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ABSTRACT

Attention is directed to processes going on in lakes which are not apparent to the observer of their scenic beauty. Explored are the lifetime of lakes, how lakes are formed, elements of a field trip to a lake, and influence of human activities on lakes. Sample post-field trip questions, references, and a glossary of terms are also included. (RE)

field guide to LAKES

Almost everyone enjoys lakes as scenic and recreational features of the landscape. But lakes also serve as excellent examples of fundamental geologic and biologic processes, both in their formation and in their day-to-day performance as aquatic habitats. This pamphlet directs attention to these processes.

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FIELD GUIDE TO

Lakes

Jacob Verduin

Series Editor: Robert E. Boyer

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Lakes

INTRODUCTION

The dry-land portion of our planet is dotted with lakes. How and when did they form? How have they changed over time? How long will they last? How are lakes related to hills, valleys, plains, and rivers? What kinds of life exist in lakes, and how are lakes influenced by this life? How do lakes influence the lives of people living on their shores? These are some questions to ask as you observe and investigate lakes in your own community.

Man depends on sources of fresh water, and lakes have always been important water supplies. But today lakes are becoming so filled with microscopic plants that the filters at city water plants are clogged by them. The edges of lakes are fouled by heaps of decaying algae, which affect the taste and smell of community drinking water. What is the condition of any lakes near you?

Have you ever observed layers of rock exposed in a road cut? These layers may once have been at the bottom of shallow seas or ancient lakes. The processes that could have formed them still go on in lakes and seas today. Geologists once explained these rock-forming processes largely in terms of physical and chemical causes. But today geologists are looking more seriously at biological processes, carried out by the plants and animals living in the water, as causes of rock formation. Think about these processes as you study nearby lakes.

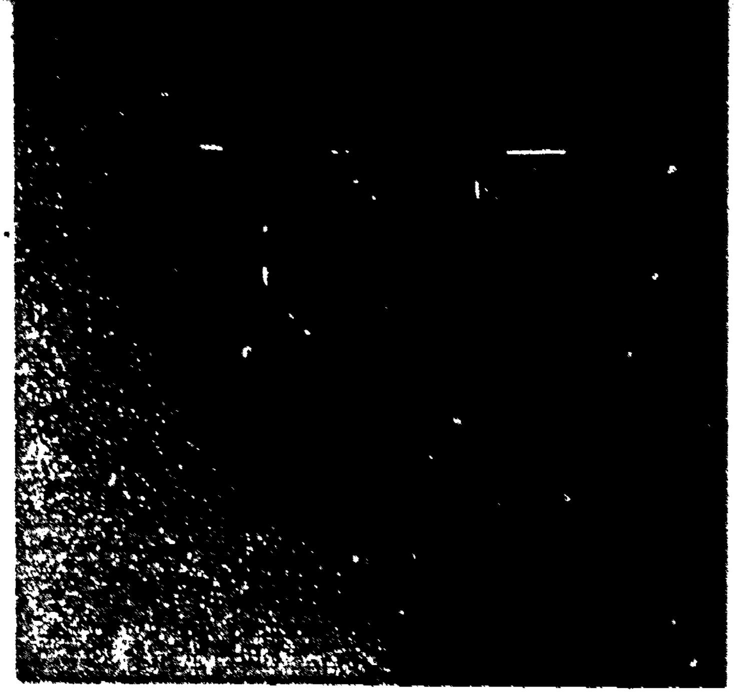


Figure 1. Ancient lakes of the Great Basin in the western United States

THE LIFETIME OF LAKES

In terms of geologic time, lakes are very short-lived features of our landscape. Geologic time is usually expressed in millions or even billions of years, but even a few thousand years may see major changes in the shape and size of a lake. Radiocarbon dating of cores collected from the bottoms of lakes in the Sand Hills of Nebraska, for example, suggests that the oldest lake bottoms are only about 5,000 years old. And although the Great Lakes took their present shapes about 10,000 years ago, their water levels and shoreline features have changed repeatedly since that time. Within the past 100 years the positions and elevations of the shorelines of the Great Lakes have changed detectably. For example, Lake Erie's shoreline is sinking near Toledo, Ohio, and rising near Buffalo, New York. Careful surveying in the Niagara Falls region shows that the land is rising about 25 centimeters every 100 years, whereas the mouth of the Portage River in the southwestern part of Lake Erie is being covered by rising water. Lake waters flood the channel of the Portage River as far as 16 kilometers upstream to the town of Oak Harbor, Ohio. At the western end of the lake, trees that grew along the shore have been submerged.

Changes in climate over the past several thousand years have also caused changes in the shapes and sizes of lakes. The highest beach lines near the north shore of Lake Superior are about 180 meters above the present lake level. The drop to the present water level took about 30,000 years, and resulted from the warmer and drier climate that came at the end of the Ice Age. This warmer climate caused the glaciers covering much of North America to recede northward to their present positions. Similarly, a warmer, drier climate caused the disappearance of two large lakes that once existed in the Great Basin in the western United States. The extent of the basin is shown in Figure 1. During the past 10,000 years evaporation shrank Lake Bonneville to the present Great Salt Lake in Utah and Lake Lahontan to a scattering of small lakes in Nevada. Study the black outline in Figure 1 and imagine how different the conditions in the southwestern desert must have been when large lakes covered much of the area. Stockton Bar near the city of Provo, Utah (Figure 2A), is an ancient sand bar formed by Lake Bonneville when it occupied the basin for thousands of years.

Another large, ancient lake bed may be seen in the Red River Valley of North Dakota and Canada. This lake, which geologists have named Lake Agassiz, once covered many square kilometers. Today its dry bottom is some of the finest farmland in that section of the country.

Figure 2 (A) Stockton Bar, an ancient sand bar near Provo, Utah

Figure 2 (B) Shoreline of former Lake Bonneville

In many of the western plains states, lake levels may change in only a few years in response to rainfall. During wet years or seasons, lakes in this area fill to their highest shores, but during dry years they shrink or even dry up completely.

Did you ever wash a blackboard and watch it dry? The wet spots shrink inward from all sides and finally disappear. If you could watch a time-lapse movie of the earth's surface taken over 10,000 years and condensed into one hour, many of its lakes would shrink and disappear just like the wet spots on the blackboard. Lakes are created when water collects in a low spot on the earth's surface. As soon as a lake forms, it begins to fill with debris and to dry up. How long it takes to fill and dry up depends on the size of the lake and the rate at which debris is brought into it.

HOW LAKES ARE FORMED

If you think of a lake as a low spot in the landscape that is filled with water, then you can think more clearly about the forces that create lakes. Water erosion produces ravines and channels in the landscape. If one end of a ravine is closed, the ravine will fill with water and form a lake. Today engineers build dams across ravines with earth fill and concrete (Figure 3) to create artificial ponds, lakes, and reservoirs. The beaver has always dammed up streams to make the ponds he needs for his home. The basic element in this lake-forming process is the movement of materials to close one end of a depression. Both man and beaver can do this, but other phenomena such as a landslide can produce the same result.

Figure 3. Some artificial lakes. (A) Table Rock Lake, Missouri. (B) Bayou D'Arbonne, Louisiana.

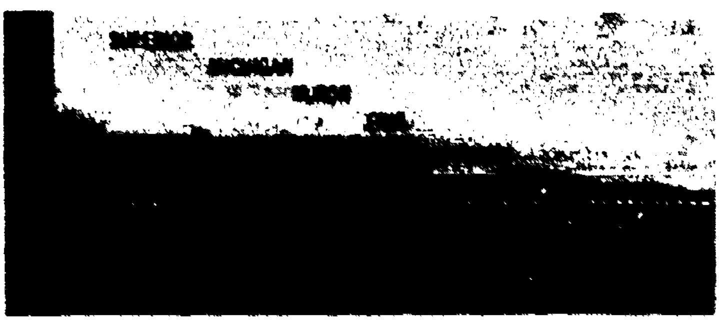
Movements of the earth's crust may change the elevation of the lower end of a valley, forming a dam by elevation of earth rather than with fill.

Another process that can create low spots in the landscape is glacial action. Flowing glaciers can move large quantities of earth, in the process gouging out depressions, leveling large areas, and depositing hills where none existed before.

The Finger Lakes in central New York were formed by two kinds of glacial activity. The southward-moving ice sheet flowed across the lowlands of the Rochester-Syracuse area and eventually covered adjacent parts of the Appalachians to the south. This moving ice deepened and accentuated valleys facing north out of the mountains, some to depths below present sea level. Later, after the ice had melted back to the north, a temporary readvance of the glacier dammed the valleys with debris to form the Finger Lakes.

The Great Lakes are deep gouges (Figure 4) made by immense glaciers that were part of a large ice sheet that advanced over the northern part of the United States some 30,000 years ago. This ice sheet extended as far south as southern Iowa, Illinois, Indiana, and Ohio. It was responsible for shaping the hills and plains in the area it covered,

Figure 4 Depth of Great Lakes in relation to present sea level



	SURFACE ELEVATION IN METERS	TOTAL DEPTH IN METERS	DEPTH RELATING TO SEA LEVEL
SUPERIOR	184	407	−223
MICHIGAN	177	282	−105
HURON	177	229	−52
ERIE	175	64	+111
ONTARIO	75	238	−163

for creating the basins of the Great Lakes, and for excavating thousands of smaller lakes in Minnesota, Wisconsin, and Michigan. Today, its original southwestern boundary is marked by the Missouri River: the fantastic volume of water that flowed from the melting ice formed a channel many miles wide to which by comparison today's river is only a tiny trickle. Many of the lakes in this glaciated area have neither inlet nor outlet, but are simply low basins surrounded by higher land. They are fed by surface runoff and underground springs supplied by ground water. Water is lost from these lakes only by evaporation. Thus, when the amount of rainfall is unusually high, the level of these lakes rises. In unusually dry years the water level drops, reflecting the relationship between rainfall and evaporation.

Between the Missouri River and the Rocky Mountains, where the landscape was not shaped by ice and the rainfall is light, the process of wind erosion is important in forming lakes. Wind erosion is most important during times of lowest rainfall. During the 1930's there were severe dust storms in this area, and the inhabitants could actually see the shape of the landscape being changed by the action of the wind. The hills marched ahead of the wind, like sand dunes or snowdrifts. In only a few years hills of wind-deposited soil existed where none had been before. The gusty winds that swept across this treeless country dug out deep hollow places. The dry seasons that caused the marching windblown deserts were followed by more abundant rainfall, and many farmers, who had learned a lesson from the drought, abandoned grain farming and seeded their land with drought-resistant grass.

This short period of drought and wind erosion is just a small sample of the kind of soil movement that must have occurred for many hundreds of years during an earlier, long-term period of warm, dry weather. The earlier dry period, which ended about 5,000 years ago, determined the present shape of the hills and valleys of the areas between the Missouri River and the Rocky Mountains. More abundant rainfall then transformed the desert to short-grass plains and stabilized the soil. The lowest wind-formed depressions filled with water and became lakes. Like lakes resulting from glacial activities, many of these lakes have neither inlet nor outlet, but gain water from surrounding land and lose it by evaporation. Because these lakes are found in areas of little rainfall and high evaporation rate, their water levels change more noticeably than those of lakes in more humid, glaciated areas.

The damming of water-eroded ravines, glacier-gouged basins, and basins left as lowlands in landscapes excavated or deposited by wind accounts for many lakes. But there are other rare but equally interesting ways in which water-filled depressions can be created.

Have you ever seen an oxbow lake? Sometimes a meandering river cuts through the narrow neck

Figure 5 An oxbow lake. Horseshoe Lake in Mississippi

of land separating the two ends of a large bend in the channel. The river then flows down the new shortened channel leaving a loop of quiet water, an *oxbow lake* (Figure 5). The strange name comes from its shape, which resembles the U-shaped piece of wood placed around the neck of oxen yoked together to pull wagons.

Crater lakes form when water collects in the crater left at the center of a volcano when the eruptions have subsided (Figure 6). Crater lakes are located far from civilization, in the midst of mountain scenery. These lakes are some of the most spectacularly beautiful on earth.

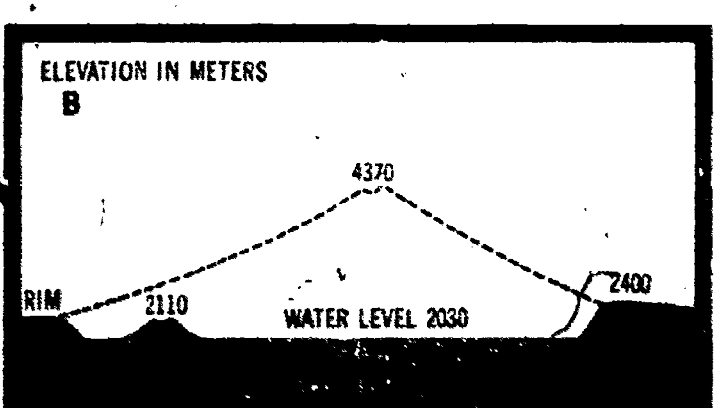
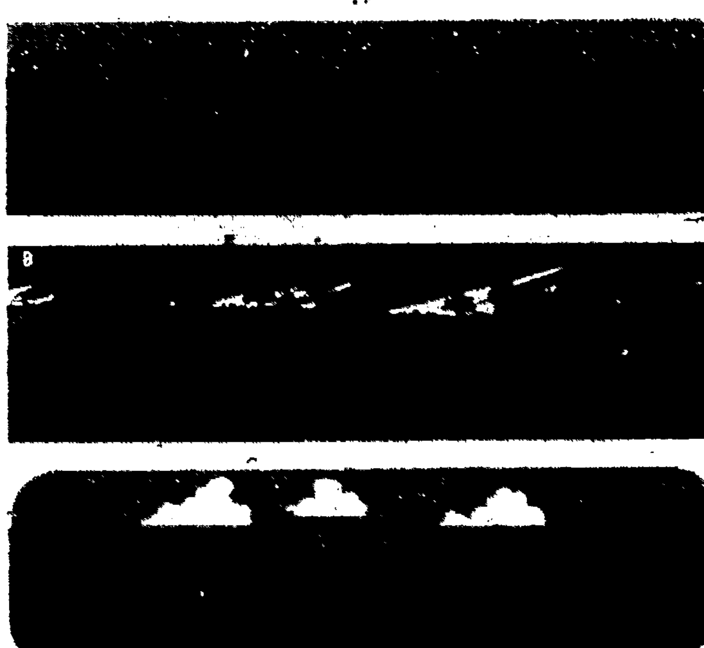


Figure 6. (A) Crater Lake, Oregon, showing cone (B) Profile diagram of this lake.

In areas where there is a great deal of limestone, *limestone sink lakes* can form. When rainwater drips through cracks in fractured limestone, chemical reactions dissolve the rock (Figure 7A). As portions of the rock dissolve, a hollow cave is formed (Figure 7B). Such a cave is the famous Mammoth Cave in Kentucky. If the cave is near the surface, however, the roof may fall in, leaving a surface depression that fills with water (Figure 7C). This is a limestone sink lake. Many of the lakes in the southeastern United States are limestone sink lakes.

Still another process is responsible for a type of saucer-shaped pond formed when great herds of buffalo roamed the western plains. During the summer, to get relief from the abundant flies, the buffalo would wallow in a shallow, wet depression to cover their hides with mud. Many years of use noticeably deepened these depressions, since each animal carried away a layer of mud. Today only the small saucer-shaped *buffalo wallows* remain. They form temporary ponds when snow melts in the spring and whenever a hard rain occurs, but they dry up completely during dry weather

Figure 7 A diagrammatic sequence illustrating the formation of a limestone sink lake



FIELD TRIP TO A LAKE

Key to the Origin of Lakes

Visit a nearby lake or pond and try to determine its origin, using the steps given below. In each step you must make a choice, until you reach the description that fits the lake you are studying.

1) a) Is it one of the American Great Lakes—Superior, Michigan, Huron, Erie, or Ontario? If so, the lake was created by glacial ice action during the past 30,000 years.
   b) Not one of the Great Lakes . . . . . . see 2).
2) a) Is there a man-made or beaver-made dam at one end of the lake? Earth-fill dams may be completely covered by vegetation, so you may have to look very carefully. A lake with a very regular shape at its downhill or downstream end may indicate the existence of a dam.
   b) No evidence of man-made or animal-made dam . . . . see 3).
3) a) Does the lake occupy an abandoned river channel bend? If so, it is an oxbow lake.
   b) Not in an abandoned river channel . . see 4).
4) a) Is the lake in an area of high mountains where there were once or are now glaciers? The presence of U-shaped valleys indicates that glaciers were once present (Figure 8). If so, a glacier may have formed this lake.
   b) Not in the mountains . . . . see 5).
5) a) Is the lake in an elongated valley that has been dammed at one end by natural agents such as landslides, earth movements, or lava flows? Examine the shape of the basin and the materials that make up the natural dam. Aerial photographs are helpful. Your local Soil Conservation Service office may have such photographs. Reelfoot Lake in Tennessee and St. Francis Lake in Missouri were created by an 1811 earthquake

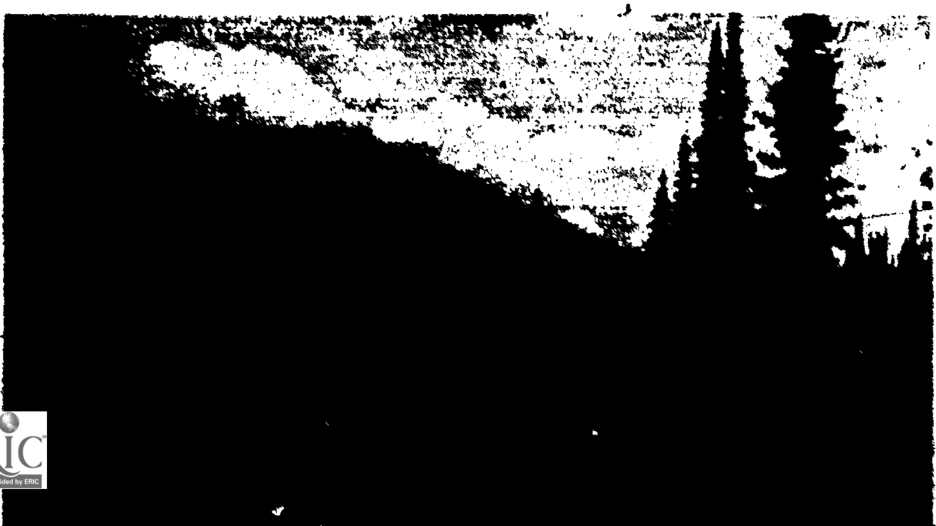


Figure 8. Glacial lakes in the Rocky Mountains (A) Tioga Pass Lake, California (B) Three Alta Lakes, Colorado (C) Bear Lake, Idaho (D) Baron Lake, Idaho (E) Lake San Cristobel, Colorado.

that reshaped several thousand square kilometers of land.

b) Not formed by natural damming . . . see 6).

6) a) Is the lake near a beach where wave action dammed a lowland area? Look for sand bars and shoals in the present beach area, because they indicate deposition through wave action. Such lakes are common near the ocean and near the shores of the Great Lakes. Sometimes this type of lake is separated from the present water line by several old beach ridges lying inland from the present beach line.

b) Not created by wave deposition . . . .see 7).

7) a) Does the lake occupy the crater of an inactive volcano? This type of lake can be recognized by the circular shape of the basin in which the lake is located, and by evidence of lava flows in the vicinity.

b) Not a crater lake . . . . see 8).

8) a) Is the lake a shallow pond on the western plains (Figure 9) created by buffalo wallowing in the mud? Remember that these ponds usually contain water only after rainy weather.

b) Not a buffalo wallow . . . . .see 9).

9) a) Is the lake located in a glaciated area ("B" in Figure 9)? . . . . see 10).

b) Not in a glaciated area . . . . see 11).

10) a) Is the lake in a region of rolling hills created by deposits of material carried in the water from a melting glacier? These rolling hills, called *moraines*, represent a region at the edge of the glacier where outflowing water deposited rock debris. Moraines were deposited repeatedly during the advances of the glaciers. They can be recognized by rounded stones of various sizes embedded in the soil. Examine a road cut in the area. If the soil contains such rounded stones, you are in a region that was formed by the action of a glacier. If your

lake is among moraines, it probably fills a depression once occupied by a piece of glacial ice. Many lakes of this type occur in Michigan, Minnesota, Wisconsin, Indiana, Illinois, and Iowa.

b) Not among rolling hills; surrounding land very flat. In the level portions of glaciated land, some low areas with no drainage outlets were left when the ice melted. These formed ponds and lakes. The origin of such lakes is essentially the same as that of the moraine lakes described in a).

11) a) Is the lake located in a region where surface shapes have been formed by wind erosion and deposition (Figure 9)? If so, it is probably a depression created by wind action that filled with water. The lakes in the Sand Hills of Nebraska are excellent examples, but others are found throughout the area labeled "C" in Figure 9.

b) Not in a region of wind erosion and deposition . . . . .see 12).

Figure 9 Map dividing the United States according to the predominant landscape-forming elements. Water erosion predominates in A, glaciation in B, wind action in C, and combinations of these three in D. The mountainous areas denoted by D are glaciated locally at high elevations, with wind and water erosion at lower elevations. Buffalo wallows are found in area C.

12) Is the lake in a lowland region where limestone is at or near the surface? If so, it may be a limestone sink lake.

If you have completed each step in this key and are still unsure about the origin of the lake you visited, don't be disappointed. Deciding how a particular lake formed is sometimes difficult even with helpful clues. In fact, geologists are still arguing about how some lakes formed. Many geologists believe that some deep circular lakes that occur in the southeastern United States are meteor craters, but others disagree. Satisfactory answers may require more thorough investigation.

After you have tried to determine the origin of your lake, answer the following questions:

1) Can you find evidence of previous water levels higher than the present lake level? If so, are these previous levels the result of annual or longer-term fluctuations in lake level? This question can be answered by estimating the age of vegetation on shore areas that were covered with water in past years. The ages of trees can be estimated from height and trunk size. If the largest trees several meters from the shore are taller and have larger trunks than those near the shore, then the region of nearby smaller trees was probably covered with water in the fairly recent past, during a period of higher water level.
2) Does the lake have an outlet?
3) How large is the watershed area of land whose runoff water feeds the lake? This question may require some help from outside sources. You may wish to contact the local office of the Soil Conservation Service for a map of the watershed area.
4) Are the shores subject to erosion? If so, how is erosion influenced by storms? Which wind direction seems to cause the most serious erosion?
5) Does water entering the lake carry much suspended matter? (See Particles Suspended

in the Water.) What effect will this matter have on lake depth? Is most of the adjacent land area cultivated or in natural vegetation? If natural, is the vegetation sparse or abundant?

By answering these questions, you will appreciate the factors that influence the lake and the processes by which it gradually fills with debris and dries up.

Seiche Period in a Lake

One factor that causes a considerable amount of mixing and stirring of water, especially in large lakes, is the seiche (pronounced saysh). The *seiche* is an oscillation, or periodic back-and-forth flow, of water in a basin.

Whenever wind or a difference in atmospheric pressure at opposite ends of a lake creates a difference in water level, the seiche is set in motion. Weather fronts crossing a lake are usually the initial cause of pressure differences. The seiche is not the same thing as a tide. The seiche swings back and forth between the ends of the basin, with a time period determined by the length of the basin and the depth of the water. This oscillation is similar to the waves set up in a bathtub when you step into the water. In large lakes the winds or pressure differences required to set the seiche in motion are almost always present, so the oscillation of water levels at the ends of the basin can be observed almost every day.

On western Lake Erie at Toledo, Detroit, and other lakeside locations, the water level typically rises and falls about 15 centimeters every day. The time period from high to low water is about seven hours, and the complete oscillation from high water to high water takes about 14 hours. When this oscillation was first observed, it was thought to be caused by tides. However, careful observation showed that the oscillation was not in phase with the moon or sun positions, and it was calculated that the tidal pulls would be much smaller than the changes in lake level that actually occurred. River mouths on the southwestern corner of Lake Erie are submerged due to the tilting of the lake basin, and the seiche in these mouths causes changes in the current as far as 16 kilometers upstream from the lake.

You can measure the time period of the seiche in an ordinary bathtub. Fill the tub to a depth of about ten centimeters, and set the seiche in motion by moving your hand or foot through the water in one quick motion along the length of the tub. Then count the number of complete oscillations—the flow from one end to the other and back—occurring per minute, and determine the observed seiche period T in seconds, using the following relationship:

$$\frac{60 \text{ seconds}}{\text{number of observed oscillations per minute}} = T \text{ (sec)}$$

For example, if you count 90 oscillations in one minute, the seiche period is 0.67 seconds.

Scientists have derived an equation for the seiche by relating length of basin and depth of water to gravity and to the time period of the oscillation:

$$T = \frac{2L}{\sqrt{gh}}$$

where T is the period of a complete oscillation in seconds, L is the length of the basin in centimeters, g is the acceleration due to gravity (980 cm/sec^2 at sea level), and h is the average depth of water in centimeters (Figure 10).

After you have measured the seiche period in your bathtub, you can compute its predicted period of oscillation T using this second equation. Measure the length of the tub L and the depth of water h to the nearest centimeter. For example, if the

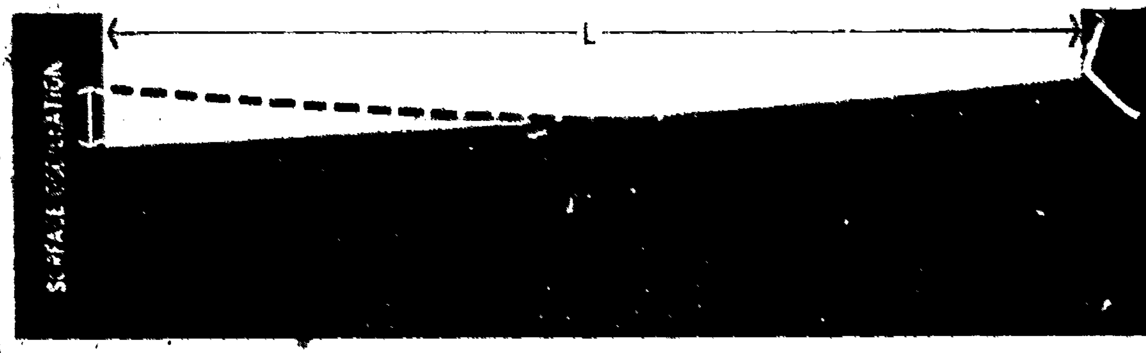


Figure 10 Diagram of a seiche in a tank.

average depth of water is 10 centimeters and the length of the tub is 150 centimeters, then

$$T = \frac{2 \times 150 \text{ cm}}{\sqrt{980 \frac{\text{cm}}{\text{sec}^2} \times 10 \text{ cm}}} = \frac{300 \text{ cm}}{\sqrt{9800 \frac{\text{cm}^2}{\text{sec}^2}}} = \frac{300 \text{ cm}}{99 \frac{\text{cm}}{\text{sec}}} = 3 \text{ sec}$$

How well does your observed period agree with the value predicted by the second equation for T? Notice that making the water four times as deep should reduce the period by half.

When you visit a lake, take a meter stick along; insert it at the water's edge or fasten it to the end of a pier so that you can measure the rise and fall of water level. Record the water level at regular time intervals to see whether you can detect an oscillation of lake level. If you know or can measure the approximate average depth and length of the lake, you can calculate the seiche period T using the second equation. This rough calculation will tell you whether your readings should be spaced seconds, minutes, or hours apart.

The seiche period and the amount of change in water level will help to determine the actual *importance* of the seiche as a mixing force in the water. If the change in level is only a few millimeters and the period is short (seconds or minutes), the mixing effect of the seiche is probably small compared to the effect of other mixing forces, such as the action of the wind. But if the change in level is several centimeters, the seiche mixing effect may be more important than any other force. In western Lake Erie, for example, although the water is nine meters deep it is thoroughly mixed from top to bottom by the action of the seiche-driven currents.

This seiche force makes the animal and plant life of western Lake Erie much like river, rather than lake, communities. The insects that live on the bottom are the kinds that usually live on river bottoms, and the algae that grow on the boulders near the shore are the same kind as are found in flowing streams. The seiche also sets up oscillating currents that surge back and forth with the rise and fall of the lake level. If you sit on a beach and watch the water movement, you may see it reverse direction in a few hours. In the winter, when fishing through the ice, you will see the fishing line drawn off by the current first to one side and then a few hours later in the opposite direction.

Particles Suspended in the Water

Erosion and sedimentation are opposite sides of the same coin. Erosion by streams picks up particles and carries them as long as the current is swift enough. When the stream flows into quiet water, it slows down and turbulence subsides, allowing the particles to settle out on the bottom. This is the process of *sedimentation*. Ponds, lakes, and especially reservoirs created by damming a stream are regions of quiet water where sedimentation occurs. Because sedimentation is an important factor in the filling of lakes, determining the amount of material carried by water running to the lake gives information about the lake's future.

A fairly simple experiment can be used to determine the load of particles, in milligrams per liter, suspended in water. You will need

Balance, preferably one that weighs quantities as small as a few milligrams
Funnel
Filter paper or paper towel cut to fit the funnel
Large beaker or jar marked at the one-liter level

Rubber tube, two or more large containers, stick for stirring

If your balance is not sensitive enough, carry out the experiment with a larger water sample, about ten liters. The procedure for the experiment is as follows (Figure 11):

1) Collect a water sample from a stream or lake.
2) Transfer one liter to a jar or beaker.
3) Set the beaker aside for several days or a week until the suspended particles settle to the bottom.
4) Weigh a piece of dry filter paper to the nearest milligram, or as accurately as possible, and record its dry weight.
5) Shape the filter paper to fit a funnel.
6) Carefully siphon off all but the bottom centimeter of water in the beaker with a rubber tube, and pour the siphoned water through the filter in the funnel. This water will be reasonably clean and will not clog the filter, but the filter will collect any particles in suspension.
7) Stir up settled materials in the small amount of water remaining in the beaker and bring them back into suspension.
8) Pour this suspension carefully into the filter to insure that all of it is deposited. Be sure that all the sediment has been removed from the beaker by rinsing it with several small portions of the siphoned water. Pour the rinse water through the paper again.
9) Dry the filter and weigh it again to the nearest milligram. The weight of suspended particles present in a liter of water is found by subtracting the weight of the clean, dry filter paper from the weight of the filter paper plus sediment.

The previous experiment provides a measure of the sediment load carried by the water. If water enters a quiet pool or lake, it will drop much of its sediment load on the bottom. Perhaps you have read estimates of the useful life of a reservoir such

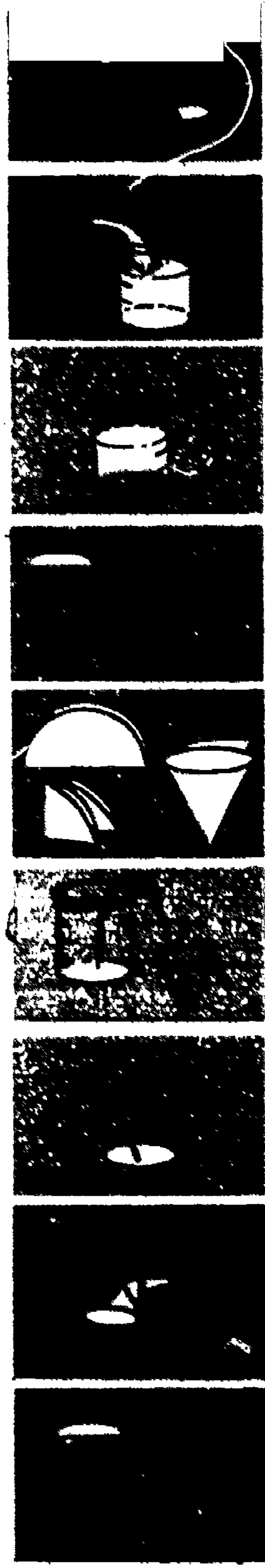


Figure 11. Procedure for determining the load of particles suspended in water.

Figure 12 Diagram of a Secchi Disk to determine light penetration

as Lake Mead behind Hoover Dam. Its lifetime is determined by the rate at which it becomes filled with sediment. This rate is, of course, directly proportional to the sediment load carried by the water that enters such a lake.

Light Energy Supply in Water

The plant community in a lake depends on sunlight for its energy. Plants use sunlight to manufacture sugars and other energy-rich compounds. Therefore, it is helpful when studying underwater plant life to have some means of measuring the depth to which light penetrates a lake. If water contains many soil particles or other debris, this will block the light and limit the depth to which plants can live. If the water in a lake is clear, light will penetrate farther and power life processes at great depths.

You can use inexpensive materials to build an instrument to measure light penetration (Figure 12):

Lid from a one-gallon paint can
Eyebolt (a bolt with a loop at the top)
Four nuts to fit the eyebolt
Waterproof paint, some black and some white
Paintbrush
About ten meters of line

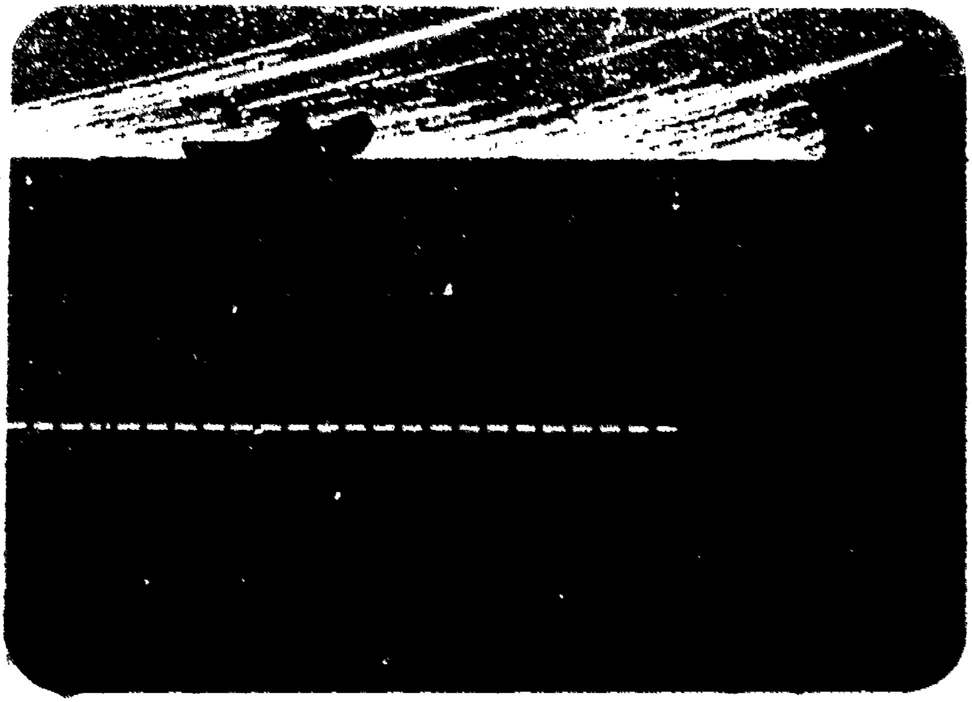
The procedure is as follows:

1) Drill a hole in the center of the lid.
2) Screw two nuts onto the eyebolt.
3) Fit the bolt through the hole in the lid.
4) Add two more nuts to the bolt, and lock the lid securely between the pairs of nuts.
5) Mark the upper surface of the lid, where the eye of the bolt protrudes, into four equal, pie-shaped sections. Paint two opposite sections white and the other two black.
6) Attach the line to the eye of the bolt, and mark the line at one-meter intervals. The instrument you have made is called a Secchi Disk.

To measure light penetration with the Secchi Disk, operate from a boat or from the end of a pier where the water is so deep that you cannot see the bottom. Let the disk down on the sunny side of the boat or pier to avoid shadows on the disk. Watch until the disk disappears from sight. Carefully pull the disk back up until you can just see it again. The depth at which the disk disappears from view is called the Secchi Disk reading, usually expressed in meters. As you can see, this reading is a measure of the clearness of the water. If the water is filled with tiny particles, the disk will quickly disappear. If the water is clear, the disk may be lowered to a considerable depth before it disappears from view.

Scientists who study light transmission in lakes have demonstrated that light is bright enough to support plants at a depth about three times as deep as the Secchi Disk reading, SD in Figure 13. The zone in which photosynthesis is possible is called the *euphotic zone*, EZ in Figure 13. If the euphotic zone extends at least halfway to the bottom of a lake, TD in Figure 13, the light energy supply is favorable for plant growth. If the euphotic zone extends much less than halfway to the bottom, the energy supply is too low for optimum plant growth.

Figure 13. Relationship between Secchi Disk reading, euphotic zone, and total depth.

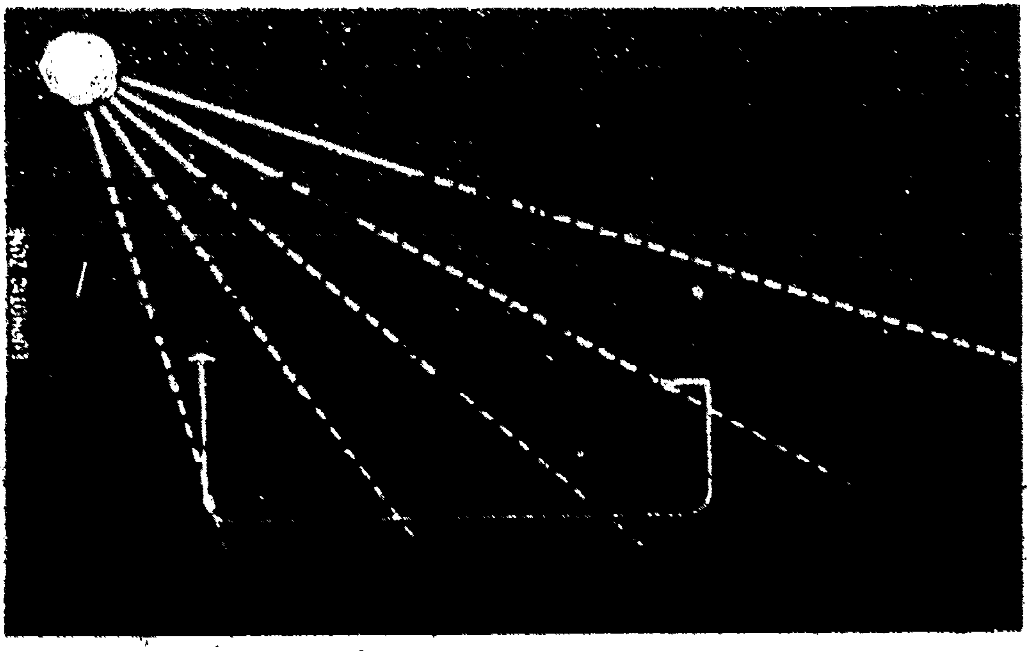


Food Sources for a Lake

Organisms in a lake can obtain their energy from two sources. Aquatic plants in the lake may be the principal food source. If this is the case, the process of energy storage, or *photosynthesis*, will be contained within the lake, and only small amounts of food will be brought in from outside. On the other hand, much of the food for a lake may come from outside sources, such as dead leaves blown in from the land or food transported by tributary systems.

A simple chemical test, applied during late afternoon on a sunny day, will usually tell you whether the community in a lake is self-sufficient or depends largely on energy from an outside source. The test depends on the fact that carbonate is one of the products of photosynthesis (Figure 14). Therefore, testing for the presence of carbonates during the afternoon when this process has been going on all day will determine whether photosynthesis in the lake itself is a major source of food supply. This test can be performed using a chemical called *phenolphthalein*, which will probably be available

Figure 14. Chemical reactions in lakes caused by photosynthesis and respiration. Any of several cations can replace calcium (Ca^{+2}) in the equations.



from a chemistry instructor. You need only a small amount in a bottle equipped with a medicine dropper to perform the test many times.

Go out to the lake about 4:00 P.M. on a sunny day and collect one-half cup of water. It is best to use a white cup so that you will have a white background against which to observe color. Add five drops of phenolphthalein to the water. If carbonates are present, the water will turn pink, giving you a positive indication that in the process of photosynthesis the plant community in the lake is actively producing carbonates from the bicarbonates in the water (Figure 14). If no pink color appears, this is evidence that the plant community does not have a very high photosynthetic rate. Thus the lake probably gets food energy from plant debris that is brought in from outside.

If you apply the phenolphthalein test at sunrise and find a pink color, you have evidence that the plant community has produced rather large amounts of carbonate. During the night, when photosynthesis cannot occur, the *respiration*, or breathing, of all plant and animal life adds carbonic acid, H_2CO_3, to the water. The carbonic acid reacts with the carbonates, CO_3^{-2}, produced by photosynthesis during the previous day (Figure 14). If the carbonates are not all removed through respiration during the night, the plant community is storing more energy than the aquatic community, both plant and animal, is using.

These carbon dioxide relationships and their corresponding phenolphthalein color changes are shown in Figure 15. The term *pH* refers to the concentration of acid, H^+ ions, in the water. When

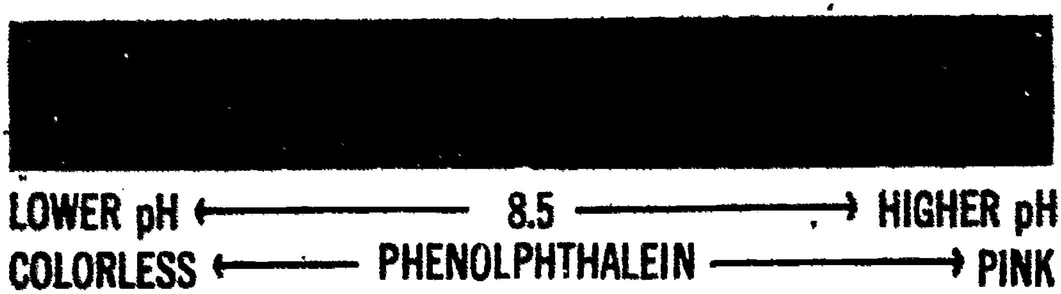
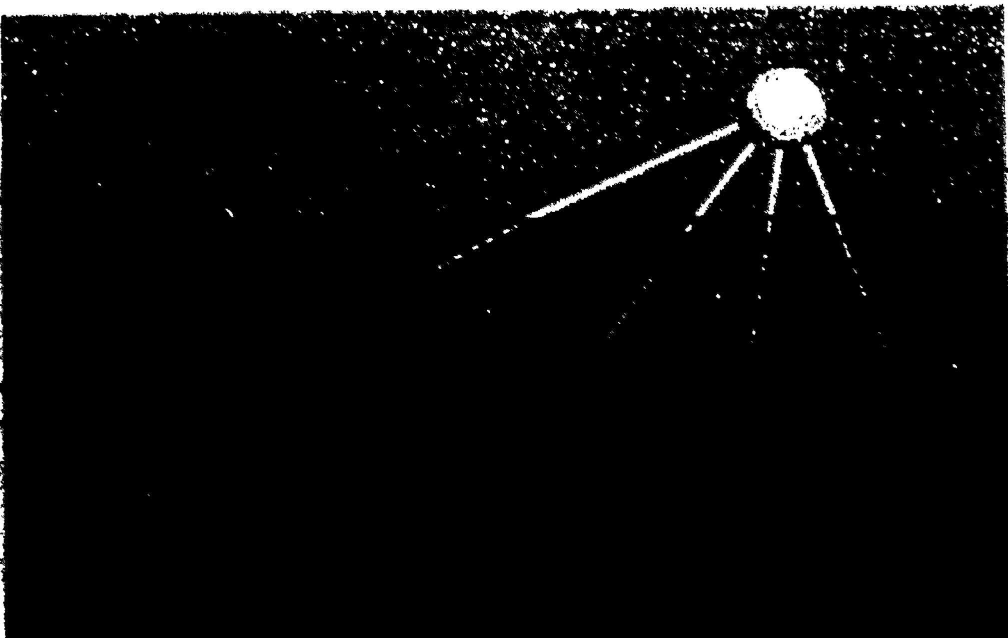


Figure 15. Diagram showing that pH rises as carbonate content increases, and pH falls as carbonic acid content increases; phenolphthalein indicator changes color in the range shown.

water contains carbonic acid, H_2CO_3, its pH will be less than 8.5, but if plants in the water remove CO_2 from bicarbonate, HCO_3^-, and produce carbonate ions, CO_3^{-2}, the pH value rises above 8.5, and the phenolphthalein indicator will turn pink. A typical lake usually shows carbonates every afternoon but not at dawn, indicating that the energy stored by photosynthesis each day approximately equals the energy used for respiration by the entire aquatic community during the night (Figure 16).

The significance of the biologic processes of photosynthesis and respiration in the economy and evolution of lakes has frequently been overlooked. For example, many aquatic biologists think that oxygen absorbed from the air is the most important source of oxygen for fish and other aquatic animals. Actually the oxygen produced by algae during the day is usually enough to supply the respiration requirements of the entire aquatic community. Many scientists who study lakes measure the amounts of free CO_2 and carbonates only once a week or month, when in fact large changes in the relative amounts of these chemicals occur during a single day. Figure 17 shows the pH changes ob-

Figure 16. Diagram of the energy cycles in a lake.

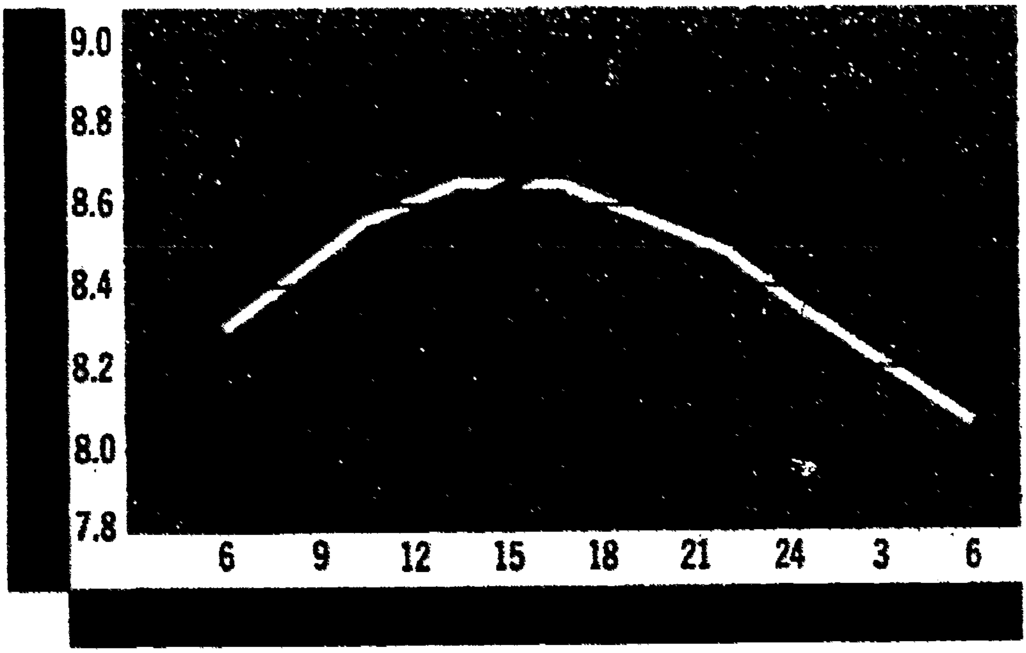


served in the western end of Lake Erie during three summer days. These changes were used to compute daily photosynthetic yields amounting to six grams of carbon stored in carbohydrates per square meter. In other words, the total CO_2 absorbed from the water under one square meter of surface adds up to six grams of carbon per day. Western Lake Erie is about nine meters deep, so the volume of water involved is about nine cubic meters.

Evaporation Rate

If you look at a map of North America and realize that large lakes once occupied North Dakota, Utah, and Nevada, you recognize that over time a great deal of evaporation must have occurred. Since evaporation rate and rainfall are influenced greatly by the moisture content of the air, the disappearance of these lakes suggests that the air has probably become drier. In the Great Lakes region the annual amount of evaporation approximately equals the amount of precipitation during the same period, about 75 centimeters. In the western states, however, rainfall is much less, only about 25 to 35

Figure 17. Changes in pH in western Lake Erie during three summer days and nights.



centimeters, and the annual evaporation from the surface of a body of water is much greater than the annual precipitation. You can appreciate the relationship between evaporation and relative humidity by performing a simple experiment that involves measuring the evaporation rate from an open water surface and expressing the rate as microliters of water evaporated per square centimeter of open water, per hour. You will need the following equipment:

Small bottle with a straight neck

Serological pipette, calibrated in 0.01 milliliter units (can be purchased from a biological supply house)

Measure the neck of the bottle to determine its inside diameter in centimeters and compute the area of the neck opening using the equation Area = πr^2, where $\pi = 3.14$ and r is the radius of the bottle neck, equal to one-half the diameter. For example, a bottle with a diameter of 1.4 centimeters will have an area of $3.14 \times (0.7)^2 = 1.5$ square centimeters.

To measure evaporation rate, fill the bottle completely to the upper rim of the neck and place it outdoors in the sun and wind. Note the exact time the bottle is placed outdoors. After two or three hours carefully refill the bottle to its original level, measuring the water needed to refill it with the pipette. The water you replace represents the amount of water evaporated during the experiment. You can compute the evaporation rate E using the following equation:

$$E = \frac{M \times 1000}{A \times H}$$

where M is the number of milliliters of water evaporated during the experiment, A is the area of the bottle neck in square centimeters, and H is the number of hours of exposure. M is multiplied by 1000 to change milliliters to microliters. Microliters are used instead of milliliters because they are the most convenient units for expressing evaporation rate in this exercise.

For example, if a bottle with a neck area of 1.4 square centimeters requires 0.33 milliliters to refill it after a two-hour exposure outdoors, then

$$E = \frac{0.33 \text{ ml} \times 1000}{1.4 \text{ cm}^2 \times 2 \text{ hrs}} = 118 \text{ microliters/cm}^2\text{hr}$$

While the evaporation experiment is going on, measure the dryness of the air. More water evaporates into dry air than into damp air, so measuring the dryness of the air is helpful in determining evaporation rate. This can be done using two thermometers (Figure 18). Cover the bulb of one thermometer with a wet cloth, and wave this wet-bulb thermometer in the air or hold it in the wind. The water evaporating from the wet cloth on the bulb of the thermometer will cool it below the air temperature. The amount of cooling is greater in dry air than in damp air; therefore, subtracting the wet-bulb temperature from the normal air temperature shown by the second, dry-bulb thermometer enables you to determine the evaporating power of the air.

A nomogram can be used for converting such wet-bulb and dry-bulb readings into vapor-pressure deficit values (Figure 19). These deficit values are expressed as millimeters of mercury, mmHg, and indicate the capacity of the air to absorb moisture. (The same units are used to measure air pressure.) If the air is dry, the vapor-pressure deficit, VPD, will be high. If the air is damp, the VPD will be low. For example, if the air temperature measured on the dry bulb is 23°C and the wet bulb cools to 14°C, the vapor-pressure deficit will be 15 mmHg (Figure 19). But if the wet bulb cools only to 20°C, the VPD will be only 5 mmHg. Water evaporates only one-third as fast in air with a VPD of 5 mmHg as it does in air having a VPD of 15 mmHg.

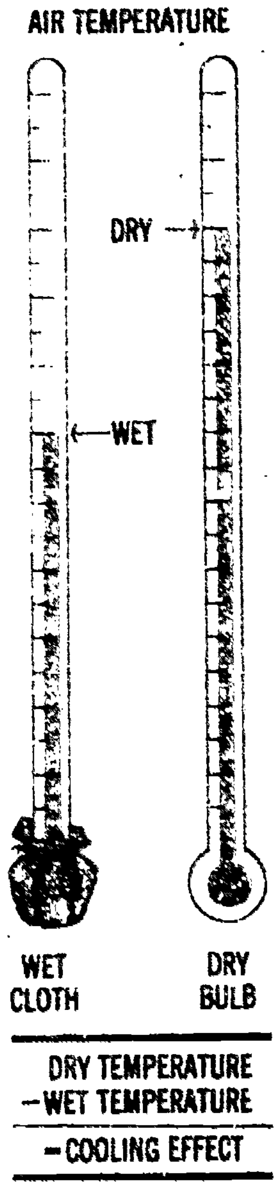


Figure 18. Comparison of temperatures registered by wet-bulb and dry-bulb thermometers allows dryness of the air to be found. Dry temperature minus wet temperature equals cooling effect.

The nomogram in Figure 19 is scaled in degrees Celsius. If you cannot get Celsius thermometers, convert Fahrenheit readings to Celsius by the following formula:

$$\text{degrees C} = \frac{\text{degrees F} - 32}{1.8}$$

Wind velocity is another important atmospheric variable affecting the rate of evaporation. If you include measurements of wind velocity in the above experiment, you can find the combined effect of wind and vapor-pressure deficit. You can use fairly

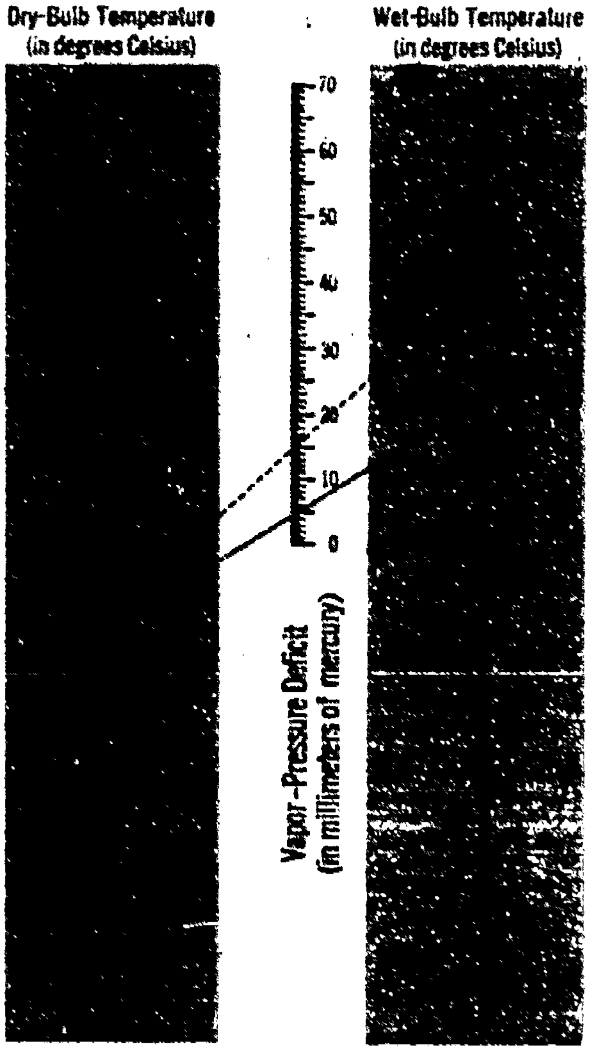


Figure 19. Nomogram relating wet-bulb and dry-bulb temperatures to vapor-pressure deficit.

inexpensive instruments to measure wind velocity. Ask your instructor for catalogs showing such instruments, or look up weather instruments in a mail-order catalog.

A sample set of evaporation data, including wind velocity and light conditions, is presented in Table 1.

Table 1. Evaporation Rates from a Small Bottle

Vapor-Pressure Deficit (mmHg)	Wind Speed (Meters/Second)	Light Conditions	Evaporation Rate from Small Bottle (Microliters/Square Centimeter-Hour)
2	0.5	dark	4
4	1.1	dusk	11
4	0.7	sunny	93
9	1.8	sunny	190
16	2.0	sunny	200

Notice the influence of sunlight on evaporation rate. Sunlight is one source of energy for evaporating water molecules from the water surface. Figure 20 is a graph of evaporation rate versus the product of vapor-pressure deficit and wind velocity, VPD × W, in meters per second, from a study of Lake Hefner in Oklahoma. Notice that the highest rates in Table 1 are much higher than those shown in Figure 20. Because the bottle neck is small and dry air is constantly renewed over it, water is removed more rapidly from the bottle than from a lake. The lake tends to increase the humidity of the air near its surface.

In addition to true evaporation, there is some removal of liquid particles directly from the water surface, expecially when winds are strong enough to cause whitecaps. This type of water removal is independent of the humidity of the air. The high value on the upper left in Figure 20 represents a windy day when the vapor-pressure deficit was near zero but a great deal of water was removed by the wind.

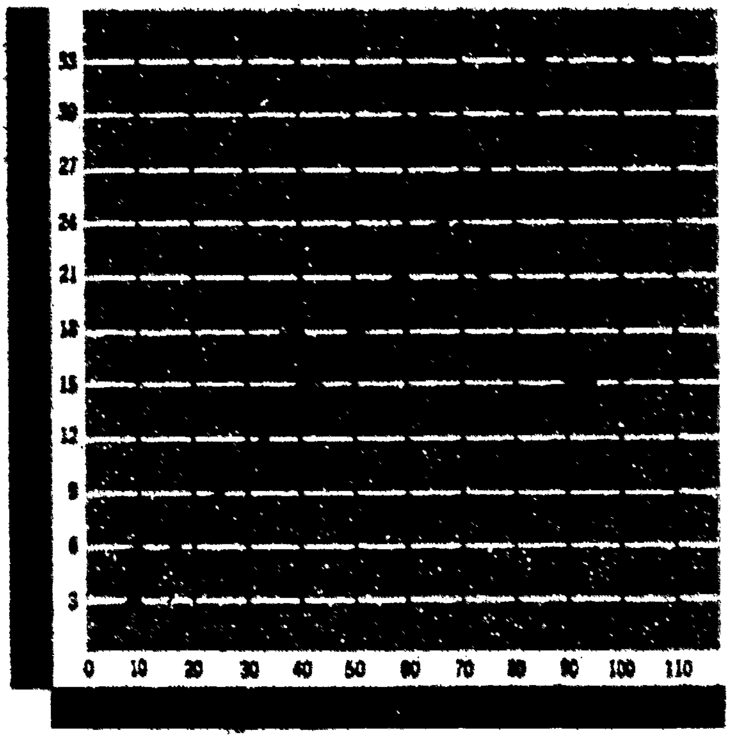


Figure 20. Graph of evaporation rate versus the product of vapor-pressure deficit and wind velocity

It seems likely that the evaporation of the large lakes that once occupied North Dakota, Utah, and Nevada resulted from an increased vapor-pressure deficit, and therefore dryness, of the air over those states. The factors causing such climatic change are not clearly understood today, but intensive studies are under way to try to learn more about what happened.

Investigation of Microscopic Plants and Animals

The photosynthetic process described earlier is carried on primarily by microscopic plants called *algae*. Algae also carry on respiration. Microscopic animals, bacteria, and fungi respire but are unable to carry on photosynthesis. You can examine algae and the microscopic animals with a compound microscope (100x and 430x magnification). Be sure that you know how to use such a microscope before you begin. If a slide with a hollow depression, a hanging drop slide, is available, use it because there is more space between slide and cover slip for the larger organisms you encounter.

The organisms you find in ponds and lakes are the members of the aquatic community. The pigmented members can provide their own food supply by storing the energy of sunlight as carbohydrates. All the other members of the community depend on these photosynthetic plants for their food. Small ponds and lakes receive an important part of their energy from the land plants nearby, especially in autumn when falling leaves are blown into the water and settle to the bottom, where they are digested by bacteria and small animals. Algae are an important food source present in ponds and lakes. Some carbohydrate leaks, or is excreted, out of the algal cells and dissolves in the water. Bacterial cells grow on the surface of algal cells even while the algae are alive and healthy. Many of the small animals graze on the algae and on the particles of dead organic matter suspended in the water. You may be able to observe a cluster of *Paramecia* busily feeding around a piece of plant debris under your microscope. You may even be able to see recently-eaten green algal cells inside transparent microscopic animals.

The microscopic community forms the base of a pyramid of food levels (Figure 21). The photosynthetic process is the foundation of this pyramid, and all members of the community derive their energy from it. Figure 21 presents some of the relationships between the different energy levels. The increasingly smaller population of each next-higher level in the diagram indicates that the energy used by members of each successive level is less than that contained in the level below it upon which the organisms feed. The arrows in Figure 21 connecting different levels show that some members of each level feed on members of lower levels. Studies made of the stomach contents of fish provide evidence for the relationships diagrammed in this figure.

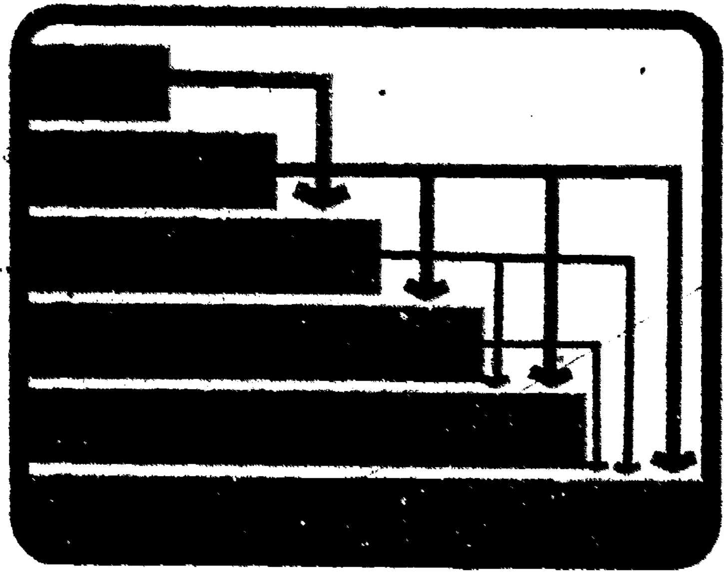


Figure 21 The pyramid of food in a lake

To study the organisms in water, collect about four liters of water from the lake or pond and allow this sample to stand overnight in a large jar to let the larger particles settle out. The next day, look carefully at the water for tiny animals just visible to the naked eye. These animals can be captured with a medicine dropper. Squeeze the bulb of the medicine dropper; place the dropper opening near one of the animals; then release the bulb, drawing the animal into the tube. Expel the water and animal onto a glass slide. Blot up excess water with a paper towel, and cover the slide with a cover slip. Examine under 100 power. Examples of these animals, called *microinvertebrates*, are shown in Figure 22.

After you have captured and examined as many of the visible organisms as you wish, insert a piece of rubber tubing about 75 centimeters long into the jar until the tubing is about one centimeter from the bottom. Siphon off the water to this level; then stir up the material settled at the bottom of the remaining water. Place a drop of this mixture on a microscope slide and examine it under 100x and 430x magnification. The pigmented plant cells—usually green, blue-green, or golden brown—will be *photosynthetic organisms*, that is, organisms able to

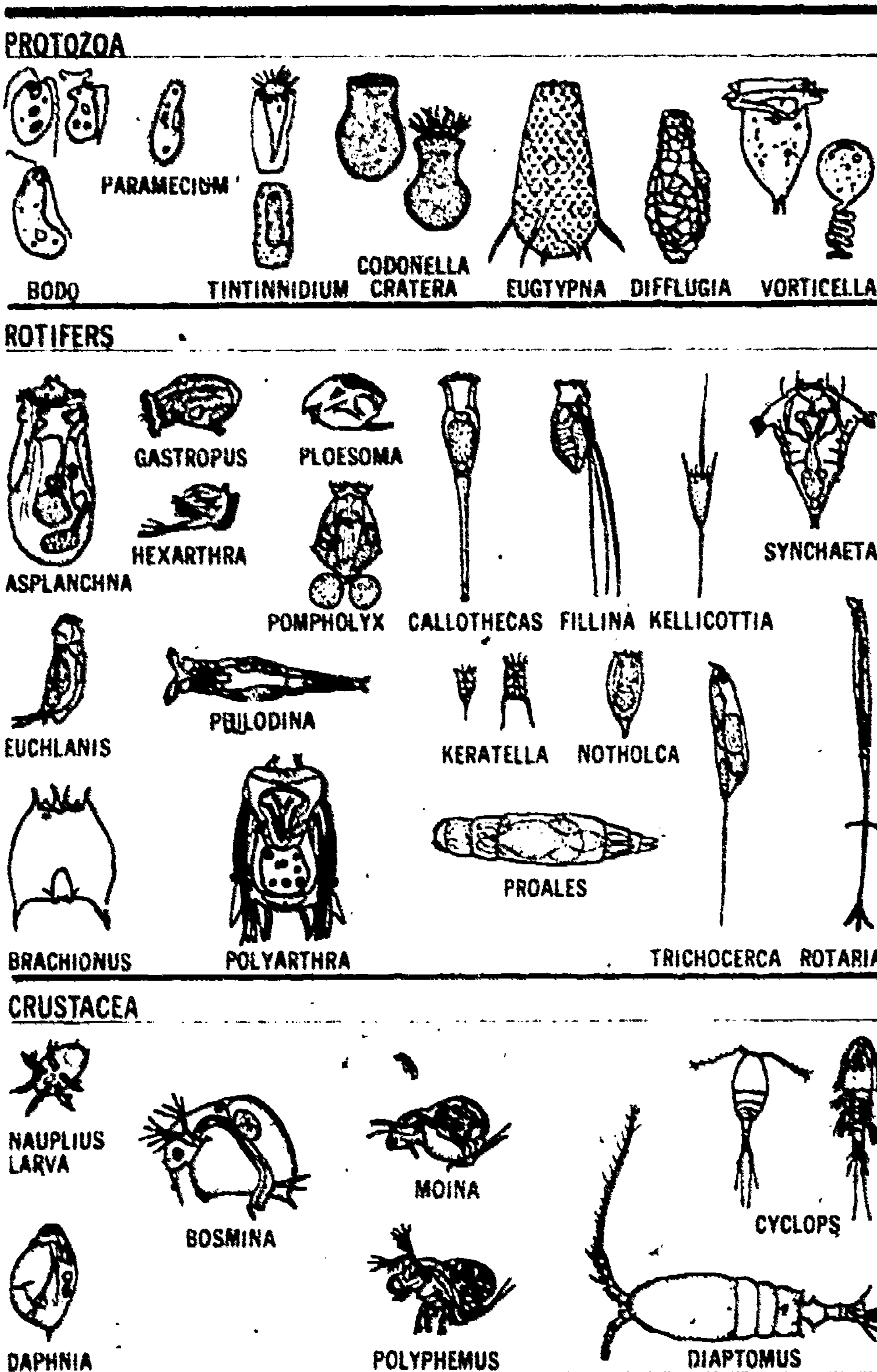


Figure 22. Micro-invertebrates common to lakes and ponds.

manufacture their own food supply from CO_2, water, and sunlight. Compare those you find with Figures 23 and 24, which show some algae, photosynthetic flagellates, and diatoms commonly encountered in lakes and ponds. The flagellates and some of the diatoms can propel themselves about in the water or on solid surfaces, while many of the other microscopic plants depend on water currents to move them about. For information about these microscopic organisms, see *How To Know the Protozoa* and *How To Know the Freshwater Algae*, listed in the References.

MAN'S INFLUENCE ON LAKE COMMUNITIES

Wherever man lives, he changes the environment around him. The effect of his actions can be seen in our lakes and ponds. Two hundred years ago the land was covered with natural vegetation—forests and prairies—and the lakes received clear water from such areas. But the clearing and plowing of fields for farming made the land much more subject to erosion. Today lakes and ponds receive a great deal of muddy water. Some of the mud settles out, increasing the rate at which a lake basin is filled. The finest particles absorb light, thus reducing the sunlight energy supply available in the deeper waters. In recent years farmers have also begun to add large amounts of chemical fertilizers to their land. Some of these fertilizers dissolve in the water draining from the land to the lake. The fertilizers make the lake waters so rich in plant nutrients that thick scums of algae float to the surface and pile up on the beaches, and organic matter decays on the bottom, depleting the oxygen supply there.

Towns and cities empty their sewers into streams and lakes. If the sewage has been passed through an efficient sewage treatment plant, the water will

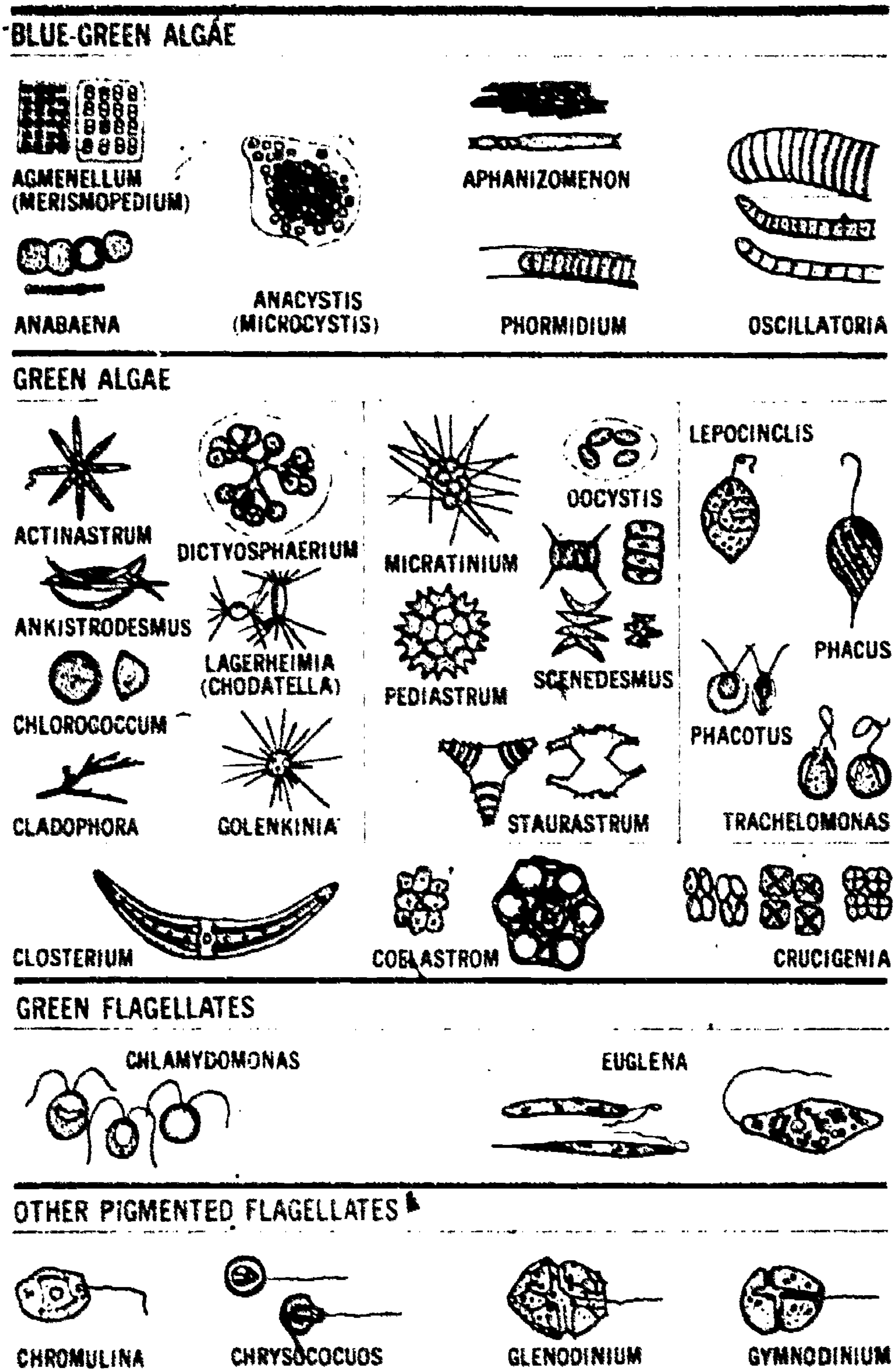


Figure 23. Algae and flagellates common to lakes and ponds

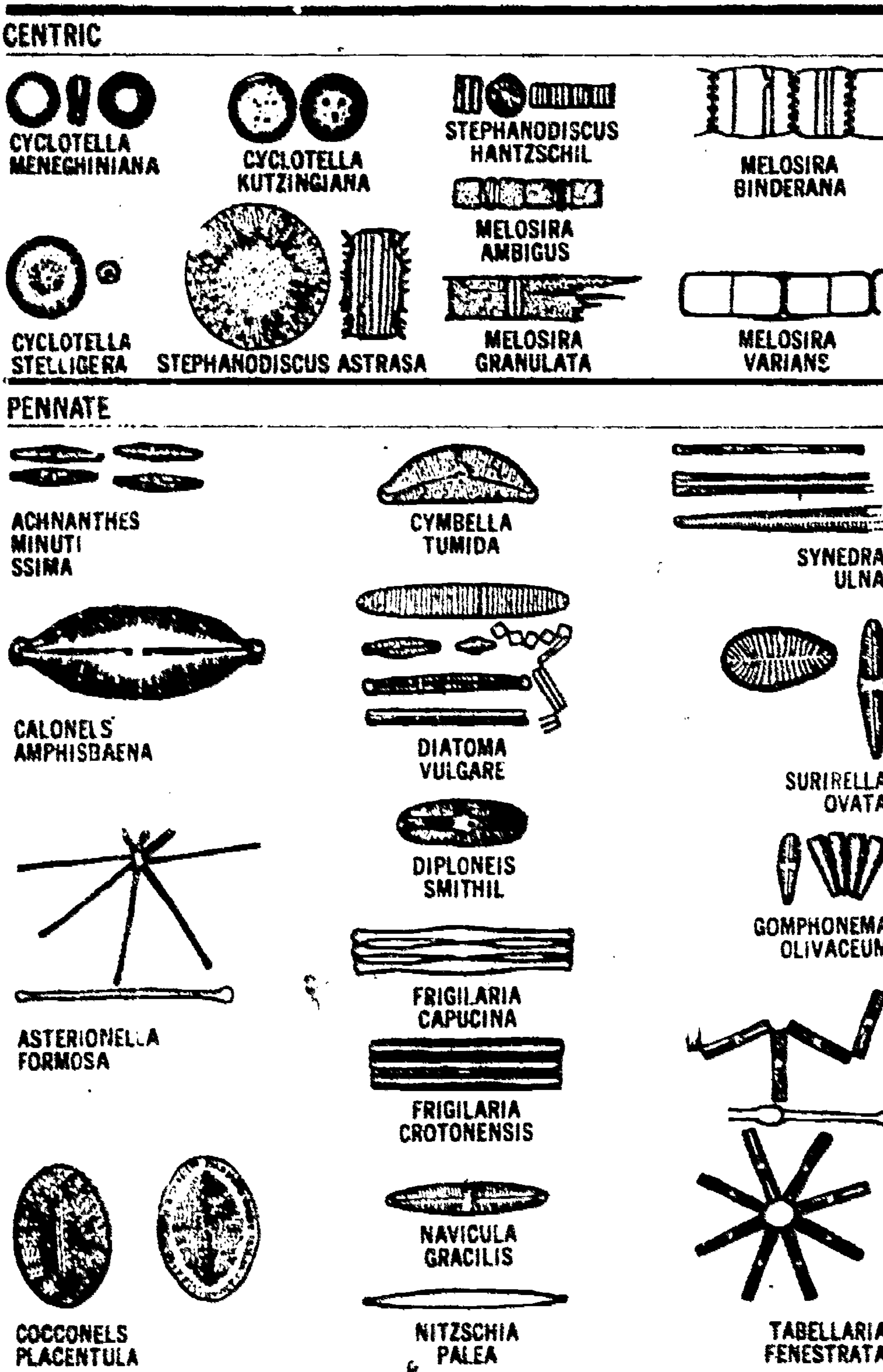


Figure 24 Diatoms commonly found in lakes and ponds

not contain solid wastes, but will still be full of chemical fertilizers left over from the digested sewage. However, many towns and cities have poor sewage treatment plants and every hard rain washes tons of garbage down the streams and into the lakes. If you drive to the nearest stream after a hard rain, you can see the floating refuse discarded by our civilization that so carelessly pollutes our fresh waters.

An additional result of progress in the past 20 years is the development of efficient detergents and soap powders that depend on phosphorus for their cleaning action. Phosphorus is a chemical fertilizer that further enriches the lakes into which it flows, thus adding to the nuisance scums of algae. Scientists have estimated that about half of the phosphorus dissolved in our lakes today comes from detergents. Even the new biodegradable detergents are rich in phosphorus.

In addition to the widespread effects of farming, city sewers, and detergents on our lakes, industries also have important local effects. Industries sometimes discharge into rivers harmful chemicals that destroy life for several miles downstream. Factories and paper mills often release heavily polluted water to streams near their operations, and mining operations may ruin nearby streams. The influence of man's activities on his lakes and rivers is one of the most serious problems we face today. More effort and money must be spent in recovering waste materials instead of dumping them into the nearest creek.

To study this problem in your own community, visit the nearest sewage treatment plant and look at the wastes flowing out of it. Are they clear and odorless? The rich chemical fertilizers that you cannot see will still be present in the water. If the waters are foamy and have a bad odor, and if visible particles are floating in them, the treatment plant is not doing its job adequately.

Also visit the downstream section of rivers used by industries near your home. If these rivers are clean and have life in them, such as river grass, fish, and aquatic insects, then the industry is recovering its wastes. If such a stream contains none of these normal forms of aquatic life, then the industry is probably releasing harmful materials that are destroying them.

QUESTIONS AFTER THE FIELD TRIP

1) What is the condition of lakes and rivers in your community? Do the waters suffer from harmful materials released into them by man's activities? If so, what can be done to improve them? Are better sewage treatment plants needed? Must industry clean up its effluents?
2) Do you live in an area of the country that was shaped by ice transported by glaciers or by wind and running water? Can you find places where soil is being moved today by wind and water?
3) What is the annual rainfall in your community? Where would you go to get this information? How would you measure it yourself? How does the annual rainfall affect the lakes in your community?
4) How dry is the air where you live? How would you measure its "dryness"? How does this property of the air affect lakes in your community?
5) Are there artificial lakes and ponds in your community? If so, why were they constructed? For recreation? Flood control? Hydroelectric power? Irrigation?
6) Deep lakes often have very little oxygen in the water near the bottom. How can you explain this? How does lack of oxygen affect the organisms living on the bottom?
7) Scientists have discovered that sewage can be oxidized effectively in shallow lagoons.

Why do you suppose that deep lagoons are less effective? List the processes that go on in such lagoons.

8) Crater lakes are usually beautifully clear but have very little life in them. What factors do you think are responsible for this scarcity of living matter?

9) If you were an engineer planning to construct a reservoir in your community, what area would you choose? Where would you place the dam? How extensive an area would be covered by water? Would many homes be destroyed? How would wildlife be affected?

10) In eastern Colorado and New Mexico the VPD is about 20 mmHg. The motels in this area find it necessary to heat their swimming pools almost every day in summer. What process do you think is responsible for cooling these pools?

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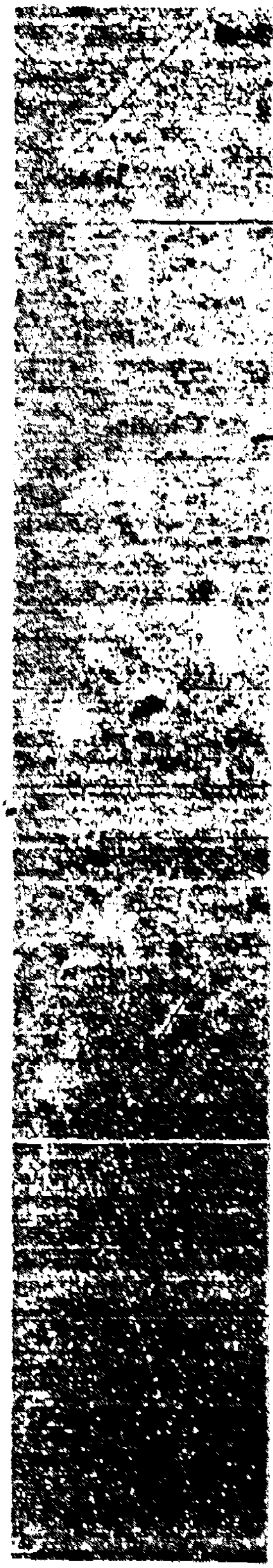

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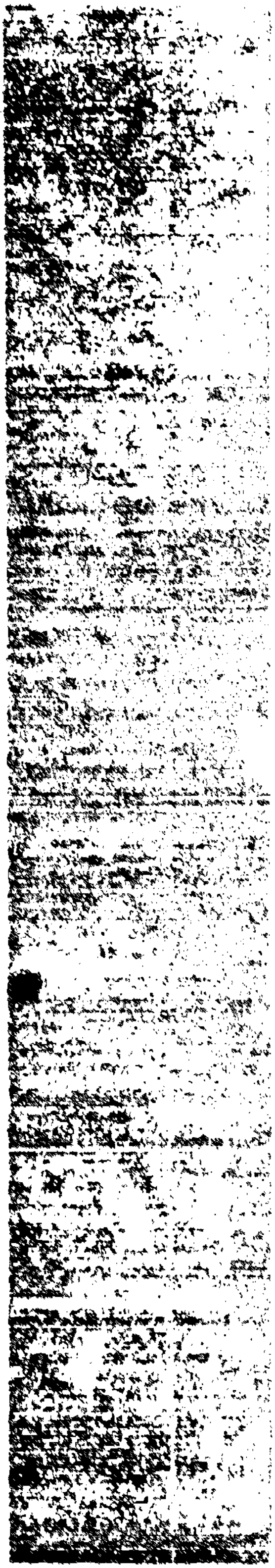

Glossary

algae—microscopic aquatic plants that carry on photosynthesis.

euphotic zone—the portion of water that receives enough light to support plant growth.

flagellates—microscopic plants and animals that move by means of tiny whiplike structures called flagella.

glaciation—formation of landscape features by large bodies of moving land ice.

lake—a water-filled depression in the landscape.

microinvertebrates—tiny animals without backbones or vertebral columns. Many different types are found in lakes and ponds.

moraine—rock debris deposited at the edge of an ice sheet.

photosynthesis—the process by which green plants store light energy by using it to produce sugars and other carbohydrates.

respiration—the process by which living organisms derive energy from sugars and other carbohydrates, proteins, and fats, breaking them down to carbon dioxide and water.

Secchi Disk—an instrument used to measure the transparency of water.

sedimentation—the process by which particles are deposited by water.

seiche—a periodic oscillation of water currents in a basin. Once it is set in motion, the seiche is maintained by the force of gravity, much like the swinging of a pendulum.

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