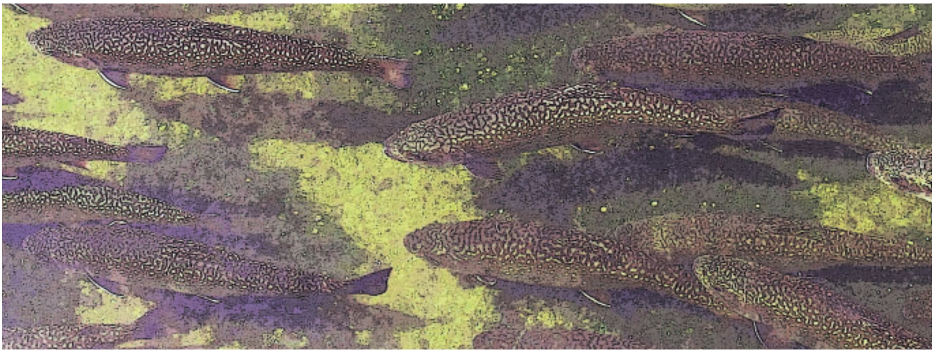


During the summer, however, more than half of the river's flow is waste water from paper pulp manufacturing. The small town adds a smaller amount of domestic waste water. Before waste treatment was established at the mill and the town's waste was diverted to the same treatment plant for economical combined treatment, the bottom of the river was heavily slimed by stringy gray-white bacteria that grew on the sugary wastes from paper pulp manufacture; in the



summer, at lower flows, and with brighter light, the bottom was covered with heavy carpets of blue green algae that developed from the added nitrogenous and phosphorous bearing wastes of the community. Some twenty miles further along other industrial wastes entered the river, and there were more small dams. Although the river was cool and turbulent, it was oxygen poor and often ran out of oxygen in the lower pools – the odor of hydrogen sulfide plagued the downstream communities of the valley on quiet nights, and sometimes lead paint of houses would be darkened.

The river flowed for nearly a hundred miles before enough of the oxygen-consuming organic wastes were biologically oxidized to permit the buildup of enough dissolved oxygen to support fish populations. By this time it was no longer a mountain river; it had moved into the meadow lands below the foothills. The water was warmer, the flows were quieter, and the water more turbid with fine silt from the farms, meadows and numerous roads. There were warm water fish and fish that moved in and out of the many spring fed tributaries of this area. Several other river meadows and streams joined the river and it became a sizeable river that was used to carry barges and paddlewheel steamers before railroads and trucks replaced them. At the "fall line" the river passed over scenic rapids, and spilled into the head of a large estuary that flowed past a very large coastal city with a long history, many glories, and a large sprawling suburban population. Water was taken above the falls for water supply – it had to be treated because it was frequently muddy from storms and because it had earthy flavors. Wastes from the city and its industries poured into the estuary at the head of tide and churned back and forth with the tidal flow, being edged seaward by the inflowing river. As the city grew, the periods of gross population and nuisance increased and objections increased – particularly from those who wished to enjoy the river.



Brook trout populations depend on cold, clear, well-oxygenated water of high purity. Chemical pollution, algae growth, and air pollution have been significant factors in the disappearance of brook trout from their native habitats.

FISH REACT TO WATER CONTENT

Migrating fish could no longer make their obligatory journeys because low oxygen blocked their upstream movements. When oxygen concentrations drop in waters containing organic wastes, the carbon dioxide concentrations rise. The rise in carbon dioxide makes it more difficult for fish to use the limited oxygen supply. To take on fresh oxygen, fish must first discharge the carbon dioxide in their own blood streams, and this is a much slower process when there are high concentrations of carbon dioxide in the water itself. Adjustments take place in the fish's blood chemistry to compensate, but these changes are slow, and most fish avoid waters that have rising concentrations of carbon dioxide or increasing acidities. They are not directly sensitive to oxygen concentrations, but they sense oxygen low and oxygen rich waters by their reaction to carbon dioxide and acidity of the water.

Heavy growths of water weeds and suspended blue green algae appeared during the bright weather, and in some parts the dissolved oxygen concentrations were much higher than normal due to photosynthetic action. But the water weeds and algae were objectionable; they fouled the boats and washed ashore in smelly windrows where flies bred and spoiled the use of beaches. The water was still useful for industrial cooling and carrying cargo, but power plants and other large water users in the area had to chlorinate the water that they took in at frequent intervals to prevent sliming, fouling and clogging of intakes, screens, channels, and tubes.

FINDING SOLUTIONS

So how do you go about finding out what you have to do and how much you have to do to improve the waters? Clearly, knowing how much of the oxygen consuming organics must be removed at various points along the changing river is part of the solution. But it is not all that needs to be known.

Understanding the water cycle is a good place to start. The three primary stages in the Hydrologic Cycle are (A) Evaporation, (B) Condensation and (C) Precipitation. Then consider some of the factors that alter the composition of water. (see Fig.1)

Pollution Enters The Water Cycle

Fig.1 This unique version to the Hydrologic Cycle shows the major sources of chemical and physical pollution. Note the important inter-relationship between air pollution and water pollution. Man-made pollutants upset the balance between natural pollution factors and natural purification processes.

1.	Dust particles and gases are filtered out of the atmosphere by falling snow and are trapped in the snow banks.
2.	Radioactivity in the atmosphere is usually carried by minute dust particles at high altitudes.
3.	Flowing water erodes rocks and soil, adding suspended solids to the water.
4.	Trees transpire terpene gas as well as moisture.
5.	Mine acid wastes have a severe effect on the pH and the chemical composition of the water into which they are discharged.
6.	Industrial gases are washed from the atmosphere by falling rain and snow.
7.	Crop dusting, an economical farming practice, contributes to both air and water pollution.
8.	Rainwater leaches chemicals from the soil and from decaying vegetation and these soluble materials are carried along in both surface and ground water.
9.	Natural aeration by rapids and waterfalls activates changes in the dissolved gases content of the water.
10.	Industrial waste water can vary greatly in its composition depending upon the industrial use of the water and the waste treatment processes employed.
11.	Dust particles caught by winds can drift great distances before being redeposited.
12.	Large quantities of soluble fertilizer salts, plus insecticides and herbicides are washed into surrounding water supplies.
13.	Barnyard wastes contribute both organic and chemical pollutants.
14.	Domestic septic systems ultimately pass to ground water supplies.
15.	As wells draw off usable ground water, undesirable brine can enter the water table from marine estuaries and the sea.
16.	Heat laden waters from power plants introduce thermal pollution.
17.	Marsh gas (methane) is manufactured naturally below the surface of marshes and swamp lands.
18.	Municipal water treatment plants must be carefully managed to prevent their discharge from causing a disease outbreak.
19.	Storm sewers carry away water that has bathed an entire city.
20.	Particles of salt from marine wave action are carried to amazing heights by coastal wind currents.
21.	Automotive exhausts are continually adding hydrocarbons that are absorbed by the moisture in the atmosphere.
22.	Oil leaks from vessels and offshore drilling operations can be disastrous.

NATURAL MECHANISMS THAT PURIFY WATER

In the river just described, there were intervals in which the flowing stream improved. Sometimes this came about because large unpolluted streams entered and mixed with the polluted water. But over long flow distances without additional wastes, there was always a noticeable improvement both in oxygen content and in most other properties. For example, below dams the water was usually much clearer, the BOD and COD values were lower, it contained less organic nitrogen and ammonia, and generally the mineral content, including phosphates and iron would be lower. Evidently, the waste materials were going either into the air or into the mud that settled in the impoundment – or in both directions. Oxidation of organics during the long residence of the water in the pool could carry these to carbon dioxide and water – the carbon dioxide could be assimilated by growing algae – algae could produce oxygen as well as cellular material – growing algae could assimilate ammonia and nitrate as well as phosphates – and iron could form insoluble ferric compounds in oxygen rich waters. Dead algae and organisms that fed on algae could settle to the bottom along with the silt and be trapped in the accumulating mud behind the dam. So it isn't unreasonable to think that these changes could go on – especially since you can demonstrate every one of the processes in a simple fish bowl aquarium filled with polluted water and allowed to stand in the light. They do happen. You can make chemical and physical tests that show that they do happen – both in the fish bowl and in the impoundment.

IMPOUNDED WATER

Holding water behind a dam simply represents time – time enough for the natural purifying processes of decay, growth, eating and scavenging, dying and settling to occur. Time in a flowing river is distance, and we should expect purifying changes with distance traveled. These show up, but many of the processes are different from those of deep ponds or lakes.

In a flowing stream, especially in tributaries and shallow rapid rivers, the changes that go on on surfaces – on the bottom and sides of the stream, on the boulders of rapids, on water grasses and weeds, are very important. The organisms that produce the changes cling or attach themselves to surfaces and work on the water as it flows by. This is more efficient than moving with the water. The slime bacteria growing on the shallow rocky bottom of the mountain section of the river oxidize organics from the paper waste more efficiently than bacteria floating free in the mixture.

The blue-green algal blanket on the stones of the polluted rapids strips nitrogenous compounds more efficiently than blue green algae suspended in the sluggish, deep waters of the estuary.

But bacterial slimes and algal blankets cannot completely purify flowing polluted shallow waters. Organisms that feed on other organisms must be added to the zoo. The principle that is important is this; when one organism feeds on another, most of the food organism is lost as carbon dioxide, water and other metabolic products, only a few percent at most become new hungry organisms. So the more kinds of organisms that can be nibbling on one another the greater the amount of organics converted to carbon dioxide, water, metabolic leftovers, detritus, and useless bits, and the smaller the total amount of final feeders. A sequence like this takes time to establish. That means flow and distance in a shallow stream or river. But it also means that conditions must be favorable for many members in a complicated food chain.

A spring flood flushes out the natural pools and settling areas and carries the discharges from these areas to the sea.

For example, heavy slime bacterial films entangle many of the small crustaceans and insect larvae that can feed on light films of bacteria and diatoms and upon protozoa that feed on bacteria. They bog down and starve in plenty. Heavy blankets of blue-green algae also smother small grazing animals – they seem to make poor food and they repress the growth of other types of algae. So the efficient sequence of Number Two eating One, and Three eating Two, and so on, can't get started until the slimes and blankets of bacteria and blue greens thin out sufficiently to give them a chance. That may mean distance – that is, time.

FLUSHING OF STREAMS AND RIVERS

This points to another very important purification process in natural waters – flood flushing of streams and rivers. Almost every spring we make fresh starts. When the winter snows melt and with the spring rains, the mountain streams scour and tumble boulders into the flooded joining streams, and these swollen by the early rains, charge down the foothills to carry the accumulated debris of the past year into the flooded meadows where it scatters over the plains. Some settles in dead ends and cutoffs, but most moves with settled stuffs from the meadows down river to the sea – much settles in the estuaries, but the strong winds and outward displacement of the spring floods move much of what left the hills to the ocean shelf along the coast. This is simply the geological process of wearing down the mountains and building the plains – water pollution came later.

The processes that go with flood purging are, in a way, the removal of "natural pollution." Man's activities are incidental. Each year a crop of leaves, grass, and all variety of organisms is grown – each year it dies and is swept to the sea. This is part of the process by which the earth is prepared for new growth.

But suppose floods and their scouring action stop – or are stopped? What should we expect, for example, if it became necessary to build dams and make pools of our major coastal rivers? We are going to do this, because we have to. We need steady water supplies for cities, for industries, and for power – to absorb heat, to cool factories and large buildings and homes. That means that the flood waters that naturally swept to the sea must be stored, and the river's flow time and surfaces must change to storage time and changes that go on in suspension. What goes to the bottom becomes very important in guessing what kind of water we can have.

There are other reasons that these changes must be made. Floods destroy valuable property, and property along waterways becomes increasingly valuable – because these waters are useful and fun.

This is the major reason that pollution control and waste treatment has become an engineering and scientific discipline and why it is of such national concern. It's not because a few people like to fish in pleasant unpopulated waters, it's because our populations increase on waters that are already heavily populated. We can do this only by controlling flows, storing water, treating and distributing it to needs, and by treating wastewaters to levels that natural processes can efficiently make useful again.

NATURAL BIOLOGICAL PROCESSES IN WASTE TREATMENT

It is interesting that we need so few conditions to maintain water of useful quality in our streams and lakes. These are (1) time and (2) space. With enough time and enough space and occasional flush flooding, we could have the best water with no effort on our part. It is also interesting that the engineered devices – the treatment processes for wastes – provide these conditions. In biological waste treatment processes, large surfaces are provided for attached bacteria, protozoa, worms, even snails, mites, insect larvae, and almost everything but fish.

In the "high rate trickling filter" for example, fifty acres of surface can be stacked on one acre by using beds of properly sorted crushed rock or plastic structures. Wastes

passed through such a bed flow as extremely shallow streams and the efficiency of organic waste oxidation is very high. Essentially, this says that the polluted water after treatment has traveled a long way – perhaps ten or fifteen miles, before it pours into the river. The debris, or sludge, is settled out in special clarifiers – as it might settle in quiet parts of the river. Then it can be disposed to digesters, driers and incinerators, or to the soil.

Activated sludge processes provide surfaces on bubbles of air blown into the wastes. These surfaces absorb organics and bacteria that attach to them, and the sludges or debris are separately disposed in the same manner as those of trickling filters. A more limited range of organisms can operate on the bubble surface, but more surface can be packed into a given volume, so that the process can be very efficient in generating purifying surfaces.

SOME MODERN PROBLEMS IN WATER POLLUTION

For the most part, modern water pollution problems are old problems on a bit larger scale. This grows from the fact that we pack more in less space and have less time for nature to help. But some problems are new, and it is interesting that the new problems get more prompt attention than most of the old ones.

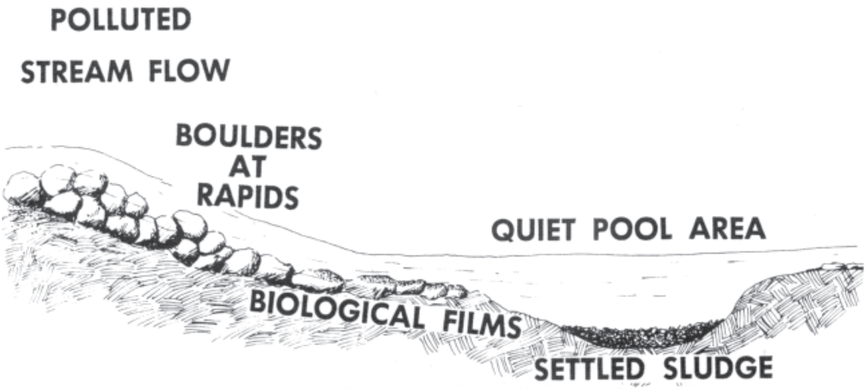


Figure 10. Polluted waters flowing over surfaces in shallow waters produce bacterial films, protozoa and small animals feed on these films; the residues slough away and settle in quiet water where other microorganisms, worms, and small animals feed on them. In time, floods flush the streams free of accumulated residues and the cycle repeats.

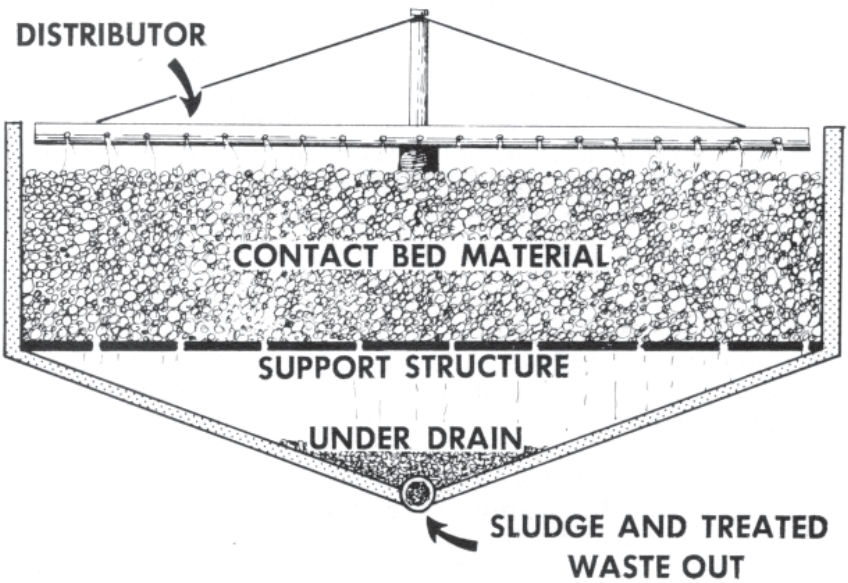


Figure 2. In a high rate trickling filter, waste waters are distributed over the surface of a bed of rocks, tiles, or plastic. Bacterial films are formed on the surfaces, and protozoa, worms, and other small animal forms feed on these as they are formed. Residues are washed down through the rocks by the rain of added waste waters; these sludges are collected by an underdrain system and are carried to digesters, driers, incinerators or other methods of final disposal. In the end there is always some organic sludge to be removed.

There has always been the problem of effects of wastes upon the taste of water. These were intensified when chlorination as a mode of disinfection for community drinking waters became common. Many "phenolic" materials in sewage as well as in oils and refinery wastes or road washings produce strong chlorophenolic odors and medicinal flavors when they react with chlorine used in water disinfection. Most instances where "chlorine" taste appears are due not to chlorine, which is tasteless in the concentrations used, but to the organic chlorine products formed. Waters can be treated with chlorine without producing obvious tastes and odors, but if proper steps are not taken, waters containing very low concentrations of some types of organics can be very odorous and tasty indeed.

RADIOACTIVE WASTES IN WATER

Radioactive wastes from processing of atomic power elements and from industries using radioisotopes require special care. Only those isotopes that have short active lives and which can be tolerated in the tissues of plants and animals that live in water or which feed on aquatic animals can be released. Long lived and cumulative materials must be sealed away until their activity has subsided to tolerable levels.

The fact that the radioactivity in these wastes cannot be altered by biological or chemical purification processes, but only by time, makes these wastes different from others. Since a number of the long lived radioactive materials become hazardous through accumulation and concentration by plants and animals in man's food chain, monitoring of food chain organisms is a common practical method for determining the presence and concentration of various radioactive materials in water. Practically, the activity of waste streams discharged to surface or ground waters is continuously monitored, and specimen animals and plants are analyzed for accumulated activity. The processes are much more elaborate than those used to follow the changes in other types of waste waters, but this is necessary because water from any one area moves to many other areas over long periods of time, and plants and animals developed in a polluted region migrate over long distances. The organisms that accumulate materials like strontium, cesium, and zinc are especially useful as specimens for monitoring studies.

ACCUMULATIVE CHEMICAL TOXINS IN POLLUTED WATERS

Some heavy metals, such as lead, accumulate to levels in aquatic animals that kill or stunt growth – when these occur in sufficient concentrations. These may be discharged from a variety of mining and manufacturing processes. A similar buildup to hazardous levels may take place when biologically stable organic poisons, various insecticides and herbicides are washed into streams.

The mechanisms by which these materials build up in the food chain and in fish, and the eventual effects upon the behavior, growth, and longevity of fish have been well established.

The behavior of these waters is, to some degree, like the group of radioactive wastes. Biological breakdown is too slow to be effective, though a variety of chemical changes may bring about detoxication.

The general recognition of the special problems from very stable agricultural poisons has brought about the development of new materials with shorter active lives – insecticides that decompose by chemical or biological action in water or in tissues to eliminate the hazard of long term accumulation in food chain organisms.

A prized source of water is converted into an open sewer by man's thoughtlessness.

WASTE PRODUCTS BREAK DOWN

More recently, there has been concern about foam producing detergent residuals and organic insecticides with very long residual action. These have been replaced by detergent bases that break down very rapidly in waste treatment systems and in natural waters. Long lasting residual insecticides are being replaced by materials that break down through chemical or biological processes before they can accumulate in aquatic animals.

We have a throw-away civilization and it has many conveniences. Retaining the conveniences requires that what we waste not accumulate to displace us. So more attention is being given to fibers and fabrics that will break down when they are disposed to the sewer, and that can be burned. Disposal in water is so convenient in the crowded life, that many new materials that come into daily use will have built-in natural degradability; in fact, most new disposable materials designed for large markets are tested to see if they can be removed in conventional wastewater treatment systems.

NITRATE AND PHOSPHATE ENRICHMENT

Two problems associated with our more intensive use of waters and our higher population concentrations are now receiving much technical attention. The first is related to the enrichment or fertilization of water by added nitrogenous materials and phosphates in sewage. Nitrogenous organics and phosphates are normal to sewage, but the inclusion of phosphates from detergents had about doubled the phosphate coming from treatment plants of cities. Intensive fertilization of high yield farm lands with concentrated nitrogen and phosphorus fertilizers also raises the nitrogen and phosphorus content of runoff waters. Waters that are free of treated sewage may contain high nitrogen and phosphorus levels and produce heavy blooms of algae; waters from the best available waste treatment may also be rich in available nitrogenous materials and phosphates. Heavy blooms of rapidly growingalgae, particularly blue-green algae, can unbalance the food chain "nibble-nibble" system by which natural waters recover their usefulness.

THERMAL POLLUTION

A second new problem that is being intensively studied is the warming of waters by heated water discharge and by the production of impoundments. We depend upon electric power – steam generated power – for almost everything we do, both in cities and in rural areas distant from the towns. Lighting, heating, air conditioning, transit, elevators make modern cities possible – the clean new air conditioned factories are powered by electricity. With the exception of a very small fraction of hydraulically generated power, the generation of electricity depends upon having something hot at one end of the plant and something cool at the other. It is a primitive system, but it is the most practical method that we have at the moment, the most economical – it is the going method. But it is wasteful. Heat must be generated by burning coal, oil, or by thermonuclear reactions, steam must be produced and allowed to push turbines around, the steam must be condensed and returned to the boiler. Some of the heat from the plant escapes up the stack with the furnace gases, but most must be taken up by something that absorbs it from the hot steam of the return cycle – this is usually water. At the generating plant it is likely that half of the heat developed will go into the cooling water. If all of the losses, including transmission and inefficiencies in refrigeration in air conditioning are included, removing one calorie of heat from an air conditioned room may mean that water somewhere must take up four to ten calories.

It is fortunate that it takes a great deal of heat energy to warm water. This is what makes it such a good "heat sink". In the end, the heat is lost from the water to the atmosphere, as evaporated vapor, or as energy directly radiated to the sky. Until this loss takes place, the heat will accumulate in the water and it will warm.

Estimating the changes and the consequences of warming of natural waters used for cooling is an extremely intricate problem, and every large plant site presents peculiarities. Heat losses from water are determined by the areas of water exposed, the movement of the overlying air, the altitude, sunshine, cloud cover and many other local geographic, climatic, and seasonal conditions.

REUSING WASTE WATERS

Since most of our problems with water pollution seem to rise from the hyperactivity of hyper-pollutions, it would seem reasonable to ask why a better solution might not be to spread the population around a bit thinner, and to calm it down. This has charm for some people, but not for a large proportion. People, particularly active people, seem to like to go where people are, and action stimulates action.

One of the great practical problems in spreading communities and new industries to any new location is water. The older cities were established where water was plentiful, at the mouths of and along great rivers where there could be harbors and water for power and transportation. They established their freshwater reservoirs in nearby unsettled mountain valleys so that they could have abundant water pouring downhill to them by gravity to displace the wastewaters further down the waterways. There are very few sites

WATER FACTS

Water exists as a liquid between	0° and 100° Centigrade (32° and 212°Fahrenheit)
Water exists as solid at or below	0° Centigrade (32° Fahrenheit)
Water exists as gas at or above	100° Centigrade (212° Fahrenheit)
One gallon of water weighs	8.33 pounds (3.778 kilograms)
One gallon of water equals	3.785 liters
One cubic foot of water equals	7.50 gallons (28.35 liters)
One ton of water equals	240 gallons
One acre foot of water equals	43,560 cubic feet (325,900 gallons)
Earth's rate of rainfall	340 cubic miles per day (16 million tons per second)

that have large, reliable water supplies of high quality left. But water is only one requirement for large industries – they must be conveniently located for skilled help, for raw materials, for markets, and other needs. Often these are available and the water is not. To use such locations requires planning for the use of water with the same intensity that planning of marketing and manufacturing is done. Many plants have been able to establish in desirable locations because they have carefully planned the uses of the water available to them – storing storm waters, using the limited good water for drinking, showers and other domestic uses, and using the treated wastewater for cooling, air conditioning, lawn watering, fire fighting and other purposes. Almost always this involves storing water during the rainy and storm runoff seasons to use during a few dry months of the year.

Making the most of such waters, which can be regarded as polluted waters brought back to usefulness, takes much analytical work and much more understanding in the design of plant uses than is required where there is an abundance of water that can be used lavishly. One value of the conservation practice of reusing waters where necessary is that it reduces the pollution of other waters. In water short area, with small stream flows, direct discharge of wastes may seriously damage the receiving waters. If the wastewaters are used for irrigating golf greens, special crops, landscaping, or held as cooling waters till heavy rains permit discharge, the usefulness of limited surface waters may be greatly extended.

RECREATIONAL WATERS

Much of the value that we place on having good water cannot be stated in terms of usefulness. We value water because of its beauty, the way that it looks to us, and the way that it makes us feel. This is water for fun and pleasure. Strangely, the qualities that we want for fun and pleasure are the most demanding of all – the clearest and cleanest, with pleasant surroundings. Is this water useful water?

When requirements for water to be useful for drinking, cooling, manufacturing and other practical application are closely examined, it can be found that merely useful water may not be satisfying for our pleasure requirements – foul waters can be treated and made drinkable, but they are not pleasant to view and be near.

The unsolved problem in water pollution is to determine what the pleasant uses of water are worth.

The water qualities that we want for fun and pleasure are the most demanding of all.

TAKING WATER SAMPLES

Great care must be exercised in taking water samples for analysis purposes. It is of great importance that the sample to be used in the analysis be representative of the water source and be free of any foreign matter that may be introduced. The container used for collecting the water sample must be clean and free from any foreign particles. In the event that the water sample is to be taken from a tap, it is important to allow the water to run for several minutes before the sample is taken. Allow the water sample to fill the collecting container several times so that it will be rinsed adequately. Unless the sample is to be tested immediately, the container should be filled to overflowing and the cap affixed securely to eliminate the possibility of an air bubble in the container. A sample bottle that is only half full with the water sample permits extensive oxidation as the sample is agitated in transit.

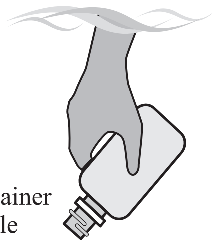
Water samples can be obtained in either glass or plastic containers. In the event the water sample is being obtained for bacterial tests, it will be necessary that a specially prepared container be used for the collection of this sample. These special collecting bottles are available from the local health department and the determination of the bacterial count in the water should be conducted by the local public health agency.

At the time of the sampling, it is important to observe if the water supply has any characteristic odor or taste and also to note if any color or hazy turbidity is present.

In removing a small portion of the water sample from the sample bottle, it is important that the original container be gently mixed to ensure that any suspended or precipitated materials are properly represented in the small sample being

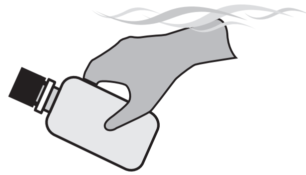
Collecting a Water Sample from River, Stream, Pond or Lake

1



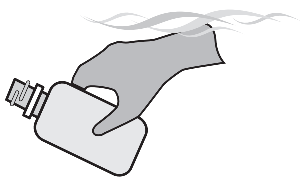
Rinse a water sampling container with the sample water.

2



Tightly cap the container, and submerge it to the desired depth.

3

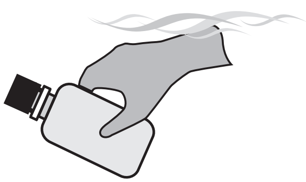


Remove the cap and allow the container to fill.

4

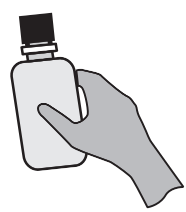
Tap the sides of the container to dislodge any air bubbles.

5



Replace the cap while the container is still submerged.

6



Retrieve the container and make sure that no air bubbles are trapped inside.

tested. The sample should not be filtered prior to the chemical analysis of the water.

Analytical results are often expressed in milliequivalents per liter. The term milliequivalent (me/L) represents 0.001 of an equivalent weight. The equivalent weight is defined as the weight of the ion divided by the number of charges normally associated with the particular ion.

The container used for collecting the water sample must be clean and free from any foreign particles.

DETECTION OF WATER POLLUTION MATERIALS AND FACTORS THAT ADVERSELY AFFECT WATER QUALITY

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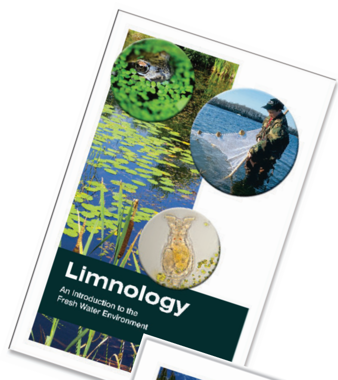

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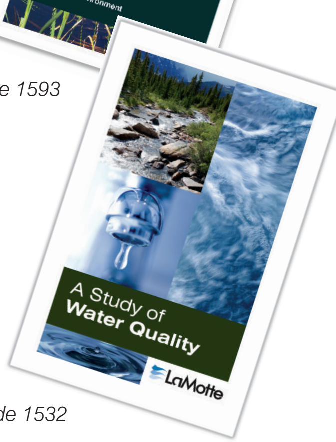

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