Lake Characteristics

The following sections briefly describe various physical, chemical, and biological characteristics of lakes. Familiarity with these characteristics will help explain how lakes work and how to interpret the monitoring data for lakes in Snohomish County. Please refer to the Glossary for definitions of underlined words.

Lake Size, Shape, Volume, and Depth

The size of a lake—the number of acres covered by the lake surface—is one of its most important characteristics. In many ways, large lakes are often seen as higher value public assets because they support more recreational users and more lakefront property than smaller lakes. However, small lakes may provide other benefits, such as more tranquil recreational opportunities. Wind and waves on larger lakes also create greater impacts to recreation, shoreline stability, and water mixing.

The shape of a lake can also be important. Long or irregularly shaped lakes tend to have longer shorelines than nearly circular lakes. This means there are potentially more shallow water areas that can support aquatic plants. Lakes with elongated shapes parallel to the prevailing winds can also experience greater impacts from wind and waves.

Lake volume is the total amount of water within a lake. Volume can be measured from a bathymetric map that shows the depth contours of the lake bottom. Lake depth is closely related to volume. Depth is usually measured as both maximum depth and average (mean) depth. Average depth (the volume divided by the lake area) is often a good indicator of the natural biological productivity in a lake. Shallow lakes tend to be more productive (they grow more algae and plants) than deep lakes because there is more mixing, there is more shoreline area for aquatic plants, and there is a relatively larger area of bottom sediments that can recycle nutrients into the water. Deeper lakes experience less thorough mixing, usually have less shoreline area for aquatic plants, and have more open water habitat.

Lake Watersheds and the Water Cycle

Each lake is a reflection of its watershed. (A watershed is simply the land area that drains into a waterbody, such as a lake.) A lake's watershed plays a major role in the hydrologic cycle that provides water for the lake. The water in a lake comes from direct precipitation on the lake surface, from direct runoff from the watershed, or from precipitation that soaks into the ground and then flows to the lake as ground water. The quantity of these water sources determines the fluctuations of water level within a lake and the speed that water moves through a lake. In general, the larger the watershed in relation to the lake (the watershed-to-lake area ratio) the faster that water will flow through the lake (flushing rate) and the shorter that water will remain in the lake (detention time).

The size of the watershed, the speed that water flushes through a lake, and the character of surrounding land use also affect the cycle of nutrients and other materials that are important to lake health. Nutrients (such as phosphorus and nitrogen), minerals, and pollutants originate from soil and vegetation and from human activities in the watershed. The amount of these substances reaching the lake is referred to as external loading. Nutrients, minerals, and pollutants entering a lake affect the clarity of water, the amount and types of algae, and even the abundance of fish in a lake. Therefore, any activity in the watershed that affects these substances has the potential to change a lake in some way. This is why lake protection and restoration must address human activities along the shoreline and throughout the watershed.

Each individual lake report includes an aerial map of the watershed and information about the amount of land development that has occurred from the mid-1970s to the mid-1990s. There is information about the number of homes along the shoreline and the density of shoreline development (the number of homes per 1000 feet of shoreline). There are also data on the degree of shoreline modification, such as bulkheads or land filling, and on the percentage of properties that have retained some native vegetation along the lake shore. Taken together, this land use information provides a picture of the watershed and shoreline conditions that affect the character of a particular lake.

Temperature and Stratification

Water temperature is one of the most important characteristics of a lake. Temperature dramatically affects the rates of chemical and biological activity in the water, which in turn affect water quality. Warmer water generally increases the rate of growth of plants and algae, and for many animals. Warm water also accelerates the decay of organic matter in a lake, especially near the lake bottom.

The temperature of water in a lake changes with the seasons and often varies with depth. In a lowland Snohomish County lake in wintertime, the water temperature is cold and is usually uniform throughout the lake. Wind and waves keep the lake well mixed. During spring and summer, the upper waters in a lake are warmed by the sun. Because warmer water is less dense, it will float above the cooler, more dense water below. The temperature and density differences tend to create distinct layers of water in the lake, and these layers do not mix easily. As the summer progresses, the temperature and density differences increase, and the separation of water layers gets stronger and more resistant to wind mixing. This process is known as stratification and occurs in all but the most shallow lakes.

The upper water layer, called the epilimnion, is warmer and receives more light than the lower layers. The epilimnion is where the majority of biological growth occurs. The colder, denser, darker bottom waters are called

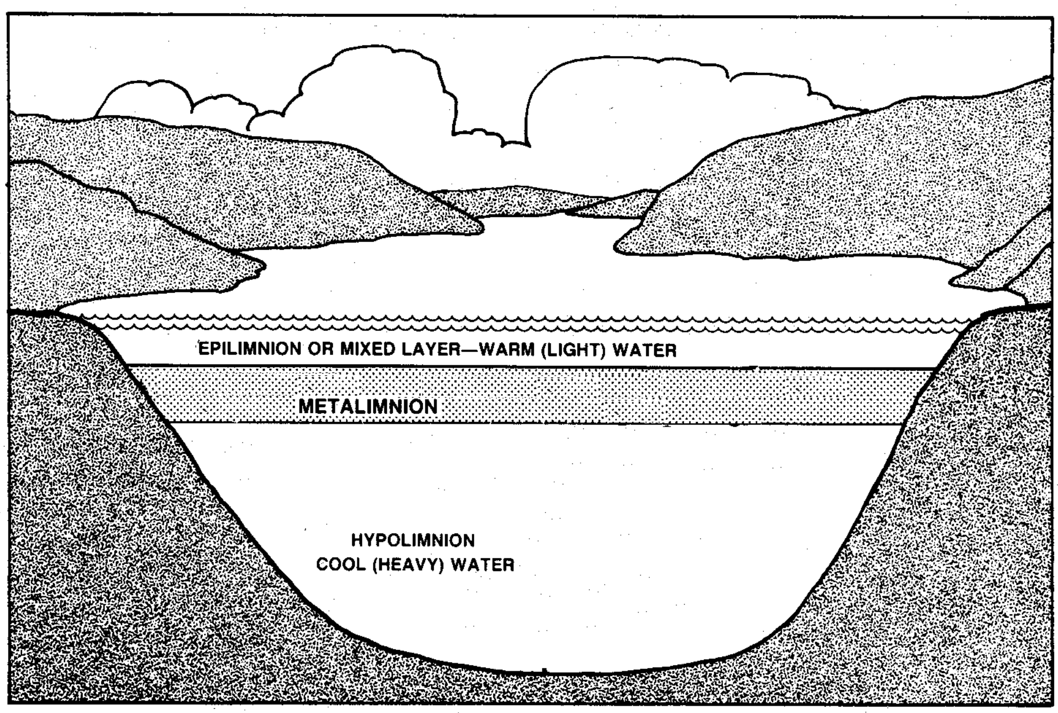


Figure 2. Lake Stratification. Adapted from *The Lake and Reservoir Restoration Guidance Manual* by the North American Lake Management Society, Second Edition, August 1990.

the hypolimnion. Plant and animal matter decays and sinks to the bottom in this stagnant layer. The metalimnion is the narrow band between the upper and lower waters where the temperature changes quickly with depth. Figure 2 illustrates the pattern of thermal stratification in a typical lake.

Later in the fall, as the upper waters cool, the temperature and density differences between the lake layers decrease. Eventually, wind and waves are able to overcome the forces separating the layers, and the entire lake mixes. This phenomenon is called fall turnover. During turnover, dissolved nutrients from the lake bottom are distributed throughout the lake. This can fertilize algae in the lake and cause rapid growths of algae known as algal blooms. Lakes that are shallow and regularly mix even during the summer have greater potential to release nutrients from the lake bottom and fuel algal blooms.

Dissolved Oxygen

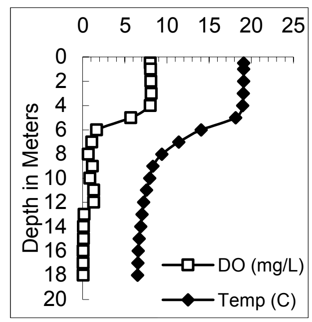
Oxygen is another key parameter of lake water quality. The availability of dissolved oxygen in water is essential for life in a lake. Most of the oxygen enters the water from the atmosphere, mainly from the mixing action of winds and waves. Aquatic plants and algae also produce oxygen as a by-product of photosynthesis.

Like temperature, dissolved oxygen levels in a lake will vary over time and with depth. For example, cold water can hold more dissolved oxygen than warm water. When 100% saturated, 40° F water will typically contain about 13 parts per million (ppm) of oxygen, while 70° F water will hold about 9 ppm. So, the cooler deep portions of lakes theoretically can hold more oxygen. In addition, oxygen levels increase during the daytime as aquatic plants and algae produce oxygen. Then at night, animals, plants, algae, and bacteria use up oxygen as they respire, which lowers oxygen levels in the water. Oxygen levels also increase after periods of strong winds and waves, and during the cold winter months when lakes are mixed and biological activity is lower.

During late spring and summer when a lake is stratified, mixing between the hypolimnion (bottom waters) and the epilimnion (upper waters) is minimal. This prevents the hypolimnion from being re-supplied with oxygen from the atmosphere or from plant and algae growth in the epilimnion. Further, even though the cold water of the hypolimnion can hold more oxygen than the warm water of the epilimnion, the activity of bacteria which decompose organic matter that has settled to the lake bottom often consumes much of the dissolved oxygen in the hypolimnion.

Figure 3. Typical Summer Dissolved Oxygen (DO) and Temperature Patterns in a Stratified Lake

(the lake surface is at the top of the graph)



This summertime combination of oxygen depletion in the hypolimnion, together with the significant warming of the epilimnion, can create problems for cold water fish, such as trout, in some Snohomish County lakes. Most fish cannot survive when oxygen levels in the water fall below 3 to 5 ppm, yet the upper waters are too warm for the needs of cold water fish. So, these fish may be limited to a narrow band near the metalimnion where the water is just cool enough and has just enough oxygen to sustain life. In extreme cases, fish can die from lack of oxygen. Warm water fish, such as bass, are better able to deal with low oxygen levels.

Another significant interaction between dissolved oxygen and lake water quality can occur during stratification when decomposition of organic matter significantly reduces oxygen in the hypolimnion. As oxygen levels at the lake bottom approach zero (anoxia), a chemical reaction can occur that releases phosphorus from the bottom sediments. This phosphorus release can fuel the growth of algae when the lake water is mixed during storms or at fall turnover.

Snohomish County SWM staff and citizen volunteers have taken numerous measurements of temperature and dissolved oxygen at various depths in many lakes during the warm months of the year. The individual lake reports contain graphs of temperature and dissolved oxygen profiles from the summers of 1995 through 2000. These graphs illustrate the changing values with depth and time. For several lakes, the data reveal potential problems for fish habitat and phosphorus releases caused by high temperatures or low dissolved oxygen.

Nutrients

Nutrients in lakes are essential for the growth of plants and algae. The key nutrients are phosphorus and nitrogen, although plants and algae also need small amounts of many other nutrients, such as iron, manganese, and molybdenum. Rooted aquatic plants get most of their nutrients from the sediments in a lake, while most algae and free-floating plants utilize nutrients directly from the water.

In most Snohomish County lakes, phosphorus is the least available of the nutrients needed for algal growth. Therefore, a scarcity of phosphorus will limit algal growth, while the addition of more phosphorus to a lake may produce excessive algae. Unfortunately, human-generated sources of phosphorus are abundant in lake watersheds and readily transported to lakes in stormwater runoff and through the air. These sources include lawn and garden fertilizers, yard wastes, soil erosion, road runoff, waste products from farm animals and domestic pets; and failing septic systems. Lakes that receive runoff loaded with large amounts of nutrients often experience problems with undesirable plant and algal growth. Therefore, almost all lake clean-up efforts require actions to control nutrient inputs from the watershed.

Lakes also recycle nutrients so that plants and algae may use them again and again. After nutrients enter a lake from the watershed or atmosphere, plants and algae take them up from the sediments and water. When the plants and algae die, they sink to the bottom and decompose, releasing stored nutrients, mostly in inorganic forms that are directly available for new algal growth.

Some nutrients are re-used immediately, but many accumulate in the bottom sediments. When dissolved oxygen levels decline in the bottom waters during stratified periods, phosphorus from the sediments is released into the overlying water. Then, when the lake mixes, these nutrients become available for algal growth in the upper waters. Some algae can even take advantage of these recycled nutrients when the lake is stratified by moving down to the hypolimnion to take up nutrients and then rising back to the upper waters to grow.

Phosphorus and nitrogen both exist in several forms. They can be dissolved in water, attached to other particles, or incorporated in organic matter. Only a fraction of the total quantity of nutrients is actually available for plants and algae to use directly. The most accurate method of assessing the nutrient richness of a lake is to measure all forms of phosphorus and nitrogen. However, simple measurements of the total amounts of phosphorus or nitrogen in lake water are less expensive and still provide a good indication of the potential for algal growth. The data summarized in the individual lake reports include total phosphorus (TP) concentrations for many lakes. In general, these measurements were taken near the surface (about one meter deep) and about one meter from the lake bottom. Total phosphorus concentrations are shown in micrograms per liter (µg/l), which is equivalent to parts per billion (ppb). The data show just how little phosphorus is actually needed to fuel algal growth.

Algae

Algae are microscopic (usually) organisms that form the base of the food web in a lake. Like green plants, most algae have pigments that allow them to create energy from sunlight through the process of photosynthesis. Algae use this energy, along with nutrients, to grow. In turn, fish and other animals in a lake either directly or indirectly consume algae for their food sources. Algal photosynthesis also produces some of the dissolved oxygen found in a lake.

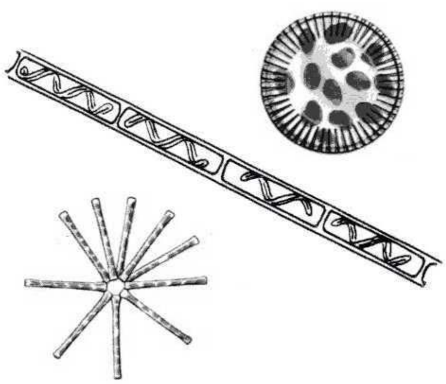


Figure 4. Examples of Freshwater Algae
Drawings by IFAS, Center for Aquatic Plants, University of Florida, 1990; and U.S. Soil Conservation Service, *Water Quality Indicators Guide: Surface Waters*, 1989.

Although algae are essential for a healthy lake, too much algae, especially nuisance types, can cause problems. Algae can coat docks and pipes, cloud the water enough to inhibit plant growth, deplete oxygen as they die and decay, create odor and taste problems, and cause one type of "swimmer's itch". Dense growths of algae are called "blooms". Algal blooms sometimes create thick, unpleasant scums on a lake's surface. Given the right conditions, some algae even produce toxins which can be deadly to pets and livestock, or harm people.

As described in the "Nutrients" section, algal blooms and their associated problems are usually the result of excess nutrients in the water. Therefore, the primary strategy for limiting algal problems is to control the sources of nutrients in the watershed, such as fertilizers, storm runoff, and septic drainfield discharges, and to control the internal release of nutrients from the sediment.

There are several ways to classify types of algae. One distinction is where they live. Algae attached to rocks, plants, or other objects are called periphyton. Free-floating algae, known as phytoplankton, are the types that often cause water quality problems in Snohomish County lakes. Scientifically, there are three main groups of algae—the green algae (Chlorophyta), the golden brown algae (Chrysophyta) which also includes a large group called diatoms, and the blue-green algae (Cyanobacteria)—and several smaller groups (euglenoids, cryptomonads, and dinoflagellates).

When lakes suffer from algal problems, often the main culprits are blue-green algae. Blue-greens are classified as bacteria (Cyanobacteria) but have many characteristics of true algae. Blue-greens also have qualities that make them especially prolific. They have odd shapes and other defenses which discourage animals from eating them, so there are fewer natural controls on their growth. Some blue-greens can also fix nitrogen directly out of the atmosphere if there is not enough of this nutrient in the water. Blue-greens can also control their buoyancy to move to the most advantageous depths in a lake to reach light or nutrients. Blue-greens are responsible for toxic blooms. The presence of blue-green algal blooms with surface scums is a strong indication that a lake is receiving excessive amounts of nutrients.

Both the amount and types of algae in a lake vary through the seasons. The amount of algae tends to be high in spring and early summer because of increasing water temperature, more sunlight, abundant nutrients from winter rains, and low amounts of grazing by microscopic animals. Because of their rapid growth, diatoms are often the algae that bloom during this period, followed by green algae. By mid-summer, the amount of algae may begin to decline as they outgrow the available nutrients and animal grazing increases. Late summer and fall may bring blue-green algal blooms, especially if nutrients have built up in the hypolimnion from sediment release and are spread throughout the lake when the lake mixes.

Monitoring the amount of algae and the types of algae in a lake helps in understanding lake conditions. Chlorophyll *a* is a common measurement of the abundance of algae in a lake. Chlorophyll *a* is the active green pigment in algal cells that is used for photosynthesis. There are only limited chlorophyll *a* data for most Snohomish County lakes. Data on the volume and abundance of the various types of algae in County lakes are even more scarce. The available data are included in the individual lake reports, but should be used cautiously because algal abundance and types change frequently in a lake, so these data provide only brief snapshots of conditions in each lake. Chlorophyll *a* is measured in units of micrograms per liter (µg/l), which is equivalent to parts per billion.

In addition, other measurements and observations by SWM staff and citizen volunteers help provide a picture of the algae in Snohomish County lakes. Living algae usually exist in the epilimnion where sunlight is available. Because the presence of algae in the upper waters reduces water clarity, measurements of clarity (or transparency) often indicate the relative amount of algae present in a lake. Also, the dissolved oxygen profiles presented for each lake sometimes show sharp increases of oxygen several meters below the surface. This situation indicates that rapid algal growth is occurring in a narrow band at the top of the metalimnion where light and nutrients are both available.

Zooplankton, Fish, Benthos, and the Food Web

Zooplankton is a general name for the tiny invertebrate animals that swim or float in lakes. Zooplankton feed on algae and bacteria and, in turn, serve as food for small fish and larger invertebrate animals.

The dominant types of zooplankton in lakes are cladocerans (such as *Daphnia*), copepods, rotifers, and protozoa. These are invertebrate animals with special adaptations for consuming algae and/or bacteria and for moving in a lake in response to light and food availability. The presence of abundant zooplankton in a lake, especially *Daphnia* which are relatively large, can control the amount of algae and reduce algae-related problems. Unfortunately, the blue-green algae are not easily consumed or desired by most zooplankton, which is one reason that blue-green algae cause so many problems in nutrient-rich lakes.

Snohomish County lakes also support a variety of fishes. The most common types of fish are cold water fish, including rainbow trout, cutthroat trout, and kokanee, and warm water fish, including the sunfish (bass, crappie, bluegills, and pumpkinseed), yellow perch, bullhead catfish, and carp. Rainbow trout are the main fish planted in local lakes by the State for recreational fishing.

Organisms that live or feed at the bottom of a lake are known as the benthos. Their role is to break down and decompose organic matter that settles to the lake bottom (such as dead algae, animals, and plant material). Various bacteria and fungi are the main decomposers, but a wide assortment of worms, insects, snails, and some fish, such as carp, are also important.

Algae, zooplankton, fish, and benthic organisms are key components of the food web and of the flow of energy and nutrients in a lake. Algae are the primary producers of organic matter in the open waters of a lake. They use energy from the sun and nutrients from the water and sediment to grow. Zooplankton consume this algae and, in turn, are consumed by small fish. Larger fish then consume smaller fish. All of these organisms produce wastes and eventually die, which supplies the benthic decomposers with food and energy. This process continually recycles many of the nutrients within a lake.

At each higher level of life, there are fewer and fewer individuals. Usually, there are only a few large fish in a lake because they depend on a large supply of smaller fish, which then depend on vast numbers of zooplankton and algae. In some cases, increasing the number of large fish can decrease the amount of small fish which reduces their consumption of zooplankton and, in turn, increases zooplankton grazing on algae, which lessens the likelihood of algal problems.

Lake monitoring conducted by SWM and citizen volunteers does not currently include measurements or samples of zooplankton or fish. However, observations recorded during other monitoring sometimes provide a partial picture of the abundance and types of these organisms in particular lakes.

Aquatic Plants

Aquatic plants are an important part of a lake ecosystem. They perform a wide variety of beneficial roles. They provide nesting sites, cover, and food for aquatic life, including fish, waterfowl, and invertebrate animals. Plants improve conditions in a lake by increasing oxygen concentrations in the water and the nearshore bottom sediments. Rooted aquatic plant communities help secure and stabilize shorelines. In some cases, aquatic plants help increase water clarity by out-competing algae for nutrients and secreting substances that inhibit algal growth.

Most aquatic plants (also known as macrophytes) are related to land plants. However, aquatic plants have special adaptations that allow them to live in wet conditions. These plants usually have true roots, stems, and leaves. Aquatic plants can be grouped into four types: emergent plants, rooted floating-leafed plants, submersed plants, and free-floating plants. Emergent plants have much of their stems and leaves growing above (emerging from) the water surface. They are usually found in shallow water or near the shore. Some examples of emergent plants found around Snohomish County lakes are reeds and bulrushes.

Rooted floating-leafed plants have leaves that float on the surface and long stems connected to the roots. Some examples of floating-leafed plants are water-lilies and watershield.

Submersed plants are rooted in the bottom and have their leaves and stems below the water surface, with flowers often projecting above the surface. The most common examples of submersed plants in Snohomish County are elodea, pondweeds, and milfoil.

Free-floating plants remain at or near the surface with root systems dangling in the water, rather than connected to the bottom sediment. Examples of free-floating plants are duckweed and bladderwort.

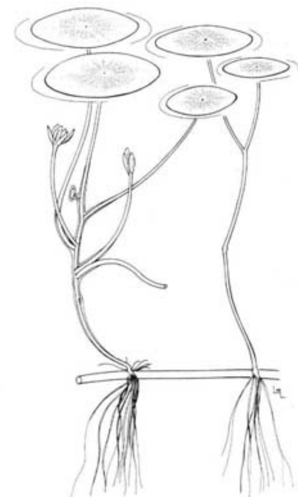


Figure 5.
Watershield—A Native Aquatic Plant
Drawing by IFAS, Center for Aquatic Plants, University of Florida, 1990

There are also several types of large algae in local lakes which look like aquatic plants. These macro-algae are simple, primitive plants that do not have true roots, stems, or leaves. These algae are upright and may be connected to the bottom sediments. The main types in local lakes are chara and nitella.

Although aquatic plants (including the macro-algae) perform important ecological functions in lakes, under certain conditions they can become problems. Excess growth of aquatic plants can interfere with swimming, boating, fishing, and wildlife habitat. In addition, invasion by non-native (exotic) plant species can seriously damage an aquatic ecosystem. Non-native plants can choke out native aquatic plants and form dense stands that are a nuisance to humans. Stands of invasive plants also create poor habitat for native fish and wildlife that rely on native vegetation.

The main non-native invasive aquatic plants in Snohomish County lakes are Eurasian watermilfoil, Brazilian Elodea, purple loosestrife, and parrotfeather. Eurasian watermilfoil (*Myriophyllum spicatum*) is a submersed plant that spreads rapidly. It has been found in Lakes Goodwin, Shoecraft, and Roesiger (and in Silver Lake in Everett). Expensive efforts are now underway to control Eurasian watermilfoil in these lakes. Purple loosestrife (*Lythrum salicaria*) is an emergent plant that grows along lake shores and chokes out native shoreline plants. Purple loosestrife has been found around several local lakes. Brazilian elodea (*Egeria densa*) is a particularly noxious aquatic plant that has invaded Lake Swartz. Parrotfeather (*Myriophyllum aquaticum*) is a hardy, invasive plant that has been found and removed twice in Nina Lake. European frog-bit has invaded Meadow Lake.

The reports for individual lakes and this county-wide summary contain information about the aquatic plant communities found at each lake, including both native and exotic plants. The maps and plant lists are based on surveys by SWM staff and observations by citizen volunteers. Two objectives of the Lake Management Program are to encourage protection of native aquatic plants and to identify and stop the spread of non-native invasive aquatic plants in Snohomish County lakes.

Water Clarity and Color

Water clarity is an important characteristic of a lake's condition. Water clarity is related to the depth to which light penetrates into the water and usually provides an indication of the health of a lake. Clarity is measured with a round black and white disk, called a Secchi disk. The disk is lowered into the water, and the exact depth at which the disk disappears or re-appears is the Secchi depth. Water clarity readings using a Secchi disk are simple and quite accurate, and are the most frequently collected lake data worldwide.

Water clarity affects fish and aquatic life in several ways. First, with poor water clarity, reduced light may limit algal photosynthesis and restrict the growth of submersed aquatic plants. If photosynthesis is restricted, both algae and plants will produce less food for fish and invertebrates. Second, reduced clarity interferes with visibility for animals finding food. Third, suspended sediment in the water can clog the gills of fish and shellfish and smother benthic invertebrates.

Several variables help determine the water clarity in a lake. The first is the amount of algae suspended in the water. The more algae present, the poorer the water clarity and the smaller the Secchi depth reading. Therefore, water clarity measurements are often a good indicator of algal abundance in a lake. Progressive decreases in Secchi depth may suggest excessive algal growth even before lake users encounter nuisance conditions. For this reason, a long-term record of Secchi depth measurements covering many years is extremely valuable. The individual lake reports rely heavily on water clarity data collected as part of the lake monitoring program.

Other factors in addition to algae can also affect water clarity. Suspended sediment will reduce water clarity. During periods of heavy rain and runoff, silt and other soil particles may wash into a lake, clouding the water. So, it is important to know if recent runoff into a lake, rather than an algal bloom, is the cause of poor water clarity.

The amount of sunlight, glare on the water, and wind disturbance of the water surface are other factors that can also affect water clarity readings. However, Secchi depth measurements are performed using a standard procedure, so multiple readings during a season and over the years will tend to neutralize the effects of wind and glare on any individual measurement.

Water color can also play a significant role in water clarity. Algae and suspended sediment can give apparent color to a lake, usually making the water greenish or cloudy or brownish depending on the source of color. In addition, some of the lakes in Snohomish County contain water with yellow and brown shades which can be quite dark. This is the result of natural dissolved organic matter, such as humic acid from decaying vegetation, which comes from surrounding bogs and wetlands or lake sediments. This humic coloring does not indicate pollution, but does reduce water clarity. The reduced light availability in colored water can also restrict algal and aquatic plant growth. Therefore, Secchi depth measurements in humic colored lakes may not accurately reflect the amount of algae or water quality conditions.

In spite of these limitations and cautions, measurements of water clarity in many lakes are a valuable means of assessing lake conditions. In general, high water clarity suggests low algal abundance and no excess nutrients, while low water clarity suggests excessive biological productivity.

pH, Alkalinity, and Conductivity

Three other characteristics of lake water quality sometimes monitored by the Lake Management Program are pH, alkalinity, and conductivity. pH is a measure of the hydrogen ion activity in water, which indicates whether the water is acidic, neutral, or basic (alkaline). The pH scale goes from 0 to 14, with 7 being neutral. A pH of 0 is extremely acidic. A pH of 14 is extremely basic or alkaline. The pH scale is exponential, meaning that a change of one whole number on the scale is a ten-fold change in acidity. So, a pH change of one whole number would mean a significant change in the chemical composition of the lake water.

The pH values in Snohomish County lakes are near neutral, ranging from about 6 to 8, with occasional values as low as 5 (more acidic) and as high as 10 (more alkaline). The lowest values are usually near the lake bottom where decomposition of organic matter creates more acidic conditions. The higher pH measurements are found within a few meters of the surface and usually indicate a zone of vigorous photosynthesis by algae. The acidity of lowland Snohomish County lakes does not appear to be increasing (pH is not dropping), which means that these lakes are not currently suffering serious impacts from acid precipitation.

Alkalinity, expressed in milligrams of calcium carbonate per liter, is a measurement of the capacity of water to resist changes in pH. This is also known as the buffering capacity of a lake. The lower the alkalinity in a lake, the more susceptible it is to fluctuations in pH (for example from acid precipitation). Also, lakes with low alkalinity are more sensitive to increased nutrient loading; i.e. they produce more algae and other biological activity. Compared to lakes in other regions, Snohomish County lowland lakes have relatively low alkalinities—most of the monitored lakes are below 50 and many are below 24 mg of calcium carbonate per liter. This means that most lakes are susceptible to potential changes in pH and to nutrient pollution.

Conductivity is a measure of the water's capacity to conduct an electrical current and is an indicator of the amount of dissolved ions in the water. Conductivity levels in the monitored lakes range from less than 50 micromhos/cm to over 100 in the upper waters. Conductivity generally increases near the bottom of lakes (with some lakes reaching as high as 200 micromhos/cm) because of the chemical changes that occur in low oxygen conditions during stratification. High conductivity levels can sometimes be an indication of contamination by human or animal sources.

Eutrophication and Trophic State

All lakes go through a process of enrichment by nutrients and sediment. In this process, known as eutrophication, nutrients and sediment contribute to the ever-increasing growth of algae and aquatic plants. As lakes continue to be enriched, they will produce more and more algae, aquatic plants, and animal life, until the lakes are so choked that further growth diminishes. Over thousands of years, lakes will gradually fill up with organic matter and sediments. Eventually, lakes will disappear from the landscape.

Eutrophication is a natural, and usually slow, process in lakes. Unfortunately, human activity often dramatically accelerates eutrophication. Watershed activities, such as the use of fertilizers, failing septic systems, pet and animal wastes, soil erosion, and runoff from impervious surfaces, can contribute sediment and excess nutrients to a lake. The result of nutrient enrichment can be nuisance algal blooms, reduced water clarity, excess aquatic plants, and low dissolved oxygen. In extreme cases, there are visual and odor problems that limit the use of a lake. Therefore, as development occurs around a lake, there is the potential for more nutrients to reach the lake and cause accelerated eutrophication.

Lakes are often described or classified by their degree of eutrophication—their trophic state. There are three primary trophic states for lakes—oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are usually deep and not very productive biologically. These lakes have few aquatic plants, limited amounts of algae and animal life, low nutrient concentrations, and high water clarity. Many alpine lakes and a few

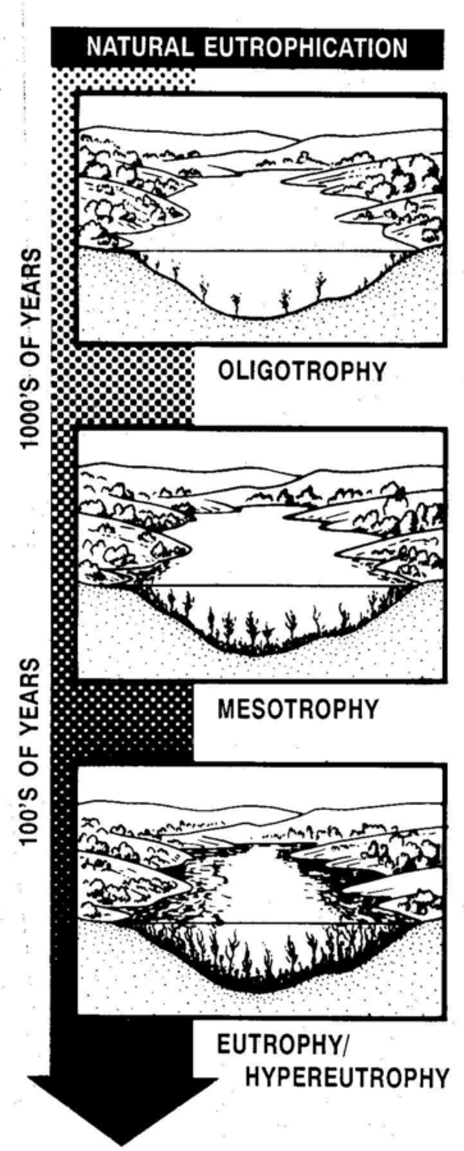


Figure 6.
The Natural Process of Eutrophication (Note: human activities can shorten this process to a matter of decades)

Illustration adapted from Holdren, et. al. *Managing Lakes and Reservoirs*, The North American Lake Management Society, 3rd. Ed., 2001.

lowland lakes in Snohomish County can be classified as oligotrophic.

Mesotrophic lakes are moderately productive. These lakes are richer in nutrients, produce more algae and aquatic plants, support denser fish populations, and accumulate more sediment from watershed runoff and from dying plants and animals. The water clarity in mesotrophic lakes is also moderate. Many of the lowland lakes in Snohomish County may be classified as mesotrophic.

Eutrophic lakes are very productive, and often shallow. Eutrophic lakes are characterized by abundant algae and plants, high nutrient concentrations, limited water clarity, and seasonal deficits of dissolved oxygen in the hypolimnion. The low oxygen levels result from decomposition of large amounts of organic matter collected on the bottom. This lack of oxygen may also cause the release of phosphorus from the lake sediments back into the water to be re-used by algae and plants. Several lowland lakes in Snohomish County are at this advanced stage of eutrophication.

These trophic categories are not value judgments, however. Oligotrophic does not necessarily mean "good" water quality or "healthy" lake conditions. Likewise, eutrophic does not always mean "bad" or "impaired" lake conditions. Instead, trophic categories describe the amount of enrichment and biological productivity in a lake, while terms such as "healthy" and "impaired" refer to the condition of a lake in relation to its desired uses or perceived natural conditions. A lake that is shallow and naturally eutrophic may be considered to be in healthy condition if the fishing is great and the algae and aquatic plants do not restrict lake users. On the other hand, a lake that is deep, clear, and oligotrophic may be considered in relatively worse condition if it shows signs of enrichment resulting from human impacts.

The trophic categories are also not exact. For this reason, lakes that show some characteristics of being oligotrophic and some mesotrophic characteristics are sometimes classified as oligo-mesotrophic. Likewise, meso-eutrophic lakes show qualities of both mesotrophic lakes and eutrophic lakes.

Some of this uncertainty comes about because the boundaries between categories are imprecise and each parameter used to assess trophic state provides only part of the picture. The primary parameters traditionally used to evaluate lake water quality and trophic state are water clarity, total phosphorus, and chlorophyll *a*. Lakes with high water clarity have less algae and suspended sediment and are probably oligotrophic. Likewise, measurements of total phosphorus in the upper waters (the epilimnion) are another method of evaluating the potential for algal production, and thus the trophic state of a lake. Chlorophyll *a* is the most common parameter for measuring algal abundance in a lake. Measurement of chlorophyll *a* in the epilimnion is another method of evaluating a lake's trophic state.

Other characteristics of a lake also give information about the trophic state. These include the abundance of aquatic plants, frequency of algal blooms, depletion of oxygen in the hypolimnion caused by decomposition of organic matter, and the build-up of phosphorus in the hypolimnion from sediment release.

Table 1 lists some threshold values for the three main parameters and their associated trophic states as suggested by several lake scientists. In all cases, the values are averages (means) of measurements taken during the warm summer months when the lakes, if sufficiently deep, are stratified (separated into warm upper waters and cool bottom waters). Using this table will be helpful in understanding the individual lake reports.

TABLE 1 **TROPHIC STATES AND ASSOCIATED THRESHOLD VALUES**			
Water Quality Parameter	**Oligotrophic**	**Mesotrophic**	**Eutrophic**
Water Clarity (Secchi depth in meters)	>4	2 to 4	<2
Epilimnion Total Phosphorus (in µg/l)	<14	14 to 25	>25
Chlorophyll *a* (in µg/l)	<2.8	2.8 to 8.7	>8.7

References: *Carlson, 1977; Porcella et. al., 1980; Chapra and Tarapchak, 1976; Cooke et. al., 1993, and Welch, 1992.*