

Lake Stratification and Mixing

Many of our Illinois lakes and reservoirs are deep enough to stratify, or form "layers" of water with different temperatures. Such *thermal stratification* occurs because of the large differences in density (weight) between warm and cold waters. Density depends on temperature: water is most dense (heaviest) at about 39°F, and less dense (lighter) at temperatures warmer and colder than 39°F.

The Stratification Process

In the fall, chilly air temperatures cool the lake's surface. As the surface water cools, it becomes more dense and sinks to the bottom. Eventually the entire lake reaches about 39°F (4°C). As the surface water cools even more, it becomes less dense and "floats" on top of the denser 39°F water, forming ice at 32°F (0°C). The lake water below the ice remains near 39°F. This situation is referred to as *winter stratification*. Winter stratification remains stable because the ice cover prevents wind from mixing the water.

Come spring, the ice melts and the surface water begins to warm above 32°F. The increasing density of the warming water along with wind action cause this surface water to sink and mix with the deeper water—a process called *spring turnover*. During this time period, most of the lake water is at the same temperature, and surface and bottom waters mix freely. Lakes with a small surface area, especially if protected from the wind, typically completely mix for only a brief time in the spring—usually just a few days. In comparison, large lakes often circulate for weeks.

As the sun continues to warm the lake surface through late spring and early summer, the temperature differences increase between the surface and deeper waters. In lake areas deeper than about 10 to 12 feet, the temperature differences eventually create a physical

force strong enough to resist the wind's mixing forces (it only takes a difference of a few degrees Fahrenheit to prevent mixing). The lake now stratifies into three layers of water—a situation termed *summer stratification*. The upper layer is a warm (lighter), well-mixed zone called the *epilimnion*. Below this is a transitional zone where temperatures rapidly change called the *metalimnion*. The *thermocline* is a horizontal plane within the metalimnion through the point of greatest water temperature change. The metalimnion is very resistant to wind mixing. Beneath the metalimnion and extending to the lake bottom is the colder (heavier), usually dark, and relatively undisturbed *hypolimnion*.

The most important actions causing lake mixing are wind, inflowing water, and outflowing water. While wind influences the surface waters of all lakes, its ability to mix the entire water volume in summer-stratified lakes is greatly reduced. This is because the rapid change in temperature and density within the metalimnion acts like a physical barrier between the epilimnion and hypolimnion. Though not an absolute barrier, it takes a lot of energy to disrupt it.

The stability of a lake's stratification depends on many factors, most importantly the lake's depth, shape, and size. Also playing a role are climate, orientation of the lake to the wind, and inflow/outflow. As noted earlier, in shallow lakes (less than about 10 to 12 feet deep) wind forces are usually strong enough to mix the water from top to bottom and thereby thwart summer stratification. Lakes with a lot of water flowing through them (i.e., a short water residence time) also do not develop persistent thermal stratification. While a temperature gradient from warmer surface to cooler bottom waters may exist in such lakes, a true metalimnion is not typically formed.

Summer stratification continues until fall when surface waters begin to cool and sink. The metalimnion begins to "erode" and weaken, and continues to do so as the lake cools. Wind energy helps mix the lake deeper and deeper. When the whole lake reaches a similar temperature, wind forces are again able to mix the lake from top to bottom in a process called **fall turnover**. The transition from summer stratification to fall turnover can occur within just a few hours, especially if accompanied by strong winds.

Effects of Stratification

Stratification has important implications for fisheries management, phytoplankton (algae) populations, and water supply quality. A discussion of a few stratification impacts follows.

Dissolved Oxygen

Just after summer stratification is established, the hypolimnion is rich in dissolved oxygen from the early spring mixing of the lake. However, because the metalimnion acts as a barrier between the epilimnion and hypolimnion, the hypolimnion is essentially cut off from oxygen exchange with the atmosphere and is often too dark for plants and algae to grow and produce oxygen by photosynthesis. In a eutrophic (nutrient-rich) lake, the hypolimnion can become anoxic (without oxygen, or anaerobic) as the summer progresses. This occurs as its supply of oxygen is consumed by bacteria and other bottom-dwelling organisms. A lack of dissolved oxygen can have serious consequences.

Phosphorus and Nitrogen: In anoxic conditions, the nutrients phosphorus and ammonia-nitrogen become more soluble (dissolvable) and are released from the bottom sediments into the hypolimnion. During the summer, stratified lakes can sometimes partially mix (such as with the passing of a cold front accompanied by strong winds and cold rains), allowing some of these nutrients to "escape" into the epilimnion and potentially stimulate an algal bloom. For similar reasons, algal blooms often are seen at fall turnover as nutrient-rich bottom water is brought to the lake surface where there is ample sunlight to support algae growth. Ammonia-nitrogen also can have an impact on fish. Fish are sensitive to ammonia and are repelled by high levels in the water.

Metals and Other Compounds: Some metals and other elements—notably iron, manganese, and sulfur (as hydrogen sulfide)—also become increasingly

soluble and are released from anoxic bottom sediments. These compounds cause taste and odor problems—a potentially serious concern in drinking water supply reservoirs. Additionally, hydrogen sulfide concentrations above 1 mg/L are lethal to many gamefish as well as some zooplankton (microscopic animals that are an important fish food).

Fish: Low oxygen levels may restrict where fish can go in a lake and limit the types and numbers of fish in the hypolimnion. Warmwater fish (e.g., bass and bluegill) need at least 5 mg/L of dissolved oxygen to survive, while coldwater fish (e.g., trout) require 6-7 mg/L. In eutrophic lakes, as summer progresses and dissolved oxygen levels become too low in the hypolimnion, fish are confined to the epilimnion and a portion of the metalimnion.

As ice covers a lake in early winter, there usually is adequate oxygen in the water to sustain fish and other aquatic organisms. You may be surprised to learn that certain algae and rooted aquatic plants grow right through the winter and photosynthesize, producing oxygen. However, bacterial decomposition of organic matter on the lake bottom can consume more oxygen than photosynthesis can replace, causing a decline in dissolved oxygen levels as the winter season progresses. If enough snow covers the ice or if the ice is opaque, sunlight may be inadequate or unable to penetrate and photosynthesis will stop. If the lake's supply of oxygen falls too low before ice-out, a partial or total fishkill can occur.

Temperature

In summer-stratified lakes, water temperatures decrease from the surface to the bottom. As discussed above, a warm surface layer (the epilimnion) "floats" on a colder layer (the hypolimnion). Different fish species prefer different water temperatures. Hence, a lake's temperature variations are important in influencing what types and how many fish will live and reproduce in that lake. If the colder, deeper waters of the hypolimnion have enough oxygen, then that area will provide a refuge for fish species that prefer, or require, cold water temperatures. However, if dissolved oxygen levels become too low in the hypolimnion and fish are forced into the warmer surface waters, coldwater fish species may not be able to survive.

The Unique Properties of Water

Water is a unique substance. To understand how lakes behave, it is useful to understand water's physical and chemical properties. The molecular structure of water and the way in which water molecules associate with each other dictate these properties:

1. Water is an excellent solvent; many gases, minerals, and organic compounds dissolve readily in it.
2. Water is a liquid at natural environmental temperatures and pressures. Although this property seems rather common and obvious, it is quite important. If water behaved at ordinary temperatures and pressures like other inorganic compounds that are chemically similar to it, water would only be present as a vapor—and lakes would not exist.
3. The temperature/density relationship of water is also unique. Most liquids become more dense (heavier) as they cool. Water also rapidly becomes more dense as its temperature drops, but only to a certain point. Water reaches its maximum density at 39.2°F (3.94°C), then it decreases slightly in density until it reaches 32°F (0°C), the freezing point. At this point, ice forms and its density decreases sharply. Ice, therefore, is much lighter than liquid water and thus forms at the surface of lakes rather than at the lake bottom.

A second important consequence of the temperature/density relationship of water is the thermal stratification of lakes. Energy is required to mix fluids of differing densities, and the amount of energy necessary is related to the difference in density. In the case of lakes, this energy is provided primarily by wind. Therefore, the changes in water density that accompany rapidly decreasing water temperatures in the metalimnion during summer stratification are of great importance. The metalimnetic density gradient provides a strong and effective barrier to lake mixing.

4. Water also has an unusually high "specific heat." Specific heat is the amount of energy required to change the temperature of 1 gram of water by 1°C. Water also has a high "latent heat of fusion," which is the energy required to melt 1 gram of ice at 0°C. These properties make lakes slow to thaw and warm in the spring and slow to cool and freeze in the fall, thus providing exceptionally stable thermal environments for aquatic organisms.

Because water gains and loses heat slowly, the presence of large lakes can exert a significant influence on local and regional climate. A good example is the Great Lakes, which have a dramatic effect on both air temperature and precipitation in the states and provinces surrounding them.