Seasonal Lake Stratification

Lakes within the Great Lakes region undergo seasonal changes with regard to their temperature-density profiles. These changes directly influence various characteristics of the lake. To begin with, one must understand the temperature-density relationship for water. For the most part, as water increases in temperature it becomes less dense. Conversely, water becomes more dense as it decreases in temperature. The exception to this rule is that water reaches its maximum density at approximately 4° Celsius. Below 4°C, as water cools the number of water molecules joined together by hydrogen bonds to form loose clusters increases. Because of the formation of these structured aggregates, below 4°C water actually becomes less dense as it cools. The molecules in ice form a very structured, open framework, so ice itself is less dense than water and, consequently, it floats. With this concept in mind, seasonal or thermal stratification within lakes can be explored

Changes in the temperature profile with depth within a lake system is called thermal stratification. This profile changes from one season to the next and creates a cyclical pattern that is repeated from year to year. Let us begin with spring. After the ice melts on a lake, the lake water is generally the same temperature from the surface to the bottom. Wind allows circulation and mixing of the lake water. Surface water can be pushed to the lake bottom and bottom water can rise to the surface (Figure 1). This circulation pattern is very important in that it allows relatively large amounts of oxygen to reach the bottom of the lake. Otherwise, oxygen would have to reach the bottom by the relatively slow process of diffusion. The mixing of the lake water at this time of year is called spring overturn.

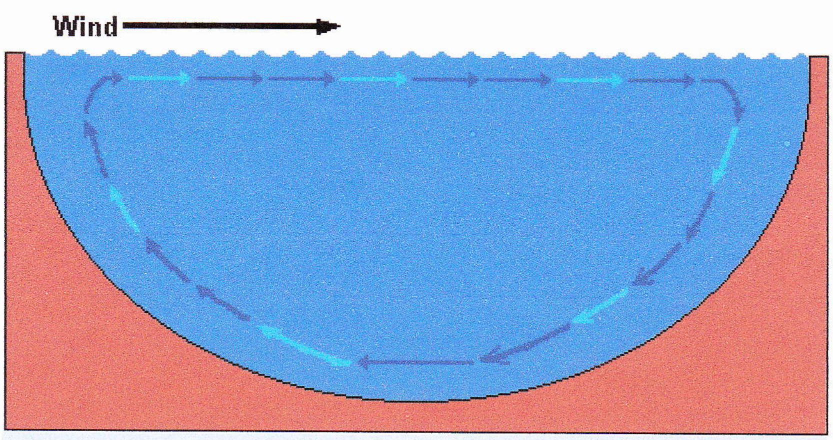

Figure 1 Complete mixing of water can occur when all water within the lake is generally the same temperature. Wind helps to drive this process.

As air temperatures rise in late spring, heat from the sun begins to warm the lake. As the amount of solar radiation absorbed decreases with depth, the lake heats from the surface down. The warm water is less dense than the colder water below resulting in a layer of warm water that floats over the cold water. The layer of warm water at the surface of the lake is called the epilimnion. The cold layer below the epilimnion is called the hypolimnion. These two layers are separated by a layer of water which rapidly changes temperature with depth. This is called the thermocline (or metalimnion). The three distinct layers of water, each with a different temperature or range of temperatures, is an excellent example of thermal stratification within a lake system. Figure 2 below shows how the depth of the epilimnion increases through the spring and into the early summer.

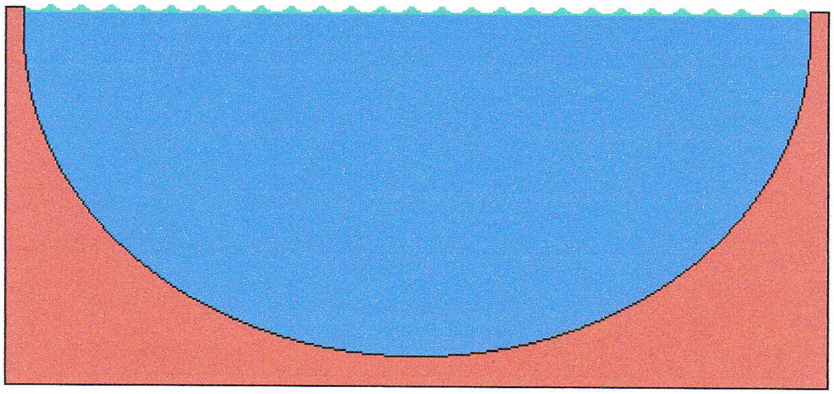

Figure 2 As summer approaches, the surface of the lake begins to get warmer. This creates a relatively warm surface layer over a relatively cool bottom layer. They are separated by a zone that changes temperature very rapidly with depth.

During the summer the epilimnion will reach a maximum depth and stratification will be maintained for the remainder of the summer. The warm water, abundant sunlight, and nutrients brought up from the lake bottom during spring overturn provide an ideal environment for algae growth within the epilimnion. Algal blooms tend to give the epilimnion a greenish hue. Stratification during the summer acts as a deterrent to complete lake mixing. Wind circulates the surface water, but the warm water of the epilimnion is unable to drive through the cold, dense water of the hypolimnion. As a result, the water is only mixed in the epilimnion (Figure 3).

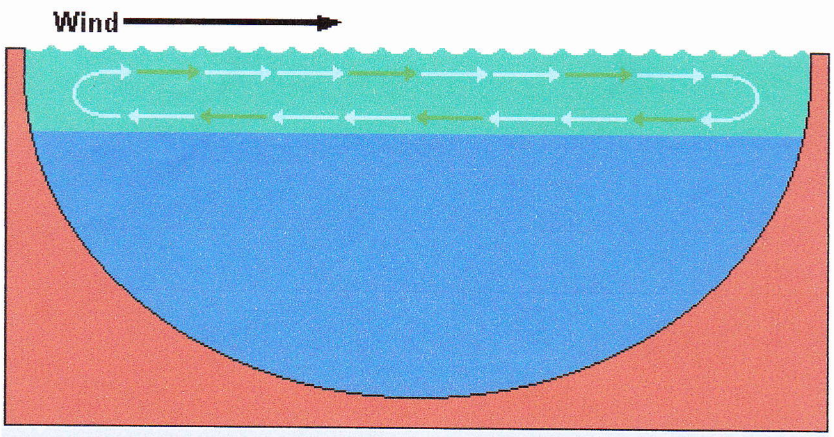

Figure 3 During summer density differences act as a barrier to complete mixing of the lake. This deprives the lake bottom of oxygen.

Without mixing to provide dissolved oxygen, the lake bottom, lacking enough light for photosynthesis to occur, tends to have a very limited supply of oxygen during the summer. Respiration by animals and bacteria can deplete the dissolved oxygen at the bottom of the lake. A stratified lake of this nature is said to be in summer stagnation. Dead algae sink to the lake bottom and are decomposed by bacteria. This accelerates the depletion of dissolved oxygen in the hypolimnion as aerobic bacteria use oxygen to decompose the wealth of organic material raining down from the epilimnion. During summer stagnation the lake bottom can become anoxic (i.e., without oxygen) and anaerobic bacteria begin to decompose organic material without the aid of dissolved oxygen. If dead algae accumulate at a faster rate than bacteria decompose the organic matter, sediment deposited in the lake will be rich in organics. This is likely because without thorough mixing to provide the surface water with nutrients from the bottom, the algae eventually begin to limit the available nutrients in the epilimnion. Lack of available nutrients can cause large die-offs of algae, adding to the organic matter on the lake bottom. Frequently, anaerobic bacteria produce hydrogen sulfide gas (H_2S), so the organic-rich sediment may have the odor of "rotten eggs". Some of the sulfur in the H_2S may combine with iron to form pyrite or "fool's gold" (FeS_2). For example, when a core composed of fine sediment is taken from the bottom of Lake Michigan and is cut open, commonly dark laminations are observed, which disappear within an hour. The dark material is likely pyrite that oxidizes (combines with oxygen) to iron oxide when exposed to air.

As autumn approaches and temperatures decrease, the epilimnion begins to decrease in depth (Figure 4). Eventually the epilimnion gets so shallow that it can no longer be maintained as a separate layer and the lake loses its stratification. Thus, as in the spring, the lake water in the autumn has generally uniform temperatures (about 4°C in late autumn), and wind can once again thoroughly mix the lake water. In addition, surface water, which is in direct contact with the cold air, gets cooled faster than the water below. This cold, dense water sinks and further helps to mix the lake, and once more oxygen and nutrients are replenished throughout the lake (Figure 5). This process is called autumn overturn.

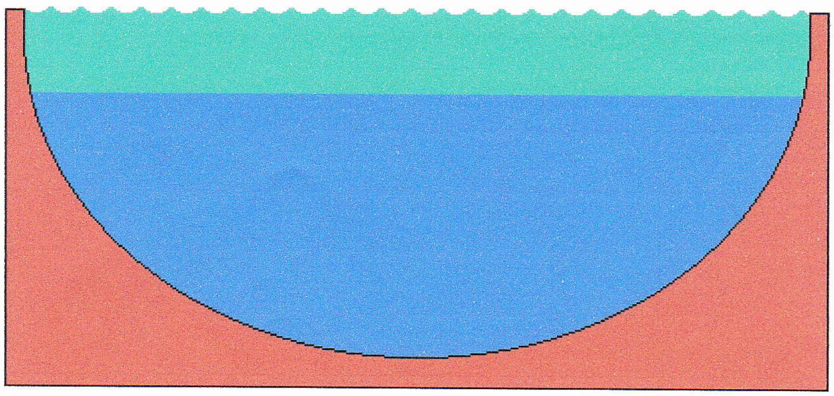

Figure 4 As seasonal temperatures decrease, so does the depth of the warm water layer known as the epilimnion. Conversely, the cold layer known as the hypolimnion increases in thickness.

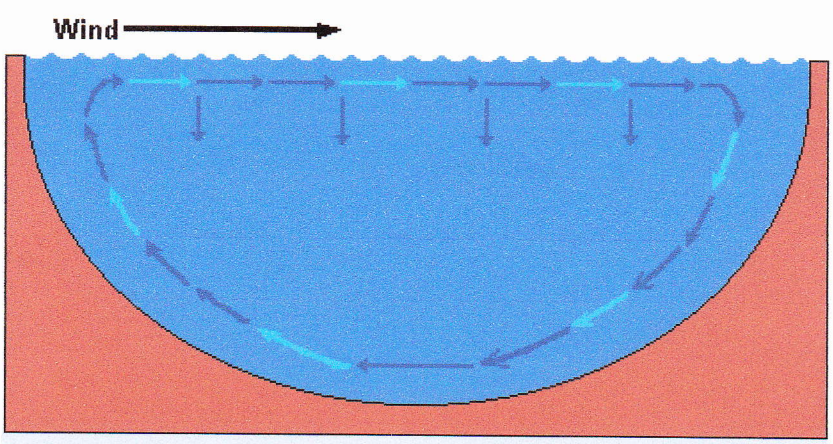

Figure 5 Complete mixing of water can occur when all water within the lake is generally the same temperature. In addition, the atmosphere cools the water at the lake's surface. This dense water sinks to the bottom and further contributes to lake mixing.

As winter approaches, the surface water is eventually cooled below 4° C. At this point, the water no longer sinks. The water molecules begin to align themselves (form more hydrogen bonds) to solidify. As water temperatures at the surface reach 0°C, ice begins to cover the surface of the lake. During the winter, ice cover prevents wind from mixing the lake water. Again, stratification can occur. A layer of low density water colder than 4°C, but warmer than 0°C forms just under the ice. Below this water, the remainder of the lake water is usually near 4° C. At this point, a lake is said to be in winter stagnation (Figure 6). As spring approaches, the seasonal cycle begins again.

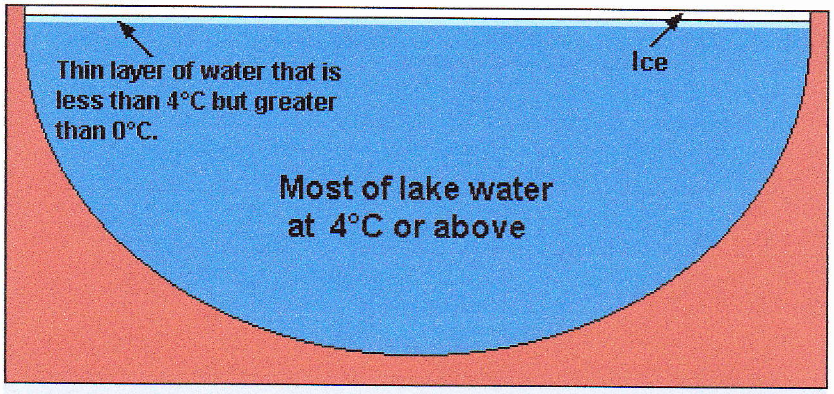

Figure 6 During the winter, ice prevents lake water mixing. Stratification can occur during this time of winter stagnation.

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