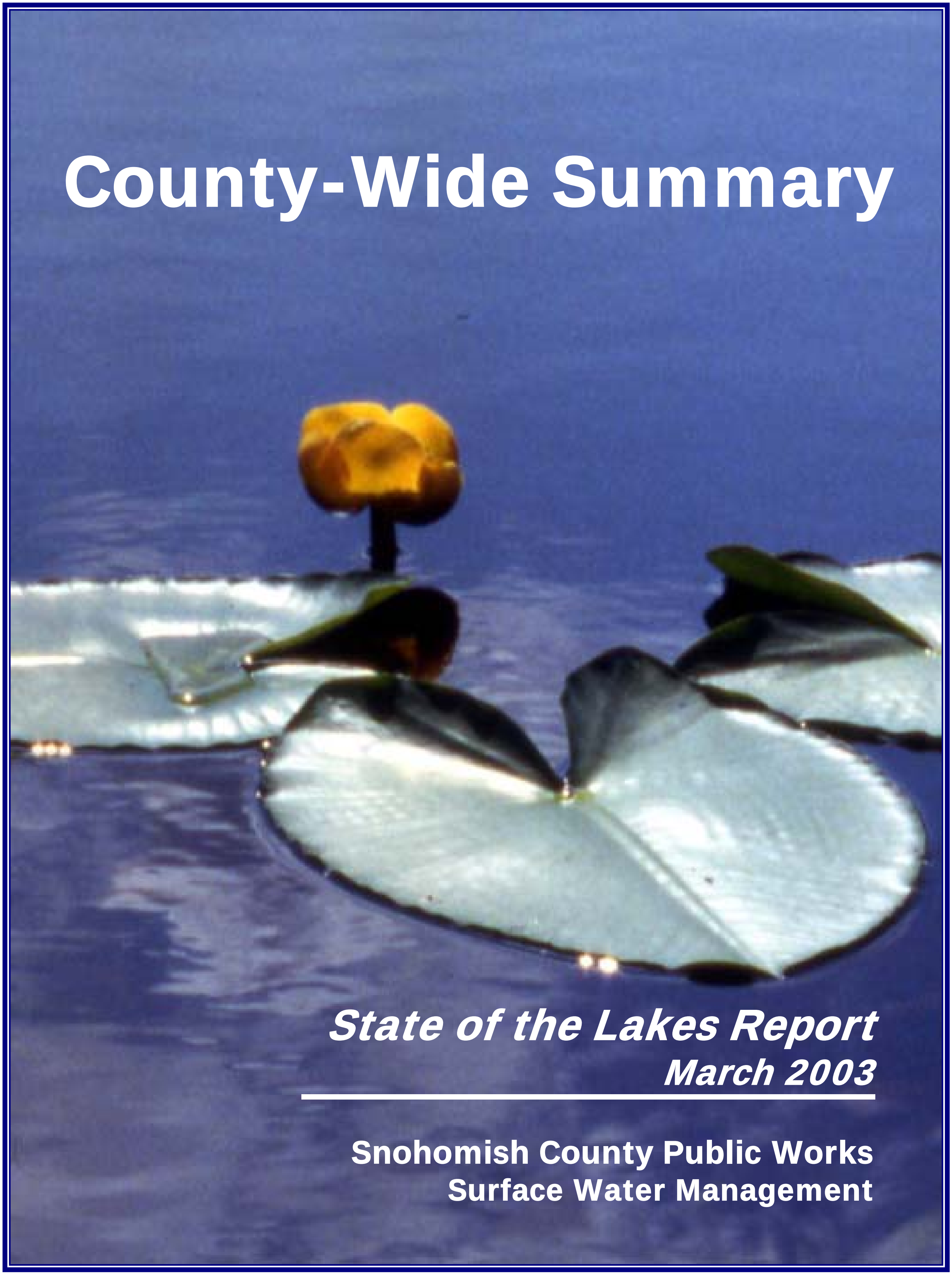
# County-Wide Summary



## *State of the Lakes Report*

***March 2003***

**Snohomish County Public Works**
**Surface Water Management**

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# STATE OF THE LAKES REPORT
## MARCH 2003

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# CONTENTS

# LIST OF TABLES



# LIST OF FIGURES

# INTRODUCTION

## Lake Management in Snohomish County

Lakes are valuable resources for the people of Snohomish County and Washington State. Many lakes in Snohomish County are in good condition. However, the health of some lakes is threatened by human activities around the lakes.

In response to this concern, Snohomish County developed a Lake Management Program to work with citizens and lake scientists to protect and restore the health of lakes. The Lake Management Program includes regular monitoring of lake conditions throughout the county, development of management plans at specific lakes as needed, implementation of management plans, and control of invasive aquatic plants.

Since 1992, Snohomish County Surface Water Management (SWM) has worked with citizen volunteers to monitor lake water quality in about 25 lowland lakes. In addition, since 1996 SWM staff have conducted more detailed monitoring of the high priority public access lakes in the county.

Monitoring the condition of lakes over time is one key to keeping them clean and protecting property values. With accurate monitoring information, SWM can work with citizens to recognize problems at an early stage when it is still possible to take preventive or corrective actions. More detailed scientific studies may still be necessary, however, to identify specific restoration actions needed at a particular lake.

There are four primary goals of lake monitoring in Snohomish County:

1. to assess the current status of water quality in lowland County lakes;
2. to observe any long-term trends in lake water quality as land use and other changes occur around lakes;
3. to identify specific water quality problems at individual lakes, including the need for additional studies or actions to solve these problems; and
4. to teach citizens more about lakes and ways to protect them.

## Purpose of This Report

This report summarizes the results of Snohomish County lake monitoring performed from 1992 through 2002, as well as occasional monitoring and studies by the County and other agencies since the mid-1970s. In addition, the report contains detailed monitoring summaries for 35 lakes. Taken together, this information describes the State of the Lakes in unincorporated Snohomish County through the year 2002. Data from future years will be summarized in later supplements.

## Lakes in Snohomish County

Lakes are bodies of fresh water deeper than 2 meters which hold in-flowing water longer than 15 days (Cowardin, et. al., 1979, WAC 173-201A). By this definition, there are about 460 lakes located in Snohomish County. Glaciers formed most of these lakes by gouging out holes in soil or bedrock or by depositing large blocks of ice whose melting created lake basins. A few lakes are remnants of abandoned river beds; several are man-made reservoirs.

Most of the lakes in Snohomish County are very small or located in the Cascade Mountains and foothills. There are about 60 lakes situated in the populated lowland portions of Snohomish County (see Figure 1). These lowland lakes range from small water bodies of less than ten acres with no public access to large lakes, such as Lake Stevens and Lake Goodwin, which support heavy recreational use. This State of the Lakes report focuses on the most important lowland lakes in unincorporated western Snohomish County.

## FIGURE 1.  SNOHOMISH COUNTY LAKES

# *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

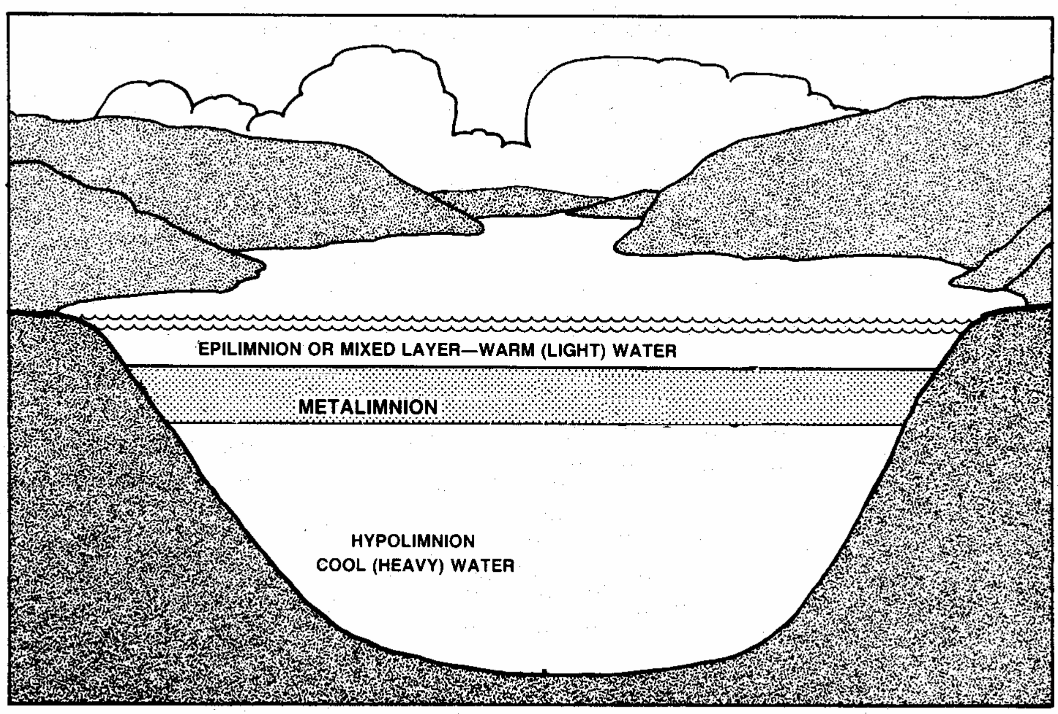



**Figure 2. Lake Stratification.** Adapted from *The Lake and Reservoir Restoration Guidance Manual* by the North American Lake Management Society, Second Edition, August 1990.

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*

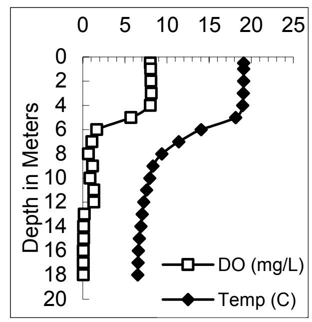
Oxygen is another key parameter of lake water quality. The availability of dissolved oxygen in water is essential for life in a lake. Most of the oxygen enters the water from the atmosphere, mainly from the mixing action of winds and waves. Aquatic plants and algae also produce oxygen as a by-product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

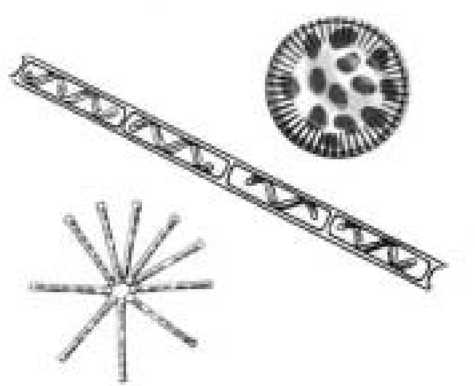


**Figure 4. Examples of Freshwater Algae**
Drawings by IFAS, Center for Aquatic Plants, University of Florida, 1990; and U.S. Soil Conservation Service, *Water Quality Indicators Guide: Surface Waters*, 1989.

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.

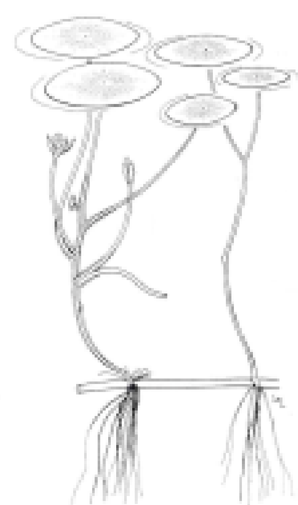


**Figure 5.**
**Watershield—A Native Aquatic Plant**
Drawing by IFAS, Center for Aquatic Plants, University of Florida, 1990

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

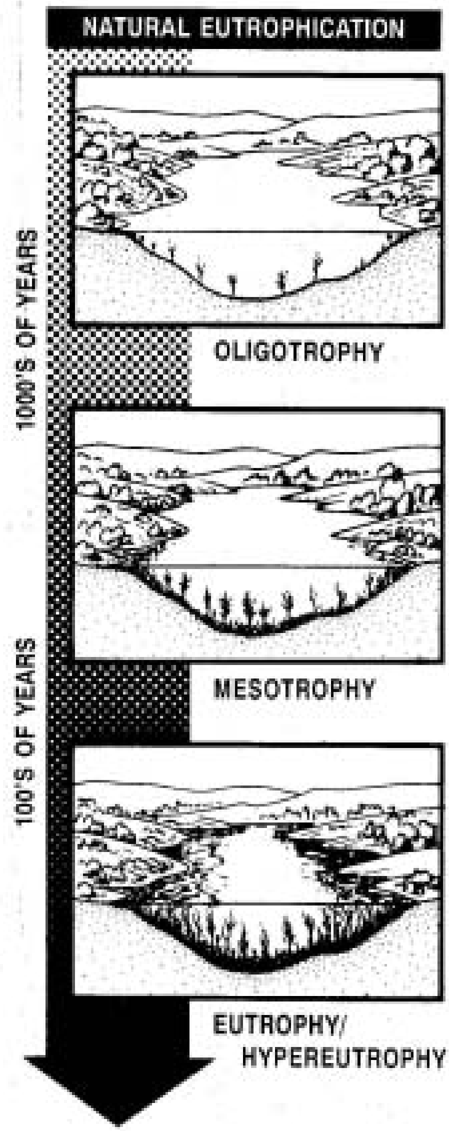



**Figure 6.**
**The Natural Process of Eutrophication (Note: human activities can shorten this process to a matter of decades)**

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

# Summary and Comparison of Snohomish County Lake Conditions

The following sections present comparative information about the lake and watershed characteristics, recreational uses, and water quality conditions of Snohomish County lowland lakes included in the Lake Management Program. Please refer to the individual lake reports for more detailed explanations of data for a specific lake.

## *Comparison of Physical Characteristics*

The lakes being monitored as part of the Lake Management Program represent a wide, but not random, sample of the lakes located in the populated lowland areas of Snohomish County. Table 2 presents the physical characteristics of these lakes and their watersheds. The data are taken from Bortleson, et. al. (1976), Sumioka and Dion (1985), and analysis of Snohomish County GIS data. Lake Stevens, which is being monitored by another agency, is included because of its importance in the county.

Some notable physical characteristics include:

- Size and Volume—The monitored lakes range in size and volume from Ruggs Lake (11 acres and 77 acre-feet) to Lake Stevens (1040 acres and 65,000 acre-feet).

- Watersheds—The sizes of lake watersheds also cover a wide range, from only 36 acres for Nina Lake to over 4,000 acres for Beecher and Stevens. The ratios of watershed area to lake area reveal that some small lakes, such as Beecher, Ruggs, and Stickney, have very large watersheds. This means that these lakes have a high potential for watershed activities to affect lake water quality. Conversely, Ki, Storm, and Stevens have very small watersheds relative to the size of the lakes. This means that the watersheds have less potential to degrade these lakes. However, there is also less water flowing through these lakes to assimilate pollution, so the effects of any pollution reaching these lakes may be magnified.

- Depth—Average (mean) depth is one of the strongest indicators of natural lake conditions. Lakes with shallow average depth, such as Beecher, Cassidy, Ruggs, and Sunday, are some of the most eutrophic lakes in the county. Conversely, Bosworth, Ki, Martha N., Roesiger, and Stevens have the greatest average depth and should be the most oligotrophic lakes in the county. However, Martha N. and Stevens, in particular, show signs of eutrophication in spite of their great depths.

| TABLE 2<br>PHYSICAL CHARACTERISTICS OF MONITORED SNOHOMISH COUNTY LAKES | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Lake Name** | **Lake Area (acres)** | **Watershed Area (acres)** | **Watershed/ Lake Area Ratio** | **Maximum Depth feet (meters)** | **Average Depth feet (meters)** | **Lake Volume (acre-feet)** | **Shoreline Length (miles)** |
| ARMSTRONG | 30 | 369 | 12.3 | 24 (7.3) | 15 (4.6) | 450 | 1.1 |
| BEECHER | 20 | 4318 | 215.9 | 10 (3.0) | 5 (1.5) | 105 | 1.6 |
| BLACKMAN | 57 | 445 | 7.8 | 29 (8.8) | 14 (4.3) | 800 | 1.5 |
| BOSWORTH | 102 | 979 | 9.6 | 79 (24.1) | 35 (10.7) | 3700 | 2.0 |
| BRYANT | 21 | 468 | 22.3 | 23 (7.0) | 14 (4.3) | 295 | 0.9 |
| CASSIDY | 123 | 2477 | 20.1 | 20 (6.1) | 11 (3.4) | 1300 | 1.8 |
| CHAIN | 21 | 472 | 22.5 | 18 (5.5) | 10 (3.0) | 210 | 0.8 |
| COCHRAN | 33 | 323 | 9.8 | 54 (16.5) | 26 (7.9) | 870 | 0.9 |
| CRABAPPLE | 35 | 690/862* | 19.7/24.6* | 49 (14.9) | 18 (5.5) | 650 | 1.1 |
| ECHO | 16 | 172 | 10.8 | 50 (15.2) | 17 (5.2) | 290 | 0.6 |
| FLOWING | 131 | 538/748* | 4.1/5.7* | 69 (21.0) | 28 (8.5) | 3800 | 2.2 |
| GOODWIN | 535 | 2604/3466* | 4.9/6.5* | 50 (15.2) | 23 (7.0) | 13,000 | 5.4 |
| HOWARD | 26 | 265 | 10.2 | 50 (15.2) | 29 (8.8) | 790 | 0.9 |
| KAYAK | 16 | 222 | 13.9 | >15 (4.5) | NA | NA | 1.4 |
| KETCHUM | 24 | 352 | 14.7 | 21 (6.4) | 12 (3.7) | 296 | 1.3 |
| KI | 96 | 452 | 4.7 | 70 (21.3) | 33 (10.1) | 3300 | 1.9 |
| LOMA | 21 | 172 | 8.2 | 28 (8.5) | 11 (3.4) | 230 | 0.9 |
| LOST | 12 | 149 | 12.4 | 45 (13.7) | 23 (7.0) | 280 | 0.7 |
| MARTHA N. | 59 | 801/1066* | 13.6/18.1* | 70 (21.3) | 33 (10.1) | 2000 | 1.8 |
| MARTHA S. | 57 | 448 | 7.9 | 48 (14.6) | 24 (7.3) | 1300 | 1.4 |
| MEADOW | 12 | 868 | 72.3 | 21 (6.4) | 14 (4.3) | 170 | 1.1 |
| NINA | 14 | 36 | 2.3 | 39 (12.0) | 24 (7.4) | 343 | 0.8 |
| PANTHER | 45 | 619/1367* | 13.8/30.4* | 36 (11.0) | 23 (7.0) | 1100 | 1.3 |
| RILEY | 30 | 273 | 9.1 | 45 (13.7) | 22 (6.7) | 670 | 1.0 |
| ROESIGER | 340 | 2272 | 6.7 | 110 (33.5) | 37 (11.3) | 12,600 | 5.9 |
| ROWLAND | 9 | 404 | 44.9 | 60 (18.3)** | NA | NA | 0.9 |
| RUGGS | 11 | 717/1665* | 65.2/151.4* | 16(4.9) | 7 (2.1) | 77 | 0.6 |
| SERENE | 43 | 223 | 5.2 | 23 (7.0) | 14 (4.3) | 580 | 1.3 |
| SHOECRAFT | 132 | 763/4230* | 5.8/32.0* | 35 (10.7) | 18 (5.5) | 2400 | 2.4 |
| SPRING | 26 | 620 | 23.8 | 10 (3.0) | NA | NA | 1.3 |
| STEVENS | 1040 | 4371 | 4.2 | 155 (47.3) | 63 (19.4) | 65,000 | 7.1 |
| STICKNEY | 24 | 2761 | 115.0 | 34 (10.4) | 15 (4.6) | 360 | 1.0 |
| STORM | 73 | 211 | 2.9 | 46 (14.0) | 22 (6.7) | 1605 | 1.7 |
| SUNDAY | 38 | 790 | 20.8 | 20 (6.1) | 8 (2.4) | 305 | 1.3 |
| WAGNER | 19 | 369 | 19.4 | 22 (6.7) | 13 (4.0) | 250 | 0.7 |

*--for those lakes located downstream in a chain of lakes, the first acreage figure and the first watershed/lake area ratio refer to the watershed immediately draining to that lake; the second acreage figure and ratio refer to the total watershed draining to that lake (including the watershed of any upstream lake(s)).
**--reported but not confirmed

### *Comparison of Shoreline and Watershed Development*

Table 3 presents a comparison of shoreline and watershed development around lakes in Snohomish County. The information comes from Bortleson, et.al. (1976) for some 1970s data, from aerial photographs, and from shoreline surveys conducted by SWM staff and volunteers. Some highlights from this comparison include:

♦ Shoreline Development—Development on the lake shore has a high potential to contribute nutrients and other pollution to a lake. In addition, development near the shore often removes native vegetation that serves to protect water quality by filtering out pollution before it reaches streams, ditches, or the lake. Therefore, the character of shoreline development may be an important factor in determining lake quality.

In general, the largest lakes have the most homes along their shorelines, while some small lakes have very few homes. However, housing density (the number of homes per 1000 feet of shoreline) gives a more accurate picture of the potential impacts of shoreline development. Echo, Goodwin, Martha S., and Serene had the highest housing densities in the mid-1990s. Armstrong, Beecher, Bryant, Cassidy, Chain, Kayak, Rowland, and Spring had the lowest densities. The most likely reasons for these differences are proximity to suburban population centers and the suitability of the shoreline soils and slopes for accommodating development.

Housing density showed the largest increases from the early 1970s to the 1990s at Cochran, Lost, and Wagner lakes. There has also been significant re-development with bigger homes and more paved areas at the large recreational lakes—Goodwin, Roesiger, and Stevens.

♦ Shoreline Modifications—Surveys conducted by SWM staff in the 1990s counted the number of homes where the lake shore has been modified by placement of either bulkheads or fill material. Such modifications can lead to increased erosion, reduced filtering of pollution, and loss of fish and wildlife habitat, especially when native vegetation is removed. More than 60% of the houses at Crabapple, Flowing, Goodwin, Ki, Martha S., and Serene had modified shorelines in the 1990s. Stevens and Roesiger were not surveyed, but also have highly modified shorelines.

On the other hand, property owners have retained some native vegetation along at least a portion of their waterfronts at many lakes. This vegetation helps prevent pollution from reaching the water. In general, those lakes with the most native vegetation are shallow, partially surrounded by wetlands, and the least developed. However, Crabapple and Serene are two lakes where significant shoreline vegetation has been retained in spite of dense development.

♦ Watershed Development—The amount and type of land development in the larger watershed also affects the water quality of a lake. Watersheds with dense commercial or residential development, or with active agriculture, have many sources of potential pollution. The estimates of watershed development in Table 3 are based on aerial photographs. Please note that watersheds refer to the immediate watersheds of each lake and include the lake surfaces, so 100% development is not possible.

Lakes with the highest percentage of development in their watersheds in the 1990s were Echo, Martha S., Ruggs, Serene, and Stickney. Martha S. and Stickney, along with Blackman, have experienced the most rapid watershed development from the 1970s to the 1990s. Several county lakes—Beecher, Blackman, Bryant, Martha S., Panther, and Sunday—had significant agricultural activity in their watersheds in the 1970s. By the 1990s, most of the agriculture in these watersheds, and significant forest lands in almost every lake watershed, had been replaced by residential development or large lot rural development. (Lake Ketchum suffered significant impacts from agricultural activity, but the overall percentage of agricultural land use there is not high.)

## TABLE 3
## SHORELINE AND WATERSHED DEVELOPMENT

| Lake Name | Number of Nearshore Homes | | Number of Homes per 1000 feet of shoreline | | % of Homes with Modified Shoreline | % of Homes with native vegetation | Percent of Watershed Developed (residential or commercial) | |
|---|---|---|---|---|---|---|---|---|
| | Early 1970s | Mid-1990s | Early 1970s | Mid-1990s | Mid-1990s | Mid-1990s | Early 1970s | Mid-1990s |
| ARMSTRONG | 8 | 11 | 1.3 | 1.9 | 36 | 64 | 3 | 5 |
| BEECHER | 8 | 10 | 0.9 | 1.2 | NA | NA | 8* | 40 |
| BLACKMAN | 20 | 40 | 2.6 | 5.1 | 30 | 52 | 8* | 50 |
| BOSWORTH | 81 | 116 | 7.7 | 11.0 | 41 | 37 | 10 | 15 |
| BRYANT | 0 | 0 | 0.0 | 0.0 | NA | NA | 4* | 20 |
| CASSIDY | 22 | 18 | 2.3 | 1.9 | 6 | 78 | 1 | 18 |
| CHAIN | 3 | 3 | 0.7 | 0.7 | 0 | 100 | 0 | 5 |
| COCHRAN | 17 | 41 | 3.5 | 8.5 | 22 | 49 | 7 | 10 |
| CRABAPPLE | 33 | 41 | 5.7 | 7.1 | 63 | 49 | 2 | 20 |
| ECHO | 29 | 44 | 8.7 | 13.2 | 57 | 41 | 10 | 65 |
| FLOWING | 61 | 104 | 5.3 | 9.0 | 66 | 37 | 19 | 35 |
| GOODWIN | 381 | 377 | 13.4 | 13.2 | 82 | 18 | 14 | 30 |
| HOWARD | 22 | 32 | 4.8 | 7.0 | 50 | 10 | 4 | 15 |
| KAYAK | 0 | 11 | 0.0 | 1.5 | 18 | 55 | 0 | 10 |
| KETCHUM | 59 | 52 | 8.6 | 7.6 | 46 | 19 | 23 | 41 |
| KI | 82 | 90 | 8.2 | 9.0 | 71 | 29 | 11 | 40 |
| LOMA | 53 | 58 | 10.8 | 11.8 | 12 | 33 | 17 | 40 |
| LOST | 19 | 42 | 5.1 | 11.4 | 3 | 64 | 12 | 50 |
| MARTHA N. | 44 | 74 | 4.6 | 7.8 | 49 | 34 | 5 | 15 |
| MARTHA S. | 85 | 97 | 11.5 | 13.1 | 72 | 34 | 25* | 80 |
| MEADOW | 0 | 22 | 0.0 | 3.8 | 0 | 100 | <5 | 15 |
| NINA | 1 | 34 | 0.2 | 8.4 | 38 | 56 | 5 | 60 |
| PANTHER | 25 | 28 | 3.6 | 4.1 | 46 | 25 | 2* | 13 |
| RILEY | 14 | 18 | 2.8 | 3.6 | 0 | 100 | 5 | 10 |
| ROESIGER | 344 | 386 | 11.0 | 12.4 | NA | NA | 9 | 10 |
| ROWLAND | 0 | 7 | 0.0 | 1.5 | 0 | 100 | 0 | 20 |
| RUGGS | 12 | 27 | 3.8 | 8.5 | 11 | 81 | 40 | 80 |
| SERENE | 93 | 94 | 13.5 | 13.7 | 60 | 64 | 56 | 75 |
| SHOECRAFT | 100 | 114 | 7.9 | 9.0 | 49 | 9 | 9 | 20 |
| SPRING | 2 | 12 | 0.3 | 1.8 | 8 | 100 | 2 | 5 |
| STEVENS | 330 | 349 | 8.8 | 9.3 | NA | NA | 20 | 55 |
| STICKNEY | 33 | 45 | 6.5 | 8.9 | 29 | 40 | 22 | 80 |
| STORM | 26 | 38 | 2.9 | 4.2 | 13 | 76 | 6 | 8 |
| SUNDAY | 23 | 31 | 3.4 | 4.5 | 13 | 87 | 2* | 10 |
| WAGNER | 2 | 11 | 0.5 | 2.8 | 9 | 54 | 5 | 30 |

* -- indicates lakes with agricultural uses on more than 20% of their watersheds

Note—the watersheds include the lake surfaces, so 100% watershed development is not possible

### *Summary of Recreational Opportunities*

Table 4 presents a summary of the public recreational facilities and opportunities available at each monitored lake. Access is important to the public because it expands the enjoyment of lakes to all the residents of Snohomish County and Washington State. However, public access, especially boating access, increases the risk of introducing invasive plant and animal species, such as Eurasian watermilfoil, to Snohomish County lakes. Regular monitoring for invasive species and enforcement of regulations that prohibit transport of invasive species will help to prevent new invasions of unwanted plants and animals.

♦ Public Access—The majority of the lakes included in the monitoring program are open for public access. In most cases, boat launches owned and operated by the Washington State Department of Fish and Wildlife provide public access for fishing and boating (but not for swimming). Blackman, Flowing, Goodwin, Martha S., Roesiger, and Stevens also have city, county, or state parks that provide additional public access, including swimming and picnicking. Seven of the lakes are private or have undeveloped public access parcels.

♦ Boating Activity—Snohomish County allows power boats and water skiing at Goodwin, Stevens, Roesiger, Shoecraft, and Flowing lakes. However, there are special skiing restrictions at the latter three lakes. Skiing is not permitted and power boats are restricted to 8 mph at Cassidy and Ki. At most other lakes, the County prohibits the use of internal combustion motor boats because of the small size of the lakes, the threat of pollution, and safety concerns. There are no specific regulations on boating at several lakes; however, the presumption is that motor boats would be discouraged because the lakes are quite small.

♦ Fisheries—The Washington State Department of Fish and Wildlife (WDFW) manages fish stocks and fishing on Snohomish County lakes. Currently, the WDFW stocks 24 of the public access lakes with catchable rainbow trout each spring. The State manages these lakes, plus Lake Stevens, for both cold and warm water fisheries. Bryant and Sunday lakes are managed for warm water fish only. The remaining eight private or limited access lakes generally support warm water fisheries, although there is no active management by the State.

| TABLE 4<br>RECREATIONAL OPPORTUNITIES | | | | |
|---|---|---|---|---|
| **Lake Name** | **Public Parks** | **Public Boating/ Fishing Access** | **Boating/ Skiing** | **Fish Species & Management** |
| ARMSTRONG | | YES (APR-OCT) | No I.C. motors | RB* |
| BEECHER | | WALK-IN | No regulations | LB, PS, YP |
| BLACKMAN | 2 city parks | YES | No I.C. motors | RB*,LB,YP,BH |
| BOSWORTH | | YES (APR-OCT) | No I.C. motors | RB*, CT, LB |
| BRYANT | | WALK-IN | No I.C. motors | LB, BC |
| CASSIDY | | YES | Power boats; 8 mph | RB*,LB,BC,PS,YP,BH |
| CHAIN | | YES | No I.C. motors | RB*, LB, PS, BC |
| COCHRAN | | NO | No I.C. motors | Unknown |
| CRABAPPLE | | YES | No I.C. motors | RB*, LB, PS, YP |
| ECHO | | YES | No regulations | RB*, PS |
| FLOWING | county park | YES | Power boats; Skiing | RB*, LB |
| GOODWIN | county & state parks | YES | Power boats; Skiing | RB*,CT,LB,SB,BC,PS,YP |
| HOWARD | | YES (APR-OCT) | No I.C. motors | RB* |
| KAYAK | | NO | No regulations | Unknown |
| KETCHUM | | YES | No I.C. motors | RB*,LB,BG,PS,BC,YP,BH |
| KI | | YES | Power boats; 8 mph | RB*, LB, YP |
| LOMA | | YES | No I.C. motors | RB*, LB, PS |
| LOST | | YES | No regulations | RB*, CT, LB |
| MARTHA N. | | YES | No I.C. motors | RB*, LB, YP |
| MARTHA S. | county park | YES (APR-OCT) | No I.C. motors | RB*, LB, YP, BH |
| MEADOW | | NO | No regulations | Unknown |
| NINA | | NO | No regulations | Unknown |
| PANTHER | | YES | No I.C. motors | RB*,LB,BC,PS,BH |
| RILEY | | YES (APR-OCT) | No I.C. motors | RB* |
| ROESIGER | county park | YES | Power boats; Skiing | RB*,K,LB,BG,YP,PS,BC,BH |
| ROWLAND | | NO | No regulations | Unknown |
| RUGGS | | NO | No regulations | BH |
| SERENE | | YES (APR-JUN,SEP-OCT) | No I.C. motors | RB*, LB |
| SHOECRAFT | | YES | Power boats; Skiing | RB*,LB,SB,BC,PS,YP |
| SPRING | | NO | No regulations | Unknown |
| STEVENS | 2 city; 3 county parks | YES | Power boats; Skiing | RB,K,CT,LB,SB,BC,YP,BH |
| STICKNEY | | YES (APR-JUN,SEP-OCT) | No I.C. motors | RB*,LB,YP,BC,BH |
| STORM | | YES (APR-OCT) | No I.C. motors | RB*, LB |
| SUNDAY | | WALK-IN | No I.C. motors | LB,YP,BC,PS,BH |
| WAGNER | | YES (APR-OCT) | No I.C. motors | RB*, LB |

I.C. -- refers to internal combustion power motors
Key to Fish Species: RB—rainbow trout; CT—cutthroat trout; K—kokanee; LB—largemouth bass; SB—smallmouth bass; BC—black crappie; YP—yellow perch; BG—bluegill; PS—pumpkinseed sunfish; BH—brown bullhead catfish
RB* -- indicates that lake is regularly stocked with rainbow trout by Washington Department of Fish and Wildlife

Source of fisheries information: Washington State Department of Fish and Wildlife (www.wa.gov/wdfw)

### *Comparison of Temperature and Dissolved Oxygen*

From spring to early fall, most Snohomish County lakes stratify between warm upper waters (epilimnion) and cool bottom waters (hypolimnion). The stronger the stratification (i.e. the greater the temperature differences between upper waters and bottom waters) the less interaction occurs between the two layers. In a strongly stratified lake, little oxygen from the surface gets to the hypolimnion, and nutrients in the hypolimnion tend to remain there until the lake turns over in the fall. Therefore, strongly stratified lakes that have rich organic sediments usually experience a loss of dissolved oxygen that can lead to a steady build-up of nutrients in the hypolimnion.

Among Snohomish County lakes, the large deep lakes, such as Stevens, Roesiger, Ki, and Bosworth, develop strong stratification during the summer. Some small, but deep or sheltered, lakes are also strongly stratified, such as Armstrong and Lost. In strongly stratified lakes with depleted oxygen in the hypolimnion, the bottom sediments exert their greatest influence after fall turnover. Phosphorus may be spread throughout the water column at turnover, resulting in severe algal blooms, unless there are high levels of iron to precipitate the phosphorus back into the sediments.

In contrast, some lakes stratify weakly or only during periods of warm, calm weather. Mostly, these are shallow lakes, including Beecher, Chain, Loma, Ruggs, Serene, Spring, and Sunday. Goodwin and Shoecraft are large, moderately deep lakes that also stratify weakly because winds and boating activity continually mix the warm waters to great depths. In weakly stratified lakes, there is less opportunity for nutrients to build up in the hypolimnion, but nutrients that are released from the sediments may become available for algal growth more easily during the summer due to mixing.

Almost all Snohomish County lakes experience moderate to severe oxygen depletion in the bottom waters over the course of the summer. Exceptions are Serene, which almost never stratifies, and Cochran, which usually has dissolved oxygen present throughout most of its hypolimnion. The lakes that experience the most severe oxygen depletion are Ketchum, Meadow, and Rowland—eutrophic lakes that are deep or protected enough to enjoy stable stratification. Prior to installation of an aeration system to provide oxygen to the hypolimnion, Lake Stevens also experienced severe oxygen depletion.

Some lakes have unusual summertime dissolved oxygen profiles. In Martha N. and, to a lesser extent, Lost Lake, dissolved oxygen levels experience a sharp drop in the metalimnion, with somewhat higher levels in the upper hypolimnion. The most likely explanation for the dissolved oxygen decrease in the metalimnion of these lakes is the unique shapes of the lake bottoms. Large areas of the bottom lie at the same depth as the metalimnion, resulting in significant organic decomposition (and oxygen depletion) at this depth.

Several other lakes consistently have spikes of high dissolved oxygen (and usually pH) in the metalimnion, which indicate the presence of strong algal growth at that depth. Lake Howard, in particular, has this pattern of super-saturated oxygen levels in the metalimnion.

## *Water Clarity Comparisons and Trends*

In the Snohomish County lake monitoring program, water clarity data (measured as Secchi depths) are perhaps the most important indicators of lake conditions. This is because Secchi depth measurements reflect the interaction of several water quality factors in a lake (algal abundance, turbidity, color); and, they focus on a characteristic that is directly meaningful to lake users (the clarity of the water). Secchi depth measurements are also simple, reproducible by different volunteers and staff, and form the longest data records for all the monitored lakes.

In general, high water clarity measurements suggest oligotrophic conditions in a lake. In contrast, low water clarity often results from heavy algal growth or suspended sediment, and usually indicates eutrophic conditions.

♦ Yearly Averages—Figure 7 shows the range of averages and the long term averages (arithmetic means) of summertime water clarity measurements recorded since 1990 for each monitored lake. The lakes are arranged from low water clarity to high water clarity. From Figure 7, it is clear that Meadow, Cassidy, and Beecher are at the eutrophic end of the spectrum—Secchi depths less than 2 meters average—while Ki, Howard, and Stevens are at the oligotrophic end—Secchi depths greater than 4 meters (using the approximate threshold values for water clarity). Please note that some lakes may have data for every year, while others have only limited data.

The lake names marked by an asterisk are those lakes that contain darkly colored water, the result of natural humic materials. The dark color reduces water clarity, but does not affect water quality. Without this natural color, these lakes might have somewhat greater water clarity (although more light might also lead to increased algae). Most likely, the effects of color are not enough to significantly change the lakes' positions in the overall county comparison.

♦ Year-to-Year Variability—Figure 7 reveals that the average water clarity in some lakes varies markedly from year to year. There is also a certain amount of variation among water clarity measurements at each lake within individual years. One way to measure the variability within the set of data for each lake is with the standard deviation. Standard deviation is a mathematical description of the dispersion of the sample data about the mean, or average, of that data. Table 5 lists the standard deviations of the summertime averages (arithmetic means) from the long-term average of water clarity for each lake over the period 1990 through 2002. This table shows that Armstrong, Martha N., Martha S., Nina, Panther, Stevens, and Sunday have the greatest variability by this measure. In particular, Armstrong and Sunday vary substantially despite having low Secchi depth averages. In contrast, Beecher, Cassidy, and Meadow exhibited the most uniform water clarity from year to year. (Beecher has fewer years of record, so the monitoring may have missed some of its natural variability.)

It also appears that the water clarity of most of the monitored Snohomish County lakes varies markedly in some years. For example, in 2001 and 2002, more than 75% of the monitored lakes had summer water clarity averages greater than their long term averages, while in 1996 and 1997 similar percentages of lakes exhibited lower than average water clarity.

Possible explanations for this group variability in any particular year include rainfall patterns, the amount of sunlight, and ambient temperature levels. Other factors may include ground water versus surface runoff patterns, water color changes caused by the amount of humic acids entering the lakes, and biological growth cycles. It is also possible that the monitoring record is too short to account for the natural variability of water clarity in Snohomish County lakes.

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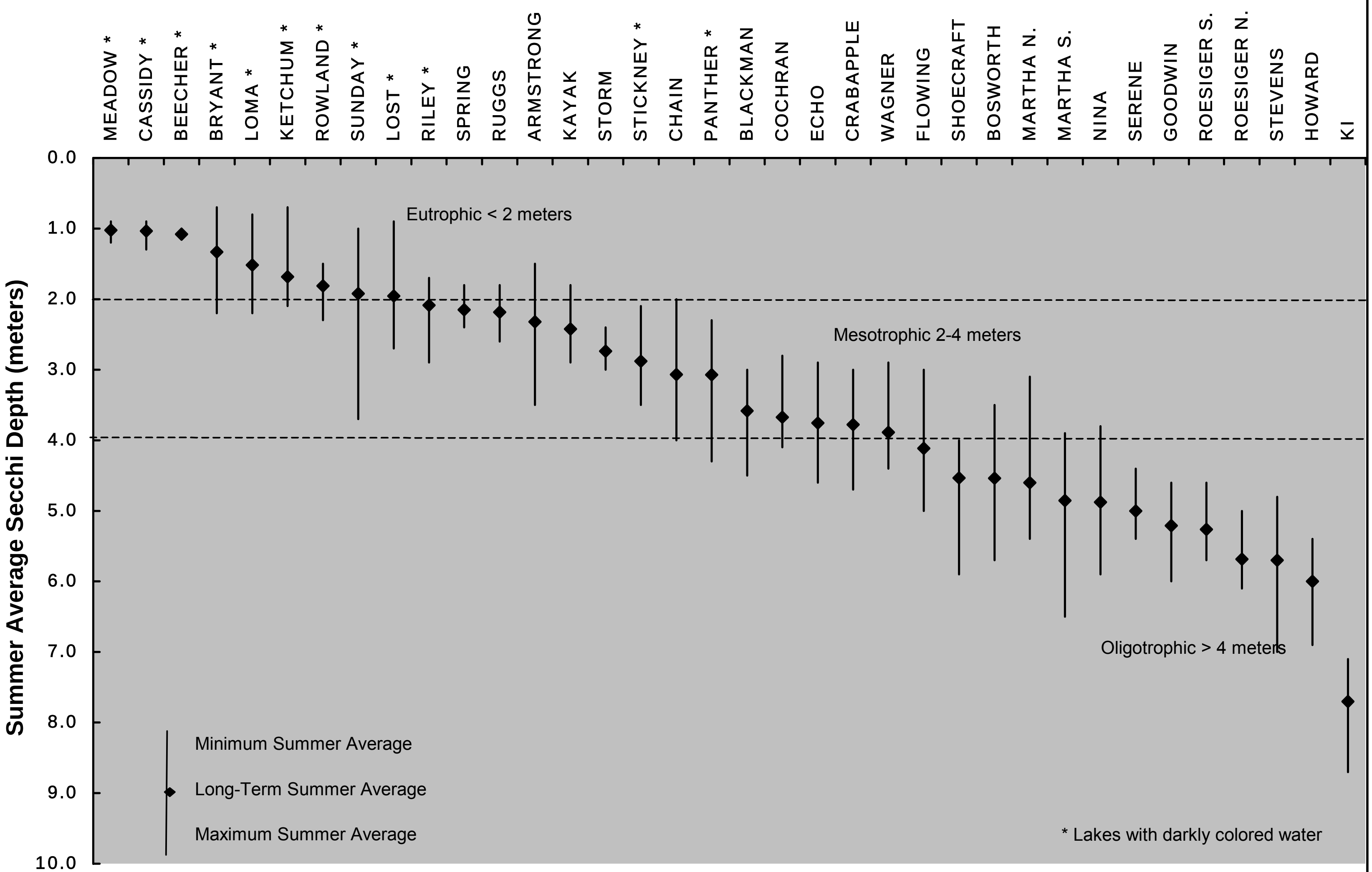
# FIGURE 7. SUMMER WATER CLARITY AVERAGES 1990-2002



| TABLE 5<br>STATISTICAL ANALYSES OF WATER CLARITY AVERAGES | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | DISTRIBUTION | | TRENDS | | | |
| Lake Name | Years of Record (sample size) | 1990-2002 Average Secchi Depth (meters) | Standard Deviation (meters) | Kendall's tau | p-value | Sen's slope | Apparent Trend |
| ARMSTRONG | 9 | 2.3 | 0.70 | -0.03 | 1.00 | -0.04 | |
| BEECHER | 5 | 1.1 | 0.04 | -0.20 | 0.82 | 0.00 | |
| BLACKMAN | 12 | 3.6 | 0.39 | 0.52 | 0.02 | 0.07 | + |
| BOSWORTH | 13 | 4.5 | 0.68 | 0.65 | 0.00 | 0.16 | + |
| BRYANT | 6 | 1.3 | 0.59 | -0.20 | 0.72 | -0.08 | |
| CASSIDY | 10 | 1.0 | 0.13 | -0.07 | 0.86 | 0.00 | |
| CHAIN | 10 | 3.1 | 0.68 | 0.22 | 0.48 | 0.10 | |
| COCHRAN | 11 | 3.7 | 0.44 | 0.22 | 0.39 | 0.06 | |
| CRABAPPLE | 10 | 3.8 | 0.57 | -0.27 | 0.38 | -0.10 | |
| ECHO | 11 | 3.8 | 0.51 | 0.60 | 0.01 | 0.10 | + |
| FLOWING | 13 | 4.1 | 0.59 | 0.63 | 0.00 | 0.12 | + |
| GOODWIN | 11 | 5.2 | 0.48 | -0.24 | 0.35 | -0.05 | |
| HOWARD | 10 | 6.0 | 0.51 | -0.07 | 0.86 | -0.01 | |
| KETCHUM | 11 | 1.7 | 0.42 | -0.07 | 0.81 | -0.01 | |
| KI | 11 | 7.7 | 0.48 | 0.20 | 0.43 | 0.04 | |
| LOMA | 11 | 1.5 | 0.47 | -0.51 | 0.04 | -0.11 | -- |
| LOST | 11 | 2.0 | 0.50 | 0.40 | 0.10 | 0.08 | + |
| MARTHA N. | 13 | 4.6 | 0.70 | 0.01 | 1.00 | 0.00 | |
| MARTHA S. | 13 | 4.9 | 0.71 | -0.19 | 0.39 | -0.05 | |
| MEADOW | 9 | 1.0 | 0.10 | 0.06 | 0.92 | 0.00 | |
| NINA | 9 | 4.9 | 0.70 | -0.50 | 0.08 | -0.15 | -- |
| PANTHER | 11 | 3.1 | 0.70 | 0.35 | 0.16 | 0.10 | |
| RILEY | 9 | 2.1 | 0.41 | 0.39 | 0.18 | 0.05 | |
| ROESIGER N. | 12 | 5.7 | 0.30 | 0.44 | 0.05 | 0.05 | + |
| ROESIGER S. | 11 | 5.3 | 0.34 | -0.27 | 0.26 | -0.02 | |
| ROWLAND | 9 | 1.8 | 0.25 | 0.75 | 0.01 | 0.08 | + |
| RUGGS | 7 | 2.2 | 0.29 | 0.81 | 0.01 | 0.13 | + |
| SERENE | 11 | 5.0 | 0.38 | 0.25 | 0.30 | 0.03 | |
| SHOECRAFT | 12 | 4.5 | 0.61 | 0.05 | 0.89 | 0.00 | |
| SPRING | 6 | 2.2 | 0.21 | -0.40 | 0.47 | -0.05 | |
| STEVENS | 12 | 5.7 | 0.70 | -0.35 | 0.13 | -0.11 | |
| STICKNEY | 10 | 2.9 | 0.46 | 0.49 | 0.07 | 0.12 | + |
| STORM | 11 | 2.7 | 0.24 | 0.45 | 0.05 | 0.03 | + |
| SUNDAY | 13 | 1.9 | 0.71 | -0.32 | 0.14 | -0.09 | |
| WAGNER | 10 | 3.9 | 0.48 | 0.27 | 0.38 | 0.10 | |

Note -- Shaded rows identify lakes with statistically significant trends in water clarity at $p \leq 0.10$.
**+** denotes lakes with apparent trends toward increasing water clarity
**--** denotes lakes with apparent trends toward decreasing water clarity

♦ Trends—One of the main goals of the Snohomish County Lake Management Program is to identify long-term changes or trends in the water quality of individual lakes. Recognizing trends (especially trends toward poorer water quality or impaired beneficial uses) can alert citizens and government agencies to future problems while there is still time to address the causes and to prevent or mitigate such problems.

However, identifying trends accurately requires reliable data over a number of years. This is one reason that lake monitoring data become more and more valuable with each additional year of monitoring. Only recently has there been a long enough monitoring record to statistically evaluate water clarity trends at individual Snohomish County lakes.

Table 5 contains the results of one statistical analysis of water clarity trends in the monitored lakes. Kendall's tau is a statistic that describes the correlation between two variables—in this case summertime water clarity averages and time. If the water clarity average for a particular lake increased every single year (in other words, if the two variables were perfectly concordant), then Kendall's tau would be 1.0. If clarity decreased every year, tau would be -1.0. If there were no changes in clarity or only random changes from year to year, then tau would be 0. Kendall's tau can be thought of as the degree of consistency in the data to follow a trend toward either a positive or negative direction. The p-value that accompanies each tau indicates the significance of the trend in that direction—the smaller the p-value the more significant the trend. In this report, a p-value less than or equal to 0.10 means that the trend is considered statistically significant and that there is a higher likelihood that the water clarity in the lake really is increasing or decreasing over time. The slopes associated with the taus show how sharply the average water clarity values are increasing or decreasing over time.

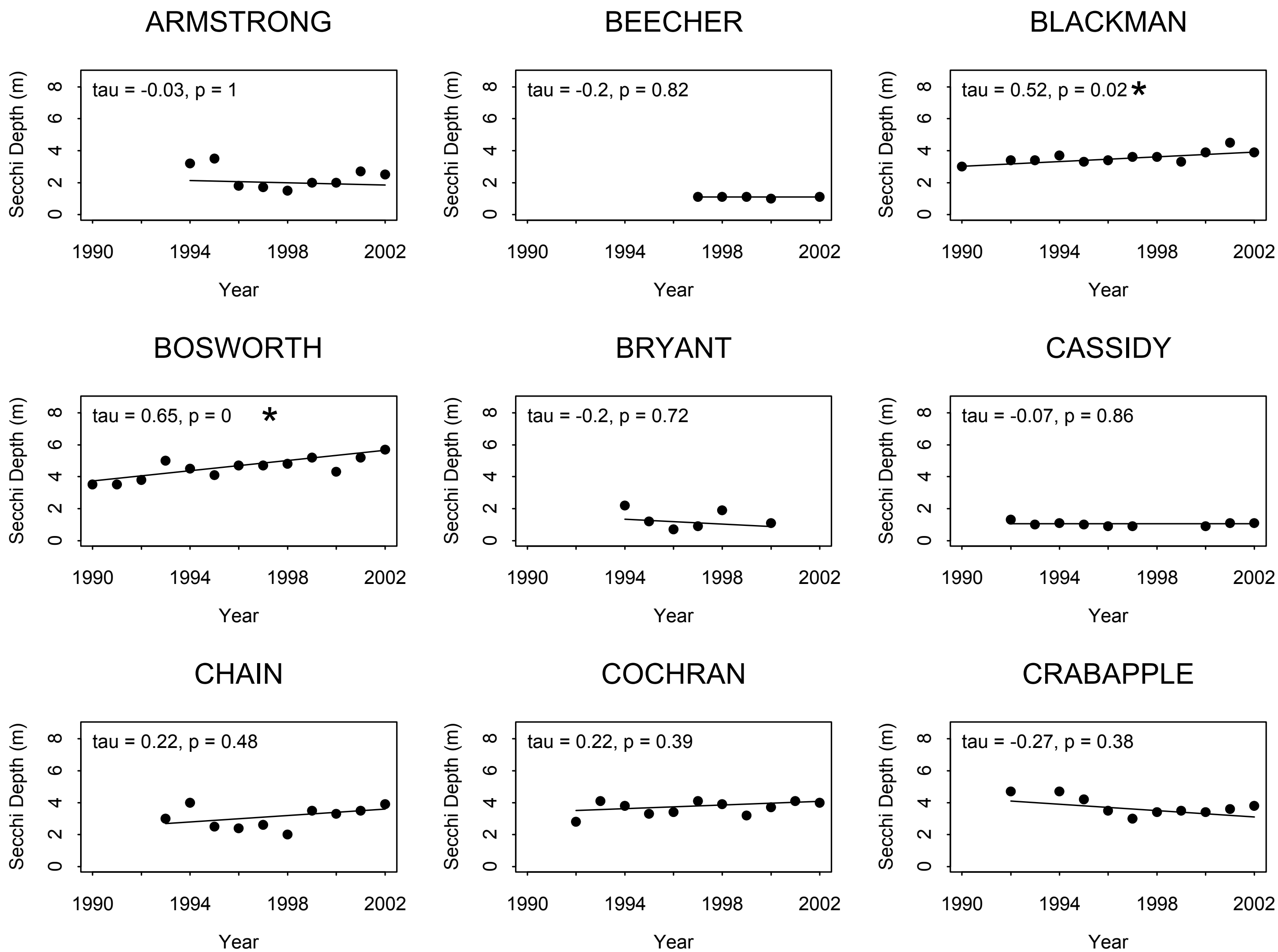
Figure 8 presents simple graphs of the Kendall's tau trend analysis for each monitored lake. The graphs show data points for summer water clarity averages from 1990 through 2002, together with the apparent trend lines.

The trend analyses in Table 5 and Figure 8 reveal that water clarity in most monitored lakes does not show a significant trend either way. This confirms the observation that there is substantial variability in water clarity from year to year in most lakes. Several lakes (shaded in Table 5) do show trends, however.

On the positive side, Blackman, Bosworth, Echo, Flowing, Lost, Roesiger N., Rowland, Ruggs, Stickney, and Storm show significant trends ($p \leq 0.10$) toward increased water clarity. The increases are modest, and the possible causes are unknown, but improvements in water clarity appear to be occurring. It is also unknown if the improved water clarities are within the natural ranges of variation for these lakes over several decades. Also, the general improvement in water clarity for more than 75% of the monitored lakes in 2001 and 2002 as a result of climatic or other factors may be a major reason for these positive trends. However, Secchi depth measurements from the early 1970s do suggest that water clarity in Echo, Flowing, Roesiger N., Stickney, and Storm lakes is better in recent years than in the past. So, at least for these lakes, it appears that water clarity is really improving.

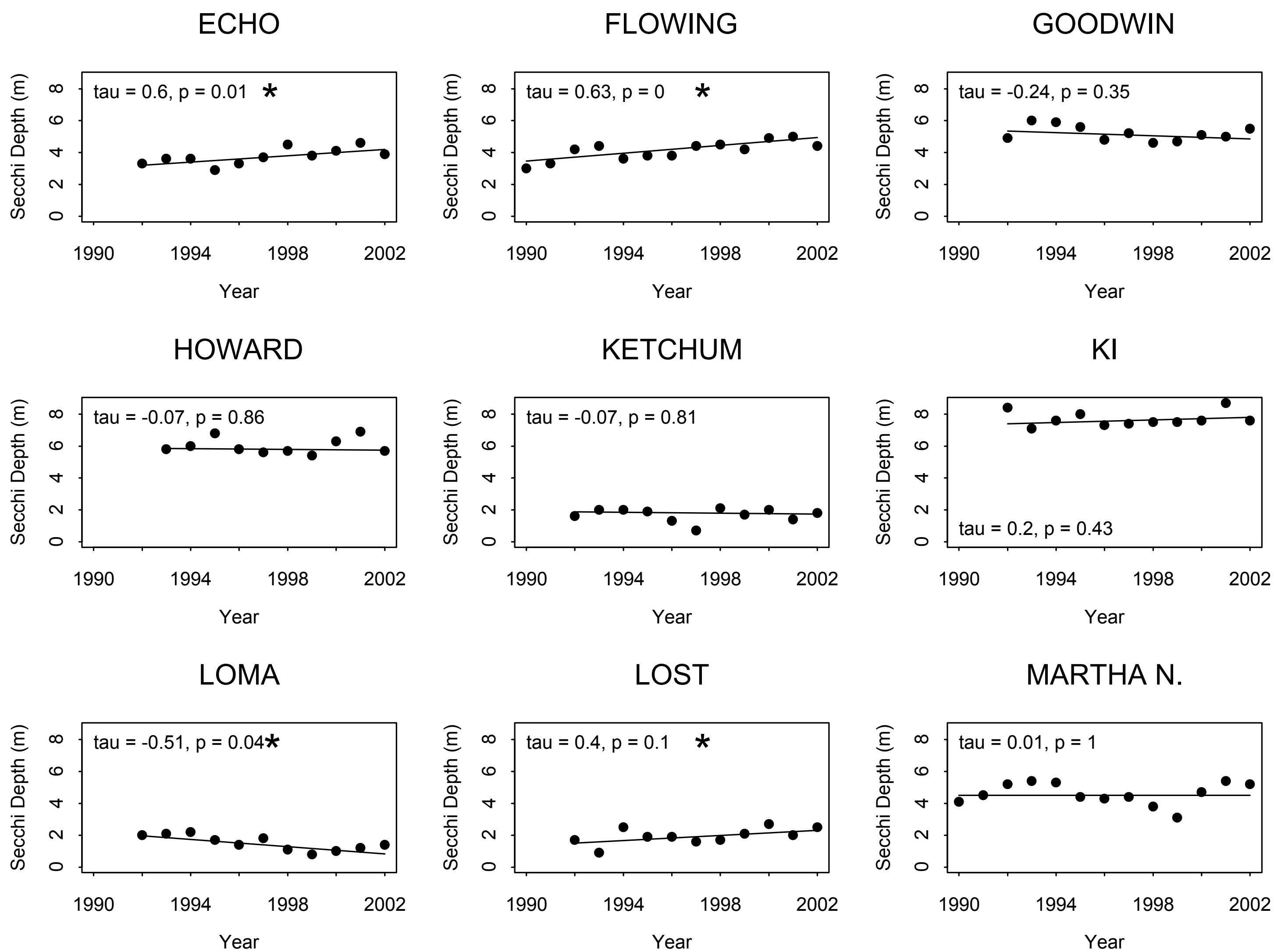
In contrast, the trend analyses for Loma and Nina suggest that water clarity is declining in these lakes. In addition, the p values indicate that Stevens and Sunday may be on the verge of significant declining trends in water clarity. It is possible that the declines in water clarity at these lakes are within the natural long-term variability of lake conditions. However, the wise course is for citizens and Snohomish County to take steps at these lakes to address the potential causes of declining water clarity.

**FIGURE 8 -- TRENDS IN WATER CLARITY SUMMER AVERAGES 1990 – 2002**



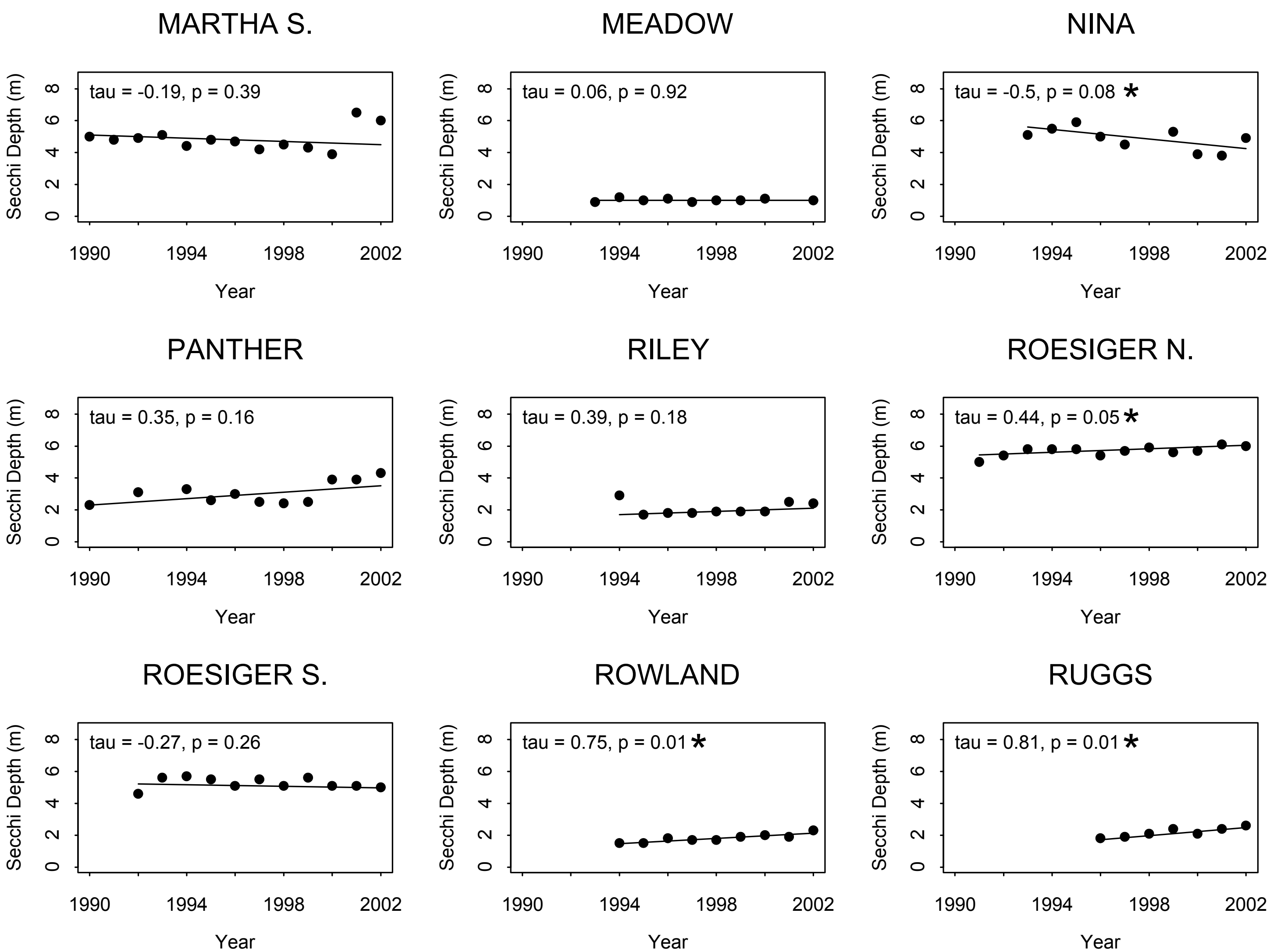

*Statistically significant trend (p ≤ 0.10)

**Figure 8 (continued)**



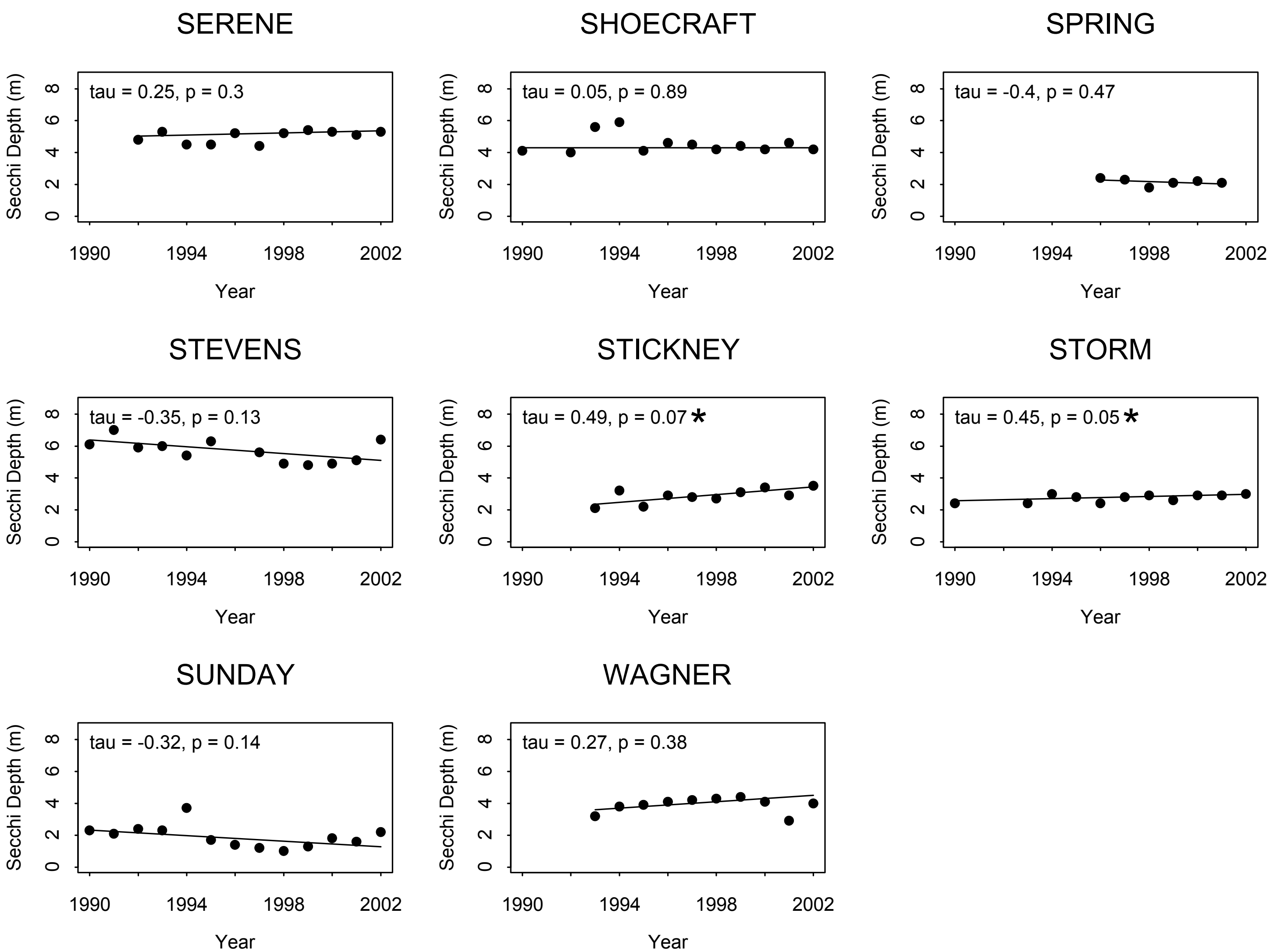

*Statistically significant trend ($p \leq 0.10$)

**Figure 8 (continued)**




*Statistically significant trend ($p \leq 0.10$)

**Figure 8 (continued)**



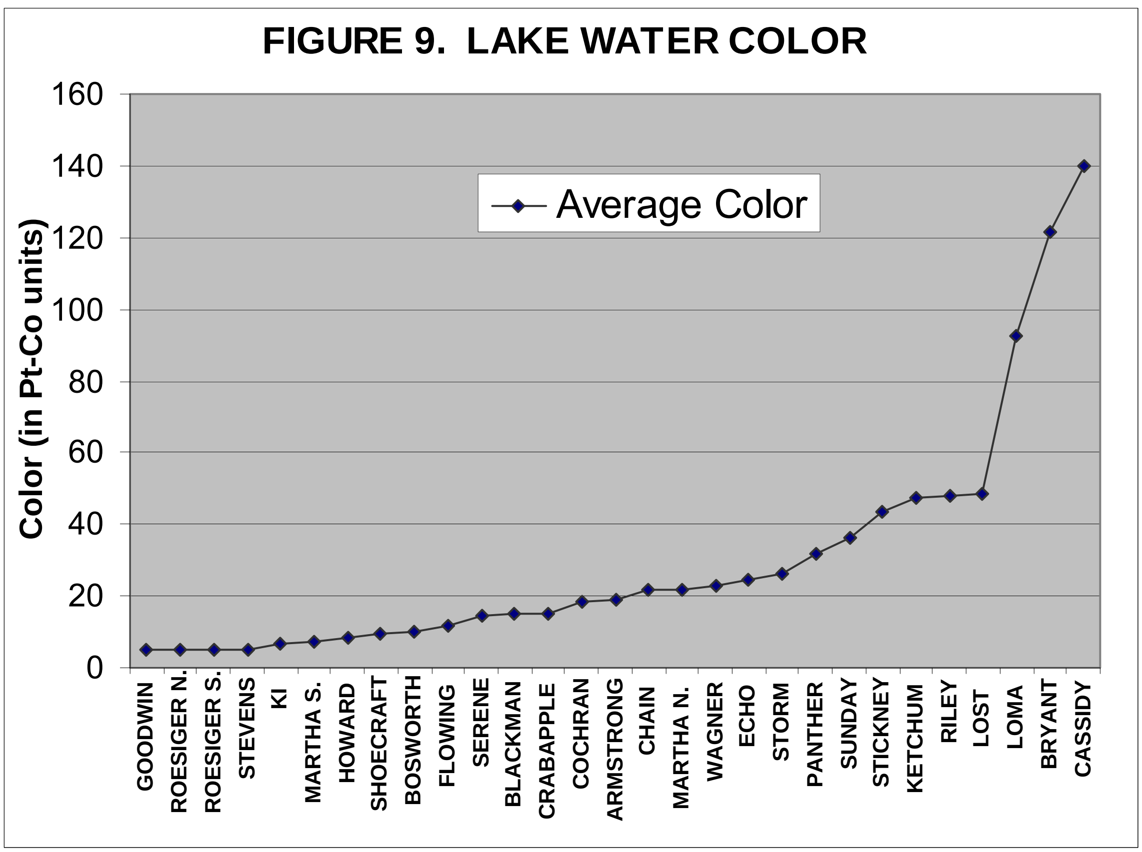

*Statistically significant trend ($p \leq 0.10$)

*Comparison of Water Color*

One of the factors affecting water clarity is the natural color of the water. Usually this color is the result of tannins absorbed in the water from humic organic matter that leaches into a lake from surrounding bogs and wetlands and from the lake sediments. This humic color—which ranges from yellow to dark brown—reduces water clarity but does not impair water quality. However, the reduced light that penetrates colored water can restrict algal and plant growth.

One or more measurements of water color (in units of platinum-cobalt) are available for most lakes during at least three years between 1973 and 1995. Although color varies somewhat from year to year in response to the amount of rainfall and runoff, these data provide a general comparison of natural water color in Snohomish County lakes. Figure 9 plots the overall average of the yearly averages of color measurements for each lake.

Clearly, Loma, Bryant, and Cassidy have the most darkly colored water. Panther, Sunday, Stickney, Ketchum, Riley, and Lost also have relatively dark water. Several other lakes, such as Meadow, Beecher, and Rowland, also have colored water, but no measurements are available for them. The dark water reduces the clarity in all these lakes somewhat and, combined with steep lake shores, significantly restricts the available habitat for aquatic plants in Bryant, Lost, Panther, and Riley. However, many of the darkly colored lakes still experience vigorous algal blooms. So, although the dark water color reduces the light available for algal growth, it appears that light is not the main factor limiting algae in these nutrient-rich lakes.



## *Total Phosphorus Comparisons and Trends*

Another important indicator of lake conditions is the concentration of nutrients present in the water. Phosphorus is typically the nutrient that limits the growth of algae in Snohomish County lakes because it is the nutrient in shortest supply. For this reason, measurements of phosphorus concentrations can be used to predict the potential for algal production in a lake, as well as the overall trophic state. However, algal growth does not always correlate directly with phosphorus concentrations in the lake because other factors can also control algal production. Other factors include the amount of sunlight, the availability of nitrogen and other nutrients, and grazing by zooplankton. In addition, some forms of phosphorus are not readily available for use by algae, so measurements of total phosphorus may not accurately predict the level of algal production. Nevertheless, measuring total phosphorus in a lake is an important indicator of lake productivity.

The lake monitoring program sampled lakes for total phosphorus concentrations each summer from 1996 through 2002, usually once per month. Discrete samples were collected at a depth of one meter for the epilimnion and at approximately one to two meters above the bottom for the hypolimnion. (Because of budget limitations, the program has not sampled other useful nutrient parameters, such as soluble reactive phosphorus and the various forms of nitrogen.)

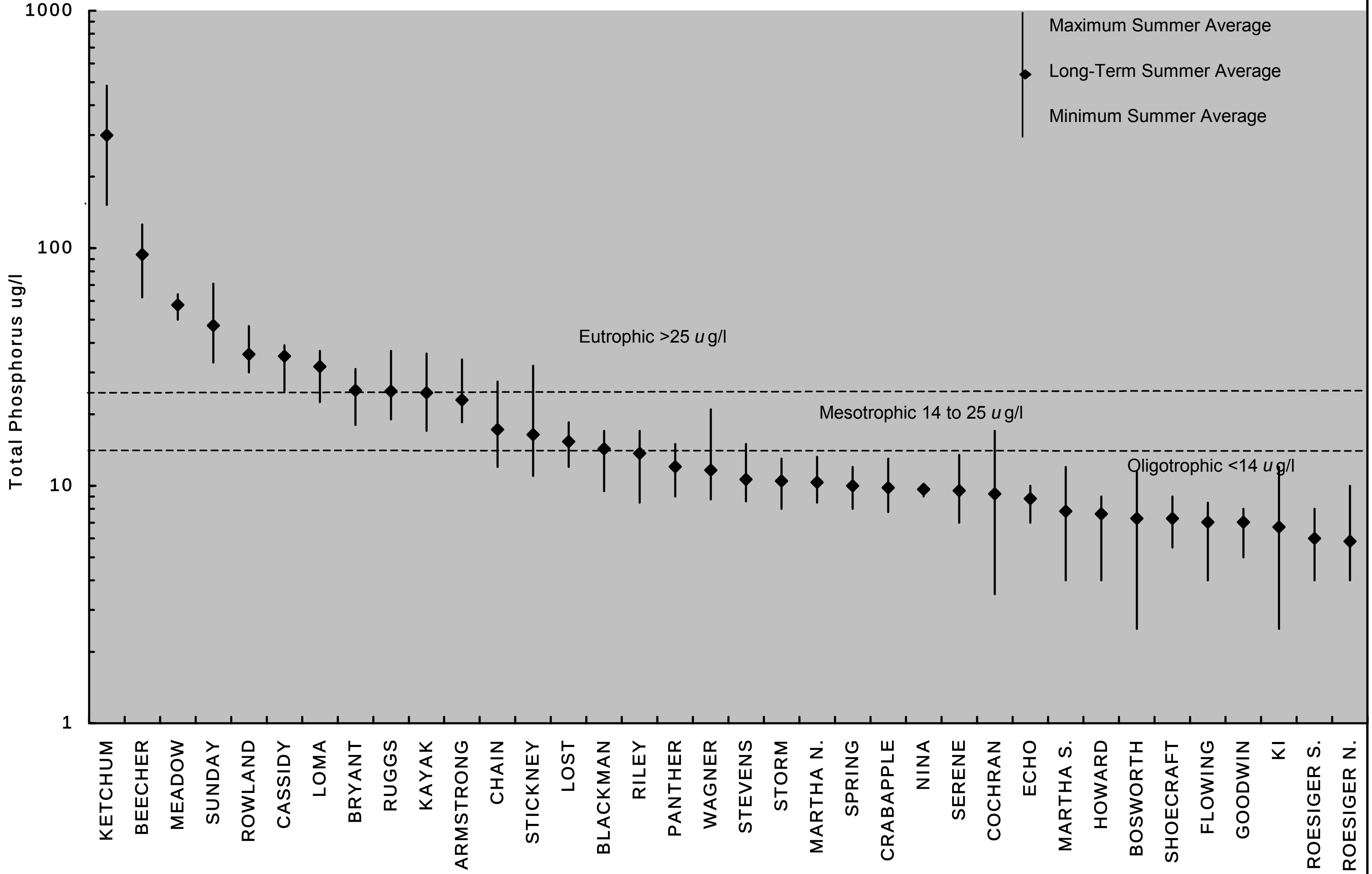
Several lakes also have a limited record of total phosphorus measurements from the 1980s and 1990s taken by other agencies. However, most of these measurements are from composite samples combining water from multiple depths within the epilimnion or hypolimnion. These composite sampling results are not included in the following analyses (except in the case of Lake Roesiger) because composite samples cannot be directly compared to Snohomish County's 1996-2002 discrete samples.

♦ Yearly Averages—Figure 10 shows the range of summertime (June through September) averages of total phosphorus concentrations in the epilimnion of the monitored lakes from 1996 through 2002. The graph also shows the long-term average of the summer averages for each lake over the monitoring period. Figure 11 shows the range of total phosphorus summer averages and the long-term average for the hypolimnion of the monitored lakes. In both graphs the lakes are arranged in order from high total phosphorus concentrations to low concentrations. Table 6 lists the summer total phosphorus epilimnion and hypolimnion averages for each lake by year.

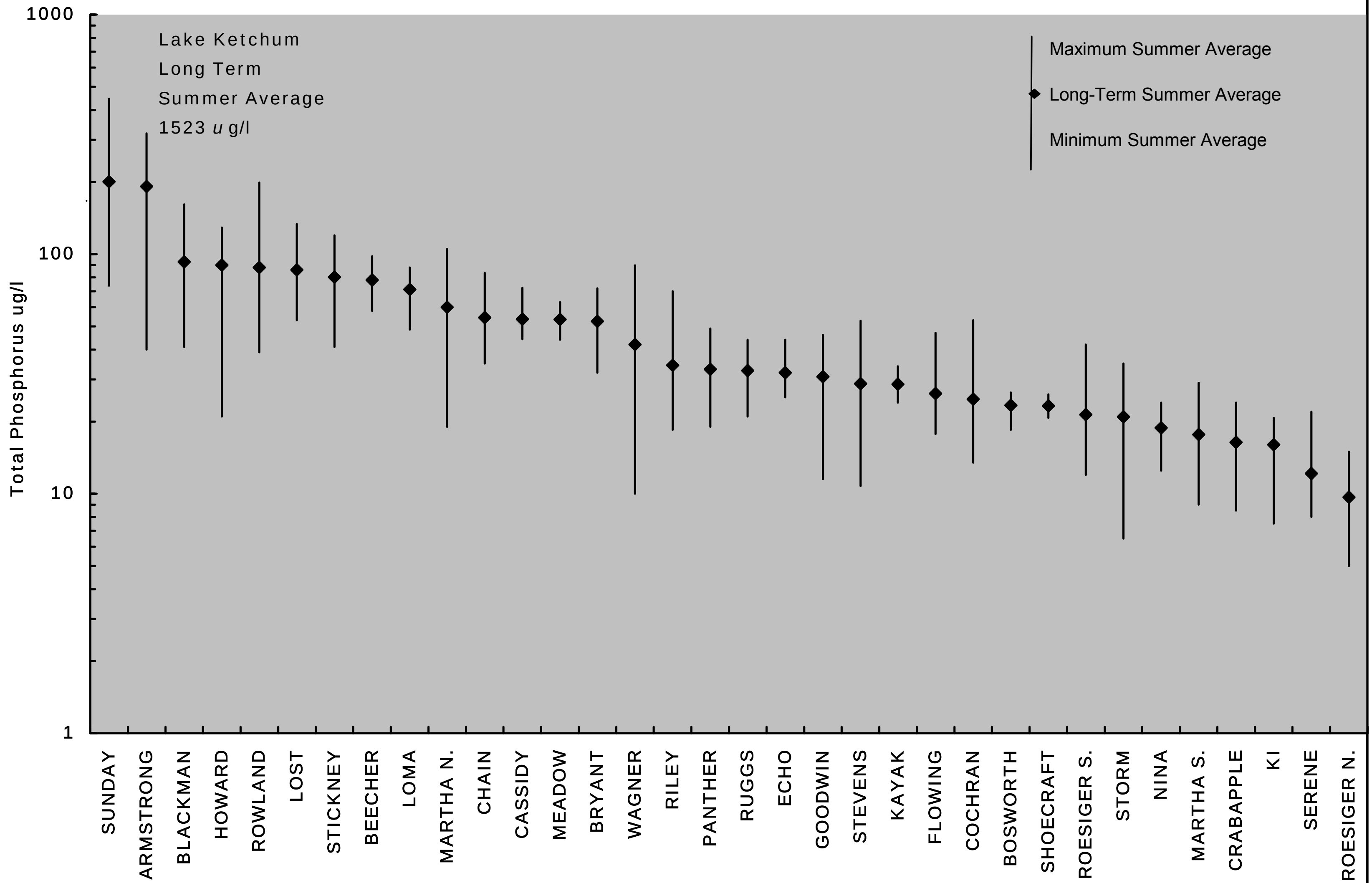
(Please note that the scales for total phosphorus in Figure 10 and Figure 11 are logarithmic to accommodate the wide range of values among lakes. Therefore, a small vertical difference may represent a large difference in values in the upper portions of the graphs. For example, the total phosphorus epilimnion averages for Lake Ki range from 3 µg/l to 12 µg/l with a long term average of 7 µg/l, while Lake Ketchum averages range from 209 µg/l to 484 µg/l with a long term average of 299 µg/l.)

Figure 10 and Table 6 reveal that Ketchum, Beecher, Meadow, and Sunday have high concentrations of total phosphorus in the epilimnion, while Lake Roesiger, Lake Ki, and several other lakes have total phosphorus concentrations consistently within the oligotrophic range. Figure 11 shows that Ketchum, Sunday, Armstrong, Blackman, Howard, and Rowland have high average total phosphorus concentrations in the hypolimnion during the summer. Moreover, Armstrong, Blackman, Howard, Ketchum, Lost, Martha N., and Stickney experience substantially higher total phosphorus concentrations in the hypolimnion than in the epilimnion.

# FIGURE 10. SUMMER AVERAGE EPILIMNION TOTAL PHOSPHORUS 1996-2002



# FIGURE 11. SUMMER AVERAGE HYPOLIMNION TOTAL PHOSPHORUS 1996-2002



Elevated total phosphorus concentrations in the deepest part of the hypolimnion may be caused by the settling of organic and other matter down toward the lake bottom, as well as by the release of phosphorus from the sediments which can occur in the absence of oxygen. Typically, phosphorus concentrations in the hypolimnion build up as the summer progresses due to these processes. However, high concentrations of phosphorus near the bottom in these lakes do not necessarily mean that the nutrients will become available for algal growth in the upper waters. The phosphorus has to be moved upward by mixing, uptake by blue-green algae, or diffusion. Additional monitoring and nutrient loading analyses would be necessary to identify the actual impacts of hypolimnetic phosphorus build-up in each lake. Nevertheless, these elevated hypolimnion phosphorus concentrations serve as warning signs indicating the potential for excess nutrients to fuel algal growth, especially in late summer or after fall turnover.

♦ Year-to-Year Variability—As stated above, total phosphorus concentrations can vary from month to month within a particular summer, especially in the hypolimnion. Table 6 shows that average total phosphorus concentrations in some lakes also varied significantly from year to year. (Caution should be used in interpreting year to year changes because 1996 and 1997 total phosphorus averages for most lakes are based on only two summer samples.) Ketchum and Sunday had the most year-to-year variation in average summer epilimnion total phosphorus, while Armstrong, Blackman, Howard, Ketchum, Lost, Sunday, and Wagner had substantial variation in hypolimnion phosphorus averages. In addition, Armstrong, Cochran, and Martha S. had at least one individual measurement of total phosphorus that was markedly higher than their typical values.

Looking at all lakes together, total phosphorus summer averages were generally lower in 1996 in both the epilimnion and hypolimnion. In contrast, most lakes had higher summer averages in 2001 in the epilimnion and hypolimnion. Possible explanations for this group variability include the influence of rainfall and runoff patterns (bringing more or less nutrients into the lakes) and temperature and sunlight patterns (affecting the amount of algal production and organic decomposition in the lakes). However, no clear relationships are apparent. More likely, the monitoring records are too short to account for the natural variability of nutrient levels in many lakes.

♦ Trends—In general, the periods of record for total phosphorus data are not long enough to establish or refute the existence of trends in most lakes. However, using Kendall's tau analysis, several lakes do show statistically significant trends toward increasing or decreasing total phosphorus concentrations. Sunday Lake appears to exhibit decreasing total phosphorus levels in the epilimnion (but not in the hypolimnion) between 1996 and 2002. In Lake Martha (N.), hypolimnion total phosphorus concentrations appear to be increasing, but no such trend is evident in the epilimnion. At Lake Ketchum, total phosphorus levels in both the epilimnion and hypolimnion appear to be declining (although less surely in the epilimnion). It is probable that reduced pollution from a former dairy farm accounts for the declining (but still very high) nutrient levels in Lake Ketchum. Reasons for possible trends at the other lakes are unknown. More years of data will be necessary to accurately analyze total phosphorus trends.

| TABLE 6<br>TOTAL PHOSPHORUS SUMMER AVERAGES 1996—2002 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Epilimnion** | | | | | | | | **Hypolimnion** | | | | | | | |
| **LAKE** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **1996-2002 Average** | **1996** | **1997** | **1998** | **1999** | **2000** | **2001** | **2002** | **1996-2002 Average** |
| ARMSTRONG | 19 | 34 | 22* | 24 | 22 | 20 | 20 | 23 | 40 | 118 | 319 | 278 | 192 | 157 | 237 | 192 |
| BEECHER | | 126 | | | | | 62 | 94 | | 58 | | | | | 98 | 78 |
| BLACKMAN | 10 | 17 | 13 | 12 | 15 | 17 | 17 | 14 | 97 | 162 | 43 | 91 | 129 | 87 | 41 | 93 |
| BOSWORTH | 3 | 12 | 6 | 7 | 9 | 8 | 7 | 7 | 25 | 27 | 24 | 19 | 27 | 20 | 24 | 23 |
| BRYANT | 30 | 31 | 18 | | 22 | | | 25 | 63 | 72 | 43 | | 32 | | | 53 |
| CASSIDY | 38 | 25 | | 35 | 39 | 41 | 37 | 36 | 73 | 44 | 51 | | | 47 | 53 | 54 |
| CHAIN | 12 | 28 | 17 | 18 | 16 | 16 | 14 | 17 | 84 | 35 | 38 | 64 | 57 | 59 | 45 | 54 |
| COCHRAN | 4 | 9 | 7 | 17* | 12 | 8 | 9 | 9 | 18 | 14 | 31 | 21 | 16 | 53 | 21 | 25 |
| CRABAPPLE | 11 | 9 | 8 | 9 | 10 | 13 | 9 | 10 | 9 | 16 | 16 | 14 | 18 | 24 | 20 | 16 |
| ECHO | 8 | 10 | 10 | 9 | 7 | 10 | 9 | 9 | 38 | 44 | 27 | 25 | 26 | 36 | 27 | 32 |
| FLOWING | 4 | 9 | 7 | 8 | 6 | 8 | 8 | 7 | 23 | 28 | 18 | 24 | 18 | 47 | 26 | 26 |
| GOODWIN | 8 | 8 | 7 | 8 | 5 | 7 | 7 | 7 | 12 | 30 | 28 | 36 | 29 | 46 | 36 | 31 |
| HOWARD | 4 | 8 | 8 | 9 | 8 | 9 | 8 | 8 | 99 | 94 | 129 | 126 | 104 | 57 | 21 | 90 |
| KAYAK | | | | 21 | 36 | | 17 | 25 | | | | 24 | 34 | | 28 | 29 |
| KETCHUM | 428 | 216 | 484 | 274 | 209 | 332 | 152 | 299 | 1875 | 1760 | 1968 | 1460 | 1157 | 1285 | 1155 | 1523 |
| KI | 3 | 8 | 5 | 5 | 6 | 12 | 9 | 7 | 8 | 17 | 20 | 21 | 18 | 13 | 17 | 16 |
| LOMA | 33 | 23 | 35 | 32 | 29 | 35 | 37 | 32 | 49 | 64 | 74 | 72 | 74 | 88 | 78 | 71 |
| LOST | 16 | 16 | 15 | 19 | 12 | 17 | 14 | 15 | 66 | 75 | 134 | 61 | 123 | 92 | 53 | 86 |
| MARTHA N. | 9 | 10 | 12 | 13 | 10 | 9 | 10 | 10 | 19 | 45 | 65 | 51 | 53 | 84 | 105 | 60 |
| MARTHA S. | 4 | 9 | 6 | 9 | 8 | 12 | 7 | 8 | 9 | 13 | 20 | 18 | 29* | 18 | 18 | 18 |
| MEADOW | | 64 | | 59 | | | 50 | 58 | | 53 | | 44 | | | 63 | 53 |
| NINA | 9 | | | 10 | | | 10 | 10 | 20 | | | 13 | | | 24 | 19 |
| PANTHER | 9 | 15 | 13 | 13 | 9 | 15 | 11 | 12 | 19 | 36 | 49 | 42 | 24 | 32 | 30 | 33 |
| RILEY | 9 | 15 | 12 | 17 | 16 | 17 | 11 | 14 | 19 | 26 | 22 | 27 | 21 | 70 | 57 | 34 |
| ROESIGER N. | 4 | 5 | 6 | 6 | 10 | | 5 | 6 | 14 | 15 | 6 | 8 | 10 | | 5 | 10 |
| ROESIGER S. | 4 | 4 | | 7 | 7 | | 8 | 6 | 42 | 21 | | 16 | 16 | | 12 | 21 |
| ROWLAND | | | 47 | | 30 | 35 | 31 | 36 | | | 61 | | 39 | 53 | 199 | 88 |
| RUGGS | | | | 19 | | 19 | 37 | 25 | | | | 44 | | 21 | 33 | 33 |
| SERENE | 7 | 10 | 9 | 14 | 7 | 12 | 9 | 10 | 8 | 22 | 15 | 9 | 8 | 11 | 12 | 12 |
| SHOECRAFT | 6 | 7 | 7 | 8 | 6 | 9 | 9 | 7 | 24 | 26 | 21 | 25 | 21 | 21 | 26 | 23 |
| SPRING | | | 12 | | 8 | | | 10 | | | | | | | | |
| STEVENS | | 8.6 | 8.6 | 11 | 10 | 15 | | 11 | | 52 | 53 | 11 | 15 | 14 | | 29 |
| STICKNEY | 12 | 32 | 15 | 13 | 11 | 17 | 15 | 16 | 72 | 74 | 65 | 93 | 97 | 120 | 41 | 80 |
| STORM | 10 | 12 | 11 | 12 | 8 | 13 | 8 | 10 | 7 | 35 | 24 | 19 | 18 | 29 | 16 | 21 |
| SUNDAY | 71 | 61 | 40 | 49 | 42 | 36 | 33 | 47 | 331 | 74 | 195 | 175 | 89 | 445 | 96 | 201 |
| WAGNER | 9 | 9 | 9 | 9 | 12 | 21 | 13 | 12 | 10 | 21 | 38 | 90 | 16 | 74 | 45 | 42 |

NOTES: Values are from total phosphorus samples taken at discrete depths, except for Roesiger N. and S. which are a mix of discrete and composite samples.

* For values marked with asterisk, median is shown rather than the average (mean) to avoid bias from one extremely high individual measurement.

### *Comparison of Algae*

Microscopic floating algae (phytoplankton) play an important role in the ecology of a lake. Zooplankton and fish depend on algae for food. However, when algal growth becomes excessive, it can interfere with use and enjoyment of a lake and threaten the health of a lake.

The data on algae types and abundance are limited for Snohomish County lakes. In most cases, the data come from the summer season only. This means that certain types of algae that are more prevalent in other seasons were missed. Also, algal blooms can come and go quickly, so the data likely missed significant episodes of algal growth during the summer. Nevertheless, a comparison of the available information does help paint a picture of the relative impacts of algae in Snohomish County lakes.

The primary measure of algal productivity is chlorophyll *a*, the active green pigment used for photosynthesis in algae. Lakes with average chlorophyll *a* levels greater than 8.7 µg/l may be considered eutrophic. Chlorophyll *a* levels less than 2.8 µg/l are usually associated with oligotrophic lakes. Mesotrophic lakes generally have average chlorophyll a levels between 2.8 and 8.7 µg/l.

As expected, in Snohomish County the shallow eutrophic lakes with high nutrient concentrations produce the highest levels of algae. Lake Cassidy (with chlorophyll *a* values up to 90 µg/l), Ketchum (up to 139 µg/l), Loma (up to 70 µg/l), and Sunday (up to 120 µg/l) consistently display the highest levels of algae. Other lakes, such as Blackman, Chain, and Stevens, also regularly have severe algal blooms. Even lakes with low nutrient levels—Goodwin, Roesiger, and Shoecraft—produce occasional widespread algal blooms.

Blue-green algae (more properly called Cyanobacteria) cause the majority of surface scums and odor problems affecting lakes. Analysis of limited algal samples from each lake in the summers of 1994 and 1995 revealed that Cassidy, Chain, Cochran, Ketchum and Lost had the highest numbers of blue-green algae cells, while the same lakes, except for Cochran, also had the highest volumes of blue-greens.

Occasionally, certain blue-green algae can also produce very poisonous toxins. These toxins can be harmful or, under certain conditions, deadly to animals or humans who drink the water. The reasons and conditions under which blue-greens produce toxins are poorly understood, but toxins usually appear only during severe algal blooms. During the summer of 2000, a toxic algal bloom was identified in Lake Ketchum. Information signs were posted, and no illnesses were reported. Toxic blooms have not been identified at any other Snohomish County lake. However, toxins could have been present at times but not sampled. Observation and identification of toxic algal blooms is one objective of the SWM lake monitoring program.

## *Comparison of Aquatic Vegetation*

Aquatic plants growing within and immediately adjacent to a lake are key components of a healthy lake ecosystem. These plants provide habitat for fish and other aquatic life and help stabilize the shorelines. The diversity, distribution, and density of aquatic plants can also indicate the productivity and trophic status of a lake, as well as provide clues about lake health.

Table 7 lists the main aquatic plant species found in the monitored lakes of Snohomish County. The table is divided into the four major types of aquatic plants—rooted floating-leafed plants, free floating plants, submersed (underwater) plants, and emergent plants. Plants listed in the table were identified by SWM or Washington State Department of Ecology staff during reconnaissance shoreline and boat surveys.

The densities and species composition of aquatic plant communities in lakes can vary significantly from year to year. For this reason, there may be additional plant species actually present in some lakes that are not included in Table 7 if the species were not encountered during the vegetation surveys. In addition, certain plants found around some lakes, such as willows, douglas' spiraea, and reed canary grass are not included because they usually grow elsewhere than lakes. Please refer to the individual lake reports for maps showing the general locations and densities of aquatic plants in particular lakes.

♦ Distribution and Diversity—Table 7 shows that *Nuphar polysepalum* (Yellow water-lily), *Elodea canadensis* (Common elodea), and several *Potamogeton* spp. (Thin-leaf pondweeds) are the most widely distributed aquatic plants in the monitored lakes. These species are found in almost every lake and are the dominant plants in most lakes. In contrast, several species, such as *Azolla mexicana* (Mexican water-fern) have been observed in only one lake.

The lakes which support the widest variety of aquatic plant species are Ketchum, Loma, Serene, Stevens, Stickney, and Sunday. Most of these lakes are shallow, which provides large areas for aquatic plant growth. Lake Stevens likely supports a diversity of plants because, despite its great depth, the lake's large size also provides abundant shallow water areas that are suitable for plant growth.

Armstrong, Crabapple, Lost, and Storm are the lakes with the least diversity, especially of plants that grow completely in the water. These lakes all have steep shorelines combined with somewhat colored water which limits the available habitat for aquatic plants to a narrow zone around the shoreline.

♦ Density—The aquatic plant surveys did not include quantitative measurements of plant biomass. However, the surveys were thorough enough to provide a reliable estimate of the relative density of aquatic plants in the monitored lakes. The surveys revealed that Blackman, Cassidy, Chain, Ketchum, Loma, Serene, Stickney, and Sunday lakes contain high densities of aquatic plants. In addition, more limited surveys of Meadow, Rowland, and Ruggs showed high plant densities. In general, these lakes are shallow, have large areas available for plant growth, and have enriched bottom sediments.

In contrast, Armstrong, Bosworth, Bryant, Ki, Lost, and Storm lakes do not support dense growths of aquatic plants, except for a few small patches. Plant densities appear to be limited by dark color (Armstrong, Bryant, and Lost) or lack of nutrient rich sediments (Bosworth, Ki, and Storm). Many of these lakes also have very steep shorelines which restrict the zone available for plant growth.

- Non-native Invasive Plants—Several exotic (or non-native) aquatic plants have invaded Snohomish County lakes. *Myriophyllum spicatum* (Eurasian watermilfoil), *Myriophyllum aquaticum* (Parrotfeather), *Lythrum salicaria* (Purple loosestrife), and *Egeria densa* (Brazilian elodea) are particularly aggressive weeds that are on the Washington State Noxious Weed list. The plants are classified as Class B; in Snohomish County the Weed Board requires that these plants be controlled. *Nymphaea odorata* (Fragrant water-lily) and *Iris pseudacorus* (Yellow iris) are ornamental non-native plants that are widespread in many lakes. *Iris pseudacorus* (Yellow iris) is a Class C noxious weed (control not required).

Eurasian watermilfoil, the most notorious of the exotic aquatic plants, has been found in Goodwin, Roesiger, and Shoecraft lakes during the 1990s. SWM is working with local citizens and the State to control milfoil at these sites. Parrotfeather has been discovered and controlled in two sites in Nina Lake. Brazilian elodea is growing in Swartz Lake, near Granite Falls. Meadow Lake is infested with *Hydrocharis morsus-ranae* (European frog-bit), a non-native plant that is on the State Noxious Weed Board's quarantine list to prohibit its sale, transport, or planting. European frog-bit has caused serious problems in other parts of North America.

| TABLE 7. AQUATIC PLANTS FOUND IN SNOHOMISH COUNTY LAKES | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Floating Leaf | | | Free Floating | | | | | | | | | Submersed | | | | | | | | | |
| LAKE NAME / PLANT NAMES | *Brasenia schreberi* (Watershield) | *Nuphar polysepalum* (Yellow water-lily) | # *Nymphaea odorata* (Fragrant water-lily) | *Azolla mexicana* (Mexican water-fern) | # *Hydrocharis morsus-ranae (European Frog-bit)* | *Hydrocotyle ranunculoides* (Floating pennywort) | *Lemna minor* (Duckweed) | *Ricciocarpus natans* (Purple-fringed riccia) | *Spirodela polyrhiza* (Greater duckweed) | *Wolffia spp.* (Watermeal) | *Ceratophyllum demersum* (Coontail)[1] | *Utricularia vulgaris* (Common bladderwort)[1] | *Chara* sp. (Stonewort, Muskgrass) | *Eleocharis* sp. (Spikerush) | *Elodea canadensis* (Common elodea) | *Fontinalis* sp. (Water moss) | *Isoetes* sp. (Quillwort) | *Myriophyllum hippuroides* (Native watermilfoil) | # *Myriophyllum spicatum* (Eurasian watermilfoil) | *Najas flexilis* (Naiad) | *Nitella* sp. (Brittlewort) | *Potamogeton amplifolius* (Large-leaf pondweed) |
| ARMSTRONG | | X | | | | | | | | | | X | | | | | | | | | | |
| BEECHER | | | | | | | | | | | | | | | | | | | | | | |
| BLACKMAN | | X | X | | | | | | | | X | | | | X | | | | | X | X | X |
| BOSWORTH | | X | X | | | | | | | | | | | | X | | | | | | | X |
| BRYANT | | X | | | | | X | | | | | | X | | | | | | | | | |
| CASSIDY | | X | | | | | | | | | X | X | | | X | | | | | | X | |
| CHAIN | | X | | | | | X | | | | X | | | | X | | | | | | X | X |
| COCHRAN | X | X | X | | | | | | | | | | | | X | | | | | | | |
| CRABAPPLE | | X | X | | | | | | | | | | | | X | | | | | | X | |
| ECHO | X | X | | | | | | | | | | | X | X | X | | | | | | | |
| FLOWING | | X | X | | | | | | | | | | | | X | | | | | | X | X |
| GOODWIN | | | | | | | | | | | | | X | | | | | | X | X | X | X |
| HOWARD | | X | X | | | | | | | | | | X | X | X | | | | | | | X |
| KETCHUM | | X | X | X | | | X | X | | X | X | | | | X | | | | | | X | X |
| KI | | X | X | | | | | | | | | | X | X | X | | | | | | | |
| LOMA | | X | X | | | | | | | | X | X | | | | X | | X | | | | |
| LOST | X | X | X | | | | | | | | | | | | | | | | | | | X |
| MARTHA N. | | X | X | | | | | | | | | | X | X | X | | | | | | | |
| MARTHA S. | | X | X | | | | | | | | | X | X | | X | | | | | X | X | |
| MEADOW | | X | | | X | | X | | X | | | | | | | | | | | | | |
| NINA | | | | | | X | | | X | | | | | | | | | | | | | |
| PANTHER | | X | X | | | | | | | | | X | | | X | | | | | | X | X |
| RILEY | X | X | | | | | | | | | | X | | | X | | | X | | | X | |
| ROESIGER | | X | X | | | | | | | | | X | | | X | | X | | X | | X | |
| ROWLAND | | X | | | | | | | | | | | | | | | | | | | | X |
| RUGGS | | X | X | | | | | | | | X | X | | | X | | | | | X | | X |
| SERENE | | X | X | | | | | | | | X | X | X | | X | | | | | | X | X |
| SHOECRAFT | | X | X | | | | | | | | | | X | | X | | | | X | X | | X |
| SPRING | X | X | | | | | | | | | | | | | | | | | | | | X |
| STEVENS | X | X | X | | | | | | | | | | X | | X | | | | | X | X | |
| STICKNEY | | X | X | | | | | | | | X | X | X | | X | X | | | | | X | |
| STORM | | X | | | | | | | | | | | | | | | | | | | | |
| SUNDAY | X | X | X | | | | X | | | X | X | X | X | | X | | | | | | X | X |
| WAGNER | | X | | | | | | | | | X | X | X | | X | | | | | | X | |

Note: Common wetland species found around many lakes, such as *Carex* spp. (Sedges), *Juncus* spp. (Rushes), *Salix* spp. (Willows), *Spiraea douglasii* (Spiraea), and *Phalaris arundinacea* (Reed canary grass), are not included in table.

# -- These species are noxious, non-native, invasive aquatic plants.

| TABLE 7 (CONTINUED) | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Submersed (continued) | | | | | | | | | | | Emergent | | | | | | | | | | | | | | |
| *Potamogeton epihydrus* (Ribbon-leaf pondweed) | *Potamogeton gramineus* (Grassy pondweed) | *Potamogeton praelongus* (White-stalked pondweed) | *Potamogeton* spp. (Thin-leaf pondweeds)[2] | *Sagittaria graminea* (Slender arrowhead) | *Sagittaria subulata* v. *gracillima* (Awl-leaf arrowhead) | *Scirpus subterminalis* (Water bulrush) | *Vallisneria americana* (Tapegrass) | | # *Myriophyllum aquaticum* (Parrotfeather)[1] | | *Dulichium arundinaceum* (Three-way sedge) | *Equisetum fluviatile* (Water horsetail) | # *Iris pseudacorus* (Yellow iris or water-flag) | *Ludwigia palustris* (False loosestrife) | # *Lythrum salicaria* (Purple loosestrife) | *Menyanthes trifoliata* (Bog bean) | *Polygonum amphibium* (Water smartweed) | *Potentilla palustris* (Marsh cinquefoil) | *Sagittaria latifolia* (Broad-leaf arrowhead) | *Scirpus* spp. (Bulrushes) | *Sparganium* sp. (Bur-reed) | *Typha* spp. (Cattails) | *Veronica americana* (American speedwell) | | **PLANT NAMES** / **LAKE NAME** |
| | | | X | | | | | | | | | | | | | | | | | | | | | | ARMSTRONG |
| | | | | | | | | | | | | | | | | | | | | | | | | | BEECHER |
| | | | X | | | | | | | | | | | | X | | | | | | | | | | BLACKMAN |
| | | | X | | | | | | | | | | | | | | | | | | | | | | BOSWORTH |
| X | | | X | | | | | | | | | | | | | | | | | | X | | | | BRYANT |
| | | | X | | | | | | | | X | | | | X | | | | | X | | X | | | CASSIDY |
| | | | X | | | | | | | | | | | | | | | | | | | | | | CHAIN |
| X | | | X | | | | | | | | | X | | | | X | | | | | | X | | | COCHRAN |
| | | | | | | | | | | | | | | | | | | | | | | | | | CRABAPPLE |
| | | | X | | X | | | | | | | | | | | X | X | | | | | X | | | ECHO |
| | | | X | | | | X | | | | | | X | X | | | | | | | | | | | FLOWING |
| | | | X | | | | | | | | | | | | | | | | | | | | | | GOODWIN |
| | | | | | | | | | | | | | | | | | | | | | | | | | HOWARD |
| | | | X | | | | | | | | | | | | | | | | | | | X | X | | KETCHUM |
| | | | X | | | | X | | | | | | | | | | | | | | | | | | KI |
| | | | X | X | | X | | | | | | | | | | | X | | | | | | | | LOMA |
| | | | | | | | | | | | | | | | | | | | | | | | | | LOST |
| | | | X | | | | | | | | | | X | | | | | X | | | | X | | | MARTHA N. |
| | | | X | | | | | | | | | | X | | | | | | | X | | X | | | MARTHA S. |
| X | | | X | | | | | | | | X | | | | | X | X | X | | | | X | | | MEADOW |
| | | | | | | | | | X | | | | | | | | | | | | | X | | | NINA |
| | | | X | | | | | | | | | | | | | | | | | | | X | | | PANTHER |
| X | | | X | | | | | | | | X | | | | | X | | | | | | | | | RILEY |
| X | | | X | X | | | X | | | | | | X | X | X | | | | | X | | X | | | ROESIGER |
| | | | X | | | | | | | | | | | | | | | | | | | X | | | ROWLAND |
| | | | | | | | | | | | | | | | | | | | | | | | | | RUGGS |
| | | | X | X | | | | | | | | | | | X | | | | | | | | | | SERENE |
| | | | X | | | | | | | | | | X | | | | | | | X | | | | | SHOECRAFT |
| | | | X | | | | | | | | | | | | | | X | X | | | | | | | SPRING |
| | X | | X | | X | | | | | | | | X | | X | | | | | | | | | | STEVENS |
| | | | X | | | | X | | | | | | | X | X | | | | | | | | | | STICKNEY |
| | | | X | | | | | | | | | | | | | X | | | | | | | | | STORM |
| | | | X | | | | | | | | | | | | | | | X | | X | | X | | | SUNDAY |
| | | X | X | | | | | | | | | | | X | | | | | X | | | | | | WAGNER |

[1] Plant species listed between the shaded categories share the characteristics of the two adjacent categories.

[2] "*Potamogeton* spp. (Thin-leaf pondweed)" refers to one or more pondweed species with narrow leaves, including *P. pusillus, P. foliosus, P. pectinatus, and P. Berchtoldii*.

### *Comparison of Trophic States*

The trophic state of a lake refers to its degree of biological productivity (primarily of aquatic plants and algae) resulting from nutrient and sediment enrichment. It is often useful to categorize lakes by their trophic states as a means of comparing conditions among lakes. Although trophic states are not value judgments, they can help in understanding when a lake is suffering from increased eutrophication.

Trophic states describe a continuum of conditions from oligotrophic (clear water with few plants and algae) to eutrophic (limited clarity with abundant plants and algae). Mesotrophic lakes fall between these extremes. The categories are not precise. Some lakes show characteristics of more than one category, so they may be placed between the three main categories.

The trophic state of a lake can be estimated in several ways. There are numeric indices based on water quality measurements that calculate the approximate trophic state, most notably the Trophic State Index of Carlson, 1977. Various scientists have also suggested threshold values for water clarity, total phosphorus, chlorophyll *a*, and other parameters that correspond to trophic states (see Table 1). Lake scientists also look at other variables, such as the density and types of aquatic plants and algae, oxygen depletion, and phosphorus build-up, to provide clues to the trophic state of a lake.

Table 8 lists the monitored lakes of Snohomish County by estimated trophic state. This categorization is based on threshold values for water clarity and total phosphorus, as well as best professional judgment using all the other information known about these lakes.

**TABLE 8**
**ESTIMATED TROPHIC STATES OF SNOHOMISH COUNTY LAKES**

| Oligotrophic | Oligo-Mesotrophic | Mesotrophic | Meso-Eutrophic | Eutrophic |
|---|---|---|---|---|
| KI | BOSWORTH | BLACKMAN | ARMSTRONG | BEECHER |
| | FLOWING | COCHRAN | CHAIN | BRYANT |
| | GOODWIN | CRABAPPLE | KAYAK | CASSIDY |
| | NINA | ECHO | LOST | KETCHUM |
| | ROESIGER | HOWARD | RILEY | LOMA |
| | SHOECRAFT | MARTHA N. | STICKNEY | MEADOW |
| | STEVENS | MARTHA S. | | ROWLAND |
| | | PANTHER | | RUGGS |
| | | SERENE | | SUNDAY |
| | | SPRING | | |
| | | STORM | | |
| | | WAGNER | | |

Many of the lakes do not fit neatly into the trophic categories in this table because they exhibit characteristics of more than one category. For example, Lake Serene and Lake Wagner have high water clarity, which is a characteristic of oligotrophic lakes. But, they are also shallow lakes with abundant aquatic plants and occasional severe algal blooms, which is more typical of eutrophic lakes. The best overall description of these lakes is that they are mesotrophic. Likewise, Lake Roesiger has very high water clarity, but is classified as oligo-mesotrophic because of moderate algal growth and aquatic plants.

Lake Stevens is one lake that is classified in a more productive category than it would be without the impacts of human activity. Because of its great depth and small watershed, the lake should exhibit oligotrophic conditions. However, Lake Stevens experiences regular, severe algal blooms as a result of nutrients coming from the watershed and the lake sediments. For this reason, Lake Stevens is classified as oligo-mesotrophic rather than oligotrophic.

*Summary of Lake Problems*

A number of lakes currently have specific problems that may be early warning signs of future trouble. Table 9 lists the most severe problems identified by lake monitoring results and by lake users in recent years. Other lakes may also experience some of the same problems, but to a lesser degree.

| **TABLE 9.**<br>**SUMMARY OF LAKE PROBLEMS** | **THE MOST AFFECTED LAKES** |
|---|---|
| **<u>Declining Water Clarity</u>**<br>Water clarity in the first two lakes showed a statistically significant decline during the period of 1992-2002. The other two lakes showed evidence of possible water clarity decreases. Continued declines in water clarity will harm public use and enjoyment of these lakes. | LOMA<br>NINA<br><br>STEVENS<br>SUNDAY |
| **<u>Nuisance Algal Blooms</u>**<br>These lakes experience regular algal blooms that are severe enough to interfere with human enjoyment of the lakes. In most cases, blue-green algae cause the nuisance conditions. | ARMSTRONG<br>BLACKMAN<br>CASSIDY<br>HOWARD<br>KETCHUM<br>LOMA<br>RUGGS<br>STEVENS<br>SUNDAY |
| **<u>Toxic Algal Blooms</u>**<br>Occasionally, some blue-green algae produce toxins during bloom conditions. These toxins can be deadly to animals, and even people, should they drink the water. So far, toxic algae have been confirmed in only one lake during a single summer episode. | KETCHUM |
| **<u>Noxious Non-native Invasive Aquatic Plants</u>**<br>Aggressive non-native aquatic plants have invaded these lakes. These plants displace native plants, interfere with boating, swimming, and fishing, and may harm wildlife. | <u>Eurasian watermilfoil</u><br>GOODWIN<br>ROESIGER<br>SHOECRAFT[1]<br><u>Parrotfeather</u><br>NINA<br><u>Brazilian Elodea</u><br>SWARTZ<br><u>European Frog-bit</u><br>MEADOW<br><u>Purple Loosestrife</u><br>BLACKMAN<br>CASSIDY<br>ROESIGER<br>SERENE<br>STEVENS<br>STICKNEY |

| TABLE 9 (CONTINUED)<br>SUMMARY OF LAKE PROBLEMS | THE MOST AFFECTED LAKES |
|---|---|
| **Nuisance Levels of Native Aquatic Plants**<br>Native aquatic plants grow in such profusion in these lakes that they create nuisance conditions for boating, swimming, and fishing. | KETCHUM<br>LOMA<br>ROWLAND<br>RUGGS<br>SUNDAY |
| **Severe Oxygen Depletion**<br>Oxygen loss in the bottom waters of these lakes during the summer is so severe that it threatens the survival of fish and other aquatic life in the lakes.[2] | CASSIDY<br>KETCHUM<br>LOMA<br>LOST |
| **Sedimentation (or Lake Filling)**<br>Sediment from runoff and dying aquatic vegetation is filling this lake to the point that boating, swimming, and fishing are threatened. | RUGGS |
| **Lake Flooding**<br>The water level in these lakes rises high enough during the winter to cause damage to yards, septic systems, and homes. | CASSIDY<br>CRABAPPLE |
| **Nuisance Waterfowl**<br>Excess numbers of ducks and geese at these lakes are creating serious impacts. Waterfowl droppings leave a mess, contribute nutrients that feed algal growth, and cause bacterial pollution. | BLACKMAN<br>ECHO<br>LOMA<br>MARTHA S.<br>NINA<br>SERENE<br>STEVENS<br>STICKNEY<br>SUNDAY |

[1] Eurasian watermilfoil has been eradicated in Lake Shoecraft; however, there is risk that the plants may re-infest the lake from nearby Lake Goodwin.

[2] Lake Stevens has an aeration system that prevents severe oxygen depletion in the hypolimnion.

*Summary of Lake Conditions*

One general conclusion that can be reached about the monitored lakes in Snohomish County is that the condition of most lakes is adequate to support public use and enjoyment of the lakes. In spite of rapid changes in lake watersheds around the county, many lakes remain healthy. In fact, several lakes show signs of improving water clarity.

However, lakes have a finite capacity to absorb impacts from human activity (and some lakes have less capacity than others). As nutrient runoff into lakes from fertilizers, failing septic systems, and impervious surfaces continues and surrounding development expands, problems may become noticeable in some lakes. In fact, several lakes already show signs of declining water quality.

Table 10 and the individual lake reports provide an overall assessment of the health of each monitored lake in Snohomish County. These assessments are subjective. They are based on the best judgments of SWM staff and regional lake scientists and on feedback from citizens. The assessments take into consideration such factors as recent trends in water clarity, the frequency of nuisance algal blooms, and the problems reported at a lake.

Lakes listed in "healthy" condition do not show signs of declining water clarity or nutrient build-up. The existing conditions in these lakes are more than adequate for recreation and other uses. These lakes "need protection" to maintain their existing water quality.

**TABLE 10**

**SUMMARY OF LAKE CONDITIONS**

| **Need Protection** (Healthy) | **Need Improvement** (At Risk) | **Need Restoration** (Impaired) |
|---|---|---|
| BOSWORTH | ARMSTRONG | CASSIDY |
| BRYANT | BEECHER | KETCHUM |
| CHAIN | BLACKMAN | LOMA |
| COCHRAN | CRABAPPLE | RUGGS |
| FLOWING | ECHO | SUNDAY |
| GOODWIN | HOWARD | |
| KI | KAYAK | |
| PANTHER | LOST | |
| RILEY | MARTHA N. | |
| ROESIGER | MARTHA S. | |
| SHOECRAFT | MEADOW | |
| STORM | NINA | |
| WAGNER | ROWLAND | |
| | SERENE | |
| | SPRING | |
| | STEVENS | |
| | STICKNEY | |

Lakes listed as "need improvement (at risk)" either show signs that water quality is beginning to decline or suffer from at least one important problem, such as excess nutrients, severe oxygen depletion, nuisance algal blooms, excess aquatic plants, or overabundant waterfowl. Unless improvements are made in one or more areas, future use and enjoyment of these lakes may be threatened.

The lakes listed as "need restoration (impaired)" suffer from at least two serious problems that are currently affecting the use and enjoyment of the lakes. Although these lakes are still healthy enough to provide many benefits to local residents and other lake users, they need restoration to return to a healthier condition. Restoration will insure the full benefits of these lakes for the people of Snohomish County.

These assessments of lake conditions are not to be confused with trophic states, which are measures of nutrient enrichment and biological productivity. A lake can be mesotrophic in terms of trophic state and still be assessed as "needing restoration" if it has much lower water clarity and higher nutrient levels than it should have naturally. Conversely, a eutrophic lake might be in healthy condition if it does not show signs of increasing algal blooms or nutrient build-up or some other serious problem.

It should also be noted that the assessments of lake conditions in this report are different from designations in the official Washington State 303(d) list. To comply with the federal Clean Water Act, every two years the State prepares a formal list of all the streams, rivers, estuaries, and lakes that do not meet State surface water quality standards. This 303(d) list indicates which specific pollutants impair or threaten the beneficial uses of these water bodies. The most recent 303(d) list includes several Snohomish County lakes. Ketchum, Martha Lake (S.), and Stevens lakes are listed for impacts from total phosphorus. Blackman is listed for total phosphorus and fecal coliform bacteria, while Sunday is listed for total phosphorus and total nitrogen.

The purpose of the lake conditions summary in this report is to provide a simple, balanced overall assessment of the health of individual lakes and of lowland Snohomish County lakes in general. Residents, lake users, and public agencies can use this summary to help set targets for lake health and identify steps to protect, improve, or restore these valuable lakes.

# Recommendations and Future Directions

This report evaluates the current health of Snohomish County lakes and identifies a variety of problems that threaten lake health and enjoyment. The following sections summarize the proposed water quality targets for lakes, recommendations for individual lakes, proposed criteria for public actions at lakes, and steps that lake residents and users can take to protect lake health.

## *Water Quality Targets*

The ideal would be for all lakes in Snohomish County to be in healthy condition. For this to happen, the lakes listed as in healthy condition need to be protected to maintain their health, lakes that are currently at risk need to be improved, and lakes listed as impaired need to be restored.

Quantifiable targets to achieve these goals would be for lakes that “Need Protection” to maintain at least their 1990-2002 average water clarity and their 1996-2002 average epilimnion and hypolimnion total phosphorus concentrations (with a few exceptions for needed improvements as described in the individual reports). The targets for lakes that “Need Improvement” or “Need Restoration” would be to increase their 1992-2002 average water clarity and reduce their 1996-2002 average epilimnion and hypolimnion total phosphorus concentrations (also with a few exceptions).

Washington State water quality standards (WAC 173-201A-030(5)) currently set 10 μg/l as the criterion for epilimnion total phosphorus concentrations in lakes that have ambient average concentrations of 4 to 10 μg/l. The criterion for all lakes with greater than 10 μg/l average total phosphorus concentrations is 20 μg/l. The data provided in this report suggest that these standards are inappropriate for some lakes. However, developing more refined numeric criteria (i.e. specific total phosphorus values) would require detailed lake specific studies in most cases. Therefore, this report recommends the use of the general targets described above for each lake category until more detailed studies, if any, are completed.

## *Summary of Recommendations for Individual Lakes*

Table 11 summarizes the recommendations for individual lakes contained in this report. The first three general recommendations apply to every lake, although they may be more critical at some lakes. The waterfowl recommendations apply to numerous lakes that have problems with excess waterfowl. Implementing these general recommendations, together with the Steps That Citizens Can Take listed after Table 11, are the most important actions for protecting and restoring lake health.

The remainder of Table 11 contains a summary of specific additional recommended actions for individual lakes.

| TABLE 11. | |
|---|---|
| **LAKE** | **SUMMARY OF LAKE RECOMMENDATIONS** |
| ALL LAKES | • Lakes are sensitive to additional nutrient impacts, so effective enforcement of County grading and drainage standards is essential for controlling runoff to lakes and limiting new sources of nutrients. Snohomish County's NPDES permit requires conformance with the detailed standards in the current Department of Ecology Stormwater Manual for the Puget Sound Region. |
| ALL LAKES | • Existing homes on the lake shore should re-establish zones of native vegetation next to the water to filter out pollution before it reaches the lake. New bulkheads should be avoided where possible. Even where bulkheads exist, native vegetation can be established above and below the structures. |
| ALL LAKES | • Monitoring the condition of lakes over time is critical for keeping them clean. Monitoring of water clarity, nutrients, algae, and aquatic plants should continue at all lakes. For some lakes, monitoring should be expanded to identify the specific sources of nutrients causing the current problems. |
| MANY LAKES | • At some lakes, the number of waterfowl (mainly resident waterfowl) are so large that they contribute a significant amount of nutrients and fecal bacteria to the lakes. In these cases, waterfowl control measures should be taken. In addition, Snohomish County should consider legislation to prohibit feeding of waterfowl. |
| ARMSTRONG | • Monitoring should focus on water clarity, algae, and phosphorus.<br>• Nutrient sources that feed the algal blooms should be identified and addressed. |
| BEECHER | • Additional monitoring is needed to better characterize current lake conditions and identify future changes.<br>• A bathymetric map and an aquatic plant survey should be completed to establish baseline conditions. |
| BLACKMAN | • Monitoring should focus on algal blooms and nutrient release from the sediments.<br>• The remaining wetlands in the watershed should be protected for their valuable role in filtering pollution that flows toward the lake.<br>• Resident waterfowl numbers should be reduced significantly. |
| BOSWORTH | • (See general recommendations for all lakes.) |
| BRYANT | • Monitoring should focus on potential impacts from the closed landfill. |
| CASSIDY | • Monitoring should focus on nutrients and algae.<br>• The extensive wetlands and native vegetation surrounding the lake should be preserved.<br>• The purple loosestrife should be controlled to protect the habitat values of the natural wetlands. |
| CHAIN | • The extensive wetlands surrounding the lake should be preserved to protect the lake from development impacts. |

| | |
|---|---|
| COCHRAN | • (See general recommendations for all lakes.) |
| CRABAPPLE | • Monitoring should determine if water clarity begins to decline again as it did for several years in the 1990s, especially in light of continued development in the watershed. |
| ECHO | • Resident waterfowl numbers should be reduced. |
| FLOWING | • (See general recommendations for all lakes.) |
| GOODWIN | • Monitoring should focus on water clarity and nutrients.<br>• Milfoil control efforts should continue. |
| HOWARD | • Monitoring should focus on understanding the build-up of nutrients in the hypolimnion and the algal blooms that occur at several meters depth. |
| KAYAK | • Additional monitoring is needed to better characterize current lake conditions and identify future changes.<br>• A bathymetric map and an aquatic plant survey should be completed to establish baseline conditions. |
| KETCHUM | • Monitoring should continue to track nutrient levels in the farm runoff.<br>• A rehabilitation plan developed for the former dairy farm should be implemented.<br>• Monitoring should help to identify potential toxic algal blooms.<br>• Wetlands north and south of the lake that are important in filtering pollution should be protected.<br>• A long-term aquatic vegetation management plan should be developed. |
| KI | • (See general recommendations for all lakes.) |
| LOMA | • Monitoring should determine if water clarity continues to decline and should focus on identifying the causes for the decline.<br>• Resident waterfowl numbers should be reduced. |
| LOST | • Because of the steep slopes draining to the lake, existing homes on the lake shore should be especially encouraged to reduce fertilizers and re-create buffers of native vegetation to filter pollution. |
| MARTHA N. | • Monitoring should focus on algal blooms and on oxygen depletion and nutrient release in the metalimnion. |
| MARTHA S. | • Monitoring should focus on changes in water clarity and nutrients.<br>• Monitoring should also focus on understanding the potential release of nutrients in the hypolimnion.<br>• Resident waterfowl numbers should be reduced. |
| MEADOW | • Additional monitoring is needed to better characterize current lake conditions and identify future changes.<br>• The extensive wetlands surrounding the lake should be protected to filter pollution and provide fish and wildlife habitat.<br>• Steps should be taken to prevent the non-native frog-bit plants from spreading to other lakes. These plants should also be monitored carefully to document their growth in the lake. |

| | |
|---|---|
| NINA | • Monitoring should determine if water clarity continues to decline and identify the causes of the decline.<br>• Additional monitoring is needed to better characterize current lake conditions and identify future changes.<br>• A bathymetric map and an aquatic plant survey should be completed to establish baseline conditions.<br>• Resident waterfowl numbers should be reduced. |
| PANTHER | • (See general recommendations for all lakes.) |
| RILEY | • The extensive wetlands surrounding the lake should be protected to filter pollution and provide fish and wildlife habitat. |
| ROESIGER | • Milfoil control efforts should continue.<br>• Forest management and harvest activities in the watershed should take precautions to control runoff and reduce nutrient pollution. |
| ROWLAND | • Additional monitoring is needed to better characterize current lake conditions and identify future changes.<br>• The extensive wetlands surrounding the lake should be protected to filter pollution and provide fish and wildlife habitat.<br>• The golf course should be managed to limit nutrient runoff. |
| RUGGS | • Monitoring should focus on nutrients, algae, and aquatic plants and on identifying the sources of sediment that is filling the lake.<br>• A bathymetric map and an aquatic plant survey should be completed to establish baseline conditions and begin to track changes. |
| SERENE | • No large-scale efforts should be made to control aquatic plants (except for the purple loosestrife).<br>• Resident waterfowl numbers should be reduced. |
| SHOECRAFT | • Milfoil control surveys should continue to ensure that these plants do not re-infest the lake. |
| SPRING | • A bathymetric map and an aquatic plant survey should be completed to establish baseline conditions.<br>• No large-scale efforts should be made to control aquatic plants. |
| STEVENS | • Detailed monitoring of the lake should continue in order to quantify the effects of the aeration system and identify possible causes of reduced water clarity.<br>• Resident waterfowl numbers should be reduced. |
| STICKNEY | • The extensive wetlands around the west side of the lake should be preserved to protect the lake from the impacts of development within its large watershed.<br>• Resident waterfowl numbers should be reduced. |
| STORM | • (See general recommendations for all lakes.) |
| SUNDAY | • Monitoring should focus on nutrients, algae, and aquatic plants.<br>• No large-scale efforts should be made to control aquatic plants without carefully evaluating the alternatives and potential impacts.<br>• Resident waterfowl numbers should be reduced. |
| WAGNER | • (See general recommendations for all lakes.) |

## *Criteria for Future Actions*

The recommendations listed in Table 11 do not indicate who should be responsible for funding and implementing the actions. Clearly, all the citizens of Snohomish County benefit from maintaining and protecting the health of the public access lakes. Therefore, the general public, through local and state government agencies, has some responsibility to be involved in actions at these lakes. However, adequate funding to address lake health problems is not currently available.

The following criteria are recommended to guide the allocation of scarce public funds for lake protection and restoration:

1. Prevention is preferable to restoration; therefore, actions to prevent or limit damage to lakes should have high priority.
2. However, where feasible, lakes which are "at risk" should be improved and "impaired" lakes should be restored to healthy conditions.
3. Lakes with the most severe problems and with significant declining water quality trends should have priority.
4. Restoration actions should be based on sound science with adequate data to support understanding of existing problems and to predict lake responses to restoration measures.
5. Control of non-native invasive species should have priority over management of native species.
6. Lakes that are the most heavily used by the public should receive priority.
7. Lakes with strong commitment from local residents should have priority.

## *Steps That All Citizens Can Take*

The responsibility for lake protection does not rest solely with public agencies, however. In fact, citizens working individually or in organized groups can have the most impact on lake health. The following recommendations are simple steps that citizens can take to address many of the main causes of lake problems.

- Learn about lake ecology and lake health;
- Use lawn and garden fertilizers sparingly; test the soil first; choose low or no phosphorus fertilizers;
- Retain or plant native vegetation adjacent to the water to protect the shoreline and filter pollution;
- Infiltrate or filter the runoff from rooftops, driveways, and patios rather than piping it to the lake;
- Cover or mulch bare soil areas;
- Use pesticides, herbicides, and household chemicals sparingly and never near the water;
- Maintain septic systems regularly—have them inspected every two years and pumped when needed;
- Conserve water both inside and outside;
- Learn to identify non-native invasive aquatic plants and animals; check boats and trailers for invaders; never empty an aquarium into a lake;
- Clean up pet wastes and keep livestock away from the lake shore;
- Do not feed geese or ducks; and
- Join with neighbors or the local property owners' association to work together to protect the lake.

# *Methods and Sources*

This report presents results of lake monitoring conducted from 1992 through 2002 as part of the Snohomish County Lake Management Program. Both citizen volunteer monitors and SWM staff collected the data. In addition, the report incorporates lake data from several other historical and recent sources.

## *Volunteer Monitoring*

The volunteer monitoring program began in 1992 with volunteers at 14 lakes. Since that time, the number of lakes monitored by volunteers has averaged about 25, with a high of 28 lakes. Most of the lakes have public access, although seven are private lakes. Some volunteers have continued with the program for all eleven years. At other lakes, there have been several different volunteers through the years.

SWM staff trained each new volunteer at the lake monitoring site and provided necessary equipment, forms, and the "Snohomish County Lake Management Program Monitoring Manual" (Appendix A in Tetra Tech, 2003). In addition, SWM staff conducted a training workshop for new and returning volunteers each May before the start of the monitoring season.

There are two levels of volunteer lake monitoring—basic and detailed.

♦ Basic Monitoring—All volunteers performed basic monitoring by conducting measurements and observations of their lake every two weeks from mid-May through October each year. (Some volunteers were not able to conduct monitoring every two weeks. The number of completed monitoring events during any one season ranged from two to as many as twenty for some lakes.) The basic monitoring measurements and observations were conducted at the deepest point in the lake, preferably between 10 a.m. and 2 p.m.

Volunteers performing basic monitoring measured water clarity, surface water temperature, and lake level. To measure water clarity, volunteers lowered a black and white Secchi disk into the lake and measured the exact point at which the disk disappeared from sight. Readings were recorded to the nearest 0.1 meter. Volunteers used armored LaMotte thermometers accurate to 0.5° C to measure surface water temperatures at 0.2 meters depth. Lake levels were determined by measuring down to the water surface from a fixed point near the lake shore. In addition to these measurements, volunteers recorded observations about the apparent amount of algae in the water, the abundance of aquatic plants, water color, the weather, and any other unusual conditions at or around the lake. The "Snohomish County Lake Management Program Monitoring Manual" contains complete protocols for the basic lake monitoring.

♦ Detailed Monitoring—Some volunteers also conducted detailed monitoring in addition to the basic monitoring. Detailed monitoring includes measuring dissolved oxygen and temperature profiles once per month from May to October and collectiing total phosphorus samples for laboratory analysis monthly from June through September. Monthly chlorophyll *a* and phaeophytin samples were added in 2002. All detailed monitoring was conducted while anchored at the deepest point in the lake.

To measure dissolved oxygen concentrations, volunteers collected water samples using LaMotte water bottles or Van Dorn-type vertical samplers. Samples were taken from 0.5 meters, 3 meters, 6 meters, and one meter above the bottom and analyzed for dissolved oxygen content using LaMotte dissolved oxygen titration kits. Volunteers measured water temperatures at one meter intervals down to 10 meters and then at two meter intervals to the lake bottom. Thermometers were placed inside the samplers and the water temperature read immediately after each water sample was brought to the surface.

Volunteers also used the samplers to collect water samples for lab analysis of total phosphorus and chlorophyll *a* during one weekend each month designated by SWM staff. Discrete samples were collected from both 1.0 meter deep and from approximately 1 meter above the bottom for total phosphorus, and from 1.0 meter deep for chlorophyll *a*. Volunteers refrigerated the samples and held them for pick-up by SWM staff early the following week.

The "Snohomish County Lake Management Program Monitoring Manual" contains complete protocols (including duplicate sampling and other quality control procedures) for the detailed lake monitoring. Figure 12 is a copy of the lake monitoring form used by volunteers doing detailed monitoring. The forms for basic monitoring are exactly the same but without spaces for temperature and dissolved oxygen profile data.

As of mid-2002, all raw data collected by volunteer monitors may be found online at the Snohomish County SWM website: www.co.snohomish.wa.us/publicwk/swm/.

## FIGURE 12. VOLUNTEER MONITORING FORM (DETAILED)

SNOHOMISH COUNTY VOLUNTEER LAKE MONITORING PROJECT

Lake Name: ______________________________ Monitoring Date: ______________

Names of Volunteers: ______________________________ Monitoring Time: ______________

MEASUREMENTS:

**Secchi Disk Depth (to nearest 0.1 meter):**

1st Secchi Reading ________ meters

2nd Secchi Reading ________ meters

Did the Secchi disk ❑ hit bottom? ❑ enter weeds?

(If the Secchi disk hits bottom or enters weeds, please take another set of Secchi readings at another nearby location.)

Air Temperature ________ degrees C

Near-Surface Water Temperature ________ degrees C

Lake Level ________ inches (distance from water to marker)

| Depth (meters) | Temperature (degrees C) | Dissolved Oxygen (mg/L) | Depth |
|---|---|---|---|
| 1 | | | |
| 2 | ______ | A _____ | Surface |
| 3 | ______ | | |
| 4 | ______ | B _____ | 3 meters |
| 5 | ______ | | |
| 6 | ______ | C _____ | 6 meters |
| 7 | ______ | | |
| 8 | ______ | D _____ | 1 meter above bottom |
| 9 | ______ | | |
| 10 | ______ | | |
| 12 | ______ | Duplicate Dissolved Oxygen | |
| 14 | ______ | | |
| 16 | ______ | ____ meters | ____ mg/L |
| 18 | ______ | | |
| 20 | ______ | Lake Depth | ____ meters |

OBSERVATIONS:

(Please check any of the following that apply):

| | None | Slight | Moderate | Heavy |
|---|---|---|---|---|
| Algae in water | | | | |
| Algae Scum | | | | |
| Aquatic Plants | | | | |
| Odor | | | | |
| Odor (circle if any) | fishy | rotten egg | musty | septic-like |

Approximate number of ducks/geese on the lake: __________

Percent Cloud Cover:
❑ 0% ❑ 10% ❑ 25% ❑ 50% ❑ 75% ❑ 90% ❑ 100%

Rain within last 2 days:
❑ none ❑ trace ❑ light ❑ moderate ❑ heavy

Current Wind Conditions:
❑ calm ❑ light ❑ breezy ❑ strong ❑ gusty

Water Color:
❑ light green ❑ greenish-brown ❑ black
❑ moderately green ❑ light brown ❑ milky green
❑ pea-soup green ❑ dark brown ❑ clear
❑ other ______________________________

Other Lake and Watershed Conditions: (e.g. oil, garbage, etc)
(Please describe:)______________________________
______________________________
______________________________
______________________________.

♦ Volunteer Monitors—Many dedicated citizen volunteers have participated in the Snohomish County lake monitoring program through the years. Without the efforts of volunteer monitors it would not have been possible to collect adequate data to evaluate the condition of most lakes.

| Table 12 | Citizen Volunteer Lake Monitors |
|---|---|
| ARMSTRONG | Brian Seguin, LeAnn Anderson, Eric Nordstrom, Kenneth Black |
| BEECHER | Nan McGuire |
| BLACKMAN | Julie Callebert, Mary Keppler |
| BRYANT | Josh Shalan |
| CASSIDY | John Naples, Glenn Phipps |
| CHAIN | Brian Vanover, Laura Reed, Travis Powell, Michael Manson |
| COCHRAN | Don Foltz, John Ruhnke, Mike Durick |
| CRABAPPLE | Deb Kocher, Mary Smith |
| ECHO | Gerald Dickson, Bernice Engel |
| FLOWING | Glen & Sherry Smith, Bob & Karen Birdseye, John Vardenega |
| GOODWIN | Karen & Mark Thompson, Steve Nelson, Michael Brown, Wally Sullivan |
| HOWARD | Suzanne Cannon, Bill Crane, Tim Schmidt, Trudi Adams |
| KAYAK | Pat & Bill Waldrop, Terrie Foote |
| KETCHUM | Bob Arnold, Jane Hilleary, Anton Ehinger |
| KI | Pam & Scott Seiber, Kathy Nairn, Idell Nieforth |
| LOMA | Bernie & Elaine Fleming, Tom & Emily Smith, Karl Ostrom |
| LOST | Guy Borgen, Gwen DeFrank, Anita Robinson |
| MARTHA N. | Nancy Dean, Joan Lucas |
| MARTHA S. | Tom Eble, John Guentz, John Moore, Kathy Pike, Keith Johnson |
| MEADOW | Doug & Robin Schaffer |
| NINA | Kerry Mauer, Joan & Paul Perry, Fred Carpenter, Terry Larsen |
| PANTHER | Ken Chisholm, Charles Gilbert, Jeff Onstad |
| RILEY | Weldon Sorgen, Sonya & Liv Engelsen, Peggy Oard, Jeff Aylor |
| ROESIGER | Elsie Sorgenfrei, Robert & Joanne Miller |
| ROWLAND | Gerry & Vera Miller |
| RUGGS | Fred & Alita Jones |
| SERENE | Lennie Rae Cooke, Fred Murray, Gary Landvatter, Glen Shadduck |
| SHOECRAFT | Fred Dockendorf |
| SPRING | Jack Halbert |
| STICKNEY | Shirley, Dennis, Sean & Casey Nicholson, Doug Elrod, Gary Weston |
| STORM | Tom Piekarski |
| SUNDAY | Lee & Dee Vega, Damon & Leslie Darley, Noel Higa |
| WAGNER | Peter Mellinger, Jim Jaskowiak |

### *SWM Staff Monitoring*

SWM staff also conducted monitoring of 25 high priority public access lakes from 1996 through 2002. During 1996 and 1997, the monitoring occurred twice during the summer. Since 1998, the monitoring has been performed monthly from June through September. Many of the lakes monitored by SWM staff were the same as those monitored by volunteers. Where volunteers performed detailed monitoring, SWM staff only monitored as necessary to cover months missed by the volunteers or to provide checks of volunteer data.

SWM staff measured water clarity and made algae, color, weather and other observations exactly as the volunteer monitors. In addition, SWM staff took dissolved oxygen, temperature, pH, and conductivity profiles at every meter of depth at the deepest point of the lakes using a Hydrolab Datasonde 3. On occasion, dissolved oxygen and temperature profiles were taken with a YSI meter. SWM staff also collected discrete samples for total phosphorus analysis at 1.0 meters and approximately one meter above the bottom and discrete samples for chlorophyll *a*/phaeophytin at 1.0 meters. All samples collected by SWM staff and detailed volunteers since 1996 were analyzed at the laboratory of Aquatic Research, Inc. in Seattle, Washington using the SM18 4500PF method for total phosphorus and SM18 10200H for chlorophyll *a* and phaeophytin. Monitoring was conducted in accordance with the Quality Assurance Plan Snohomish County Lake Management Program (Tetra Tech, revised in 2003). Duplicate field samples were collected and blind samples submitted to the lab. All raw data collected by SWM staff may be found online at the Snohomish County SWM website (www.co.snohomish.wa.us/publicwk/swm/).

SWM staff performed visual surveys of aquatic plants at each public access lake one or more years since 1994. Plants were observed from a boat using a viewscope, and samples were retrieved by rake for identification. The locations and estimated densities of aquatic plants were then mapped for each lake. SWM staff also conducted surveys of shoreline development and modifications for most lakes.

### *Other Data Sources*

In addition to lake data collected by volunteer monitors and SWM staff since 1992, this report also incorporates data from several other published and unpublished sources. The individual lake reports include summaries of the data from these other sources. Some of these data are also used in the county-wide comparisons of lake conditions in cases where the parameters and methods were comparable to volunteer and SWM-collected data.

- Department of Ecology Lake Assessment Program—The Washington State Department of Ecology conducted a lake water quality assessment program from 1989 through 2000. Data were collected by Ecology staff and by citizen volunteers. In the early 1990s, Ecology monitoring occurred at as many as 11 lakes in Snohomish County; but by the late 1990s, only four lakes were being monitored. Ecology and SWM staff made efforts to share data and avoid having volunteer monitors at the same lakes. The Snohomish County basic monitoring protocols were patterned closely after Ecology monitoring methods so that the data would be comparable. This report uses both published and unpublished Ecology lake water quality assessment data (including Brower and Kendra, 1990; Coots, 1991; Rector, 1994; Rector, 1996; Rector and Hallock, 1991; Smith and Rector, 1997; Smith, Parsons and Hallock, 2000).

- Lake Stevens Drainage Improvement District #8—Since 1997, Drainage Improvement District #8 has collected water quality data year round at Lake Stevens and, on occasion, at Lake Cassidy (Gray & Osborne, 1998, 1999, 2000, 2001, and 2002). SWM staff regularly coordinate with the District on monitoring methods and parameters for Lake Stevens.

♦ Historical Sources—Limited historical water quality information is available for some lakes. The State of Washington conducted one-day reconnaissance sampling at numerous Snohomish County lakes in the early 1970s, including 26 lakes covered in this State of the Lakes report (Bortleson et. al., 1976). The State also monitored four lakes in the Seven Lakes area on several dates in 1973 (McConnell et. al., 1976). In 1981, the State again conducted one-day reconnaissance sampling of 15 Snohomish County lakes, including 10 of the lakes tested in the 1970s (Sumioka and Dion, 1985).

During the 1980s and early 1990s, Snohomish County, Washington State, and other local agencies conducted detailed Phase I diagnostic studies on several lakes with particular problems and strong public interest. Studies were completed for the Seven Lakes (Entranco, 1986), Lake Stevens (Reid, Middleton, & Associates, 1983 and KCM, 1987), Lake Roesiger (KCM, 1989), Martha Lake (Entranco, 1991), Blackman Lake (KCM, 1994), and Lake Ketchum (Entranco, 1997). These detailed studies include lake water quality data collected intensively for at least one year on the subject lakes.

### *Data Management and Analysis*

The lake field data collected by citizen volunteers and by SWM staff were screened soon after they were received to determine if the data met the standards of the Lake Management Program. Likewise, all water quality data received from the lab were evaluated to be sure that the data met the data quality objectives. With limited exceptions, all the field data collected by volunteers and staff were acceptable for use in the characterizations of lake conditions contained in this report. Unfortunately, none of the nutrient data (phosphorus and nitrogen series) collected during the summers of 1994 and 1995 met the data quality objectives because of laboratory problems. These data were discarded. All the nutrient samples collected from 1996 through 2002 were analyzed at another laboratory—Aquatic Research, Inc.—and the results were acceptable.

Soon after screening each set of data, SWM staff entered all the data into a network database for archiving and analysis. Each year's data were displayed in simple tables. Secchi depth (water clarity), temperature, and dissolved oxygen readings were analyzed by simple graphing techniques. Further analyses were performed for water clarity and total phosphorus data because these data are numerous and the parameters are key for determining lake condition and trophic status.

The first step was calculating averages (means) as a way to characterize the central tendency of the data sets. May through October water clarity data for each year were combined into a "summer" average because this is the period of stratification for most lakes. These warm months of the year are also the period when the lakes are most heavily used and when algal and aquatic plant growth or other problems cause the most concerns. Averages were calculated for each "summer," even if only two measurements were available, because water clarity data for most lakes are relatively consistent and because the data provide at least a limited picture of lake conditions for that summer. However, analyses and conclusions based on larger data sets will always have more power and validity that those based on a few measurements.

Another problem with having only a few measurements during a summer is that one or more measurements taken near the same time might bias the average toward the lake conditions of that time. (For example, two Secchi depth measurements within a week in August would bias the summer average if there were only one other measurement, perhaps taken in June, during that summer.) To address this problem, the summer water clarity averages were calculated based on a specific algorithm. First, multiple measurements taken on the same sampling trip (even if by different persons) were averaged to give a value for that day. Second, measurements (or “daily” values) taken five days or less apart were averaged to give a “weekly” value. (This interval combines one or more measurements taken near the same time, but does not group measurements if a monitor was taking readings each weekend.) Then, all weekly values from May through October were averaged to give a “summer” average, which is reported in the individual lake reports and in lake-to-lake comparisons. The long-term water clarity averages used in the lake-to-lake comparisons are the averages of each summer average over the period of record. Minimum and maximum water clarity values reported for each summer refer to the “daily” values recorded for the lake.

Total phosphorus measurements were also averaged to give a “summer” average for each year. However, total phosphorus samples were not closely spaced in time, so daily values and weekly averages were not calculated. Also, most phosphorus measurements were taken from June through September. Only total phosphorus data from samples collected at discrete depths (near the surface and near the lake bottom) were used in calculating summer and long-term averages. Composite samples—where portions of the sample come from more than one depth—are not directly comparable to discrete samples, so they were not included in the averages, but the results are summarized under Other Data in the individual lake reports. (The one exception to this procedure is the handling of total phosphorus data from Lake Roesiger. Composite sampling data are included in the averages because nearly all the phosphorus data for this lake are from composite samples. Care should be taken in comparing total phosphorus data and averages from Lake Roesiger with results from other lakes.)

The summer averages for water clarity and total phosphorus were also analyzed for apparent trends over time. Using Kendall’s tau as a measure of trends revealed that several lakes are experiencing trends toward lower or higher water clarity. Most lakes have long enough water clarity records to be able to evaluate trends in this manner. However, the total phosphorus records were not yet long enough (generally 7 years) to discern any apparent trends in most cases.

# Glossary

Acre-Foot – The volume of water that would cover an area of one acre to a depth of one foot; equivalent to 43,560 cubic feet, or 325,850 gallons of water.

Algae – Small aquatic plants occurring as single cells, multi-celled colonies, or filaments. Algae contain chlorophyll and form the base of the food web in lakes.

Algal Bloom – A heavy growth of algae in a lake resulting from high nutrient concentrations and favorable weather conditions.

Alkalinity – The capacity of water to neutralize acids; the buffering capacity of water to resist a change in pH.

Anoxia – A condition where no dissolved oxygen remains in the water, usually occurring near the bottom in stratified lakes which have large amounts of decomposing organic matter in the lake sediments.

Bathymetric Map – A map showing the depth contours of the bottom of a lake.

Benthic – Referring to the bottom of a lake, which supports a community of small organisms that live on or in the sediment and are important in decomposing organic matter.

Blue-green Algae – One of the main groups of algae that is responsible for many of the unpleasant algal blooms in lakes. More properly known as Cyanobacteria, blue-green algae are physically like bacteria, but function more like plants.

Chlorophyll *a* – A type of green pigment found in all algae, which plays an essential role in photosynthesis.

Conductivity –A measure of the capacity of water to conduct an electrical current; an indicator of the amount of dissolved ions in the water.

Dissolved Oxygen – The oxygen gas that is dissolved in water and available for use by microorganisms and fish.

Emergent – Aquatic plants that have their roots and lower stems in the water while the upper portions of the plants stand above the water surface.

Epilimnion – The uppermost, warm, well-mixed layer of water in a lake during stratification.

Eutrophic – Description of a lake that is rich in nutrients and highly productive of plants and algae.

Eutrophication – The natural process of lake enrichment caused by accumulating nutrients and sediment that results in increased growth of plants and algae, reduced water clarity, and lake filling. Human activities that add nutrients and sediment to a lake can greatly accelerate this process.

Food Web – The system of feeding interactions occurring among the organisms in a lake.

Hypolimnion – The deep, cooler layer of water in a lake isolated from surface influences during stratification.

Limnology – The study of fresh waters, especially lakes.

Loading (External and Internal) – The total amount of nutrients (could also refer to sediment and other materials) introduced into the water of a lake; external loading comes from sources outside the lake, such as streams, direct runoff, pipes, ground water, and the air; internal loading comes from sources within the lake itself, such as recycling from the bottom sediments and release from decaying plants and animals.

Macrophytes – Another term for aquatic plants, either rooted or floating, that grow in lakes.

Mesotrophic – Description of a lake that contains moderate levels of nutrients and produces moderate amounts of plants and algae.

Metalimnion – The layer of lake water between the epilimnion and hypolimnion during stratification, where water temperature and density change rapidly with depth.

Nutrient – Any chemical element, ion, or compound that is essential for life and growth, such as nitrogen, phosphorus, carbon, and oxygen.

Oligotrophic – Description of a lake that contains few nutrients and produces little algae and aquatic plants.

Periphyton – Algae that grow attached to underwater surfaces, such as rocks, pilings, and aquatic plants.

pH – A measure of the concentration of hydrogen ions in a substance such as water. Values go from 0 to 14; a pH of 7 is neutral; values below 7 are increasingly more acidic, while values greater than 7 are increasingly more basic (alkaline). Each increment represents a ten-fold change in acidity.

Phosphorus – One of the nutrients essential for growth. Phosphorus availability often limits plant and algal growth in a lake because it is the nutrient in shortest supply.

Photosynthesis – The process by which chlorophyll-containing cells in plants and algae produce organic matter from carbon dioxide and water using light energy.

Phytoplankton – Microscopic algae that float freely in open water.

Productivity – The rate at which aquatic plants and algae create organic matter through photosynthesis.

Secchi Disk – A black and white disk (usually 8 inches in diameter) used to measure light transparency (water clarity) in a lake.

Stratification – The layering of lake water caused by differences in temperature and density. Stratification is typical of deeper lakes during the warm summer months

Submersed – Aquatic plants that grow entirely, or almost entirely, under the water.

Trophic State – The degree of eutrophication of a lake. Lakes may be classified as oligotrophic, mesotrophic, or eutrophic.

Turnover – The mixing of lake water from top to bottom that usually occurs in the fall and is caused by the cooling of surface waters and wind energy.

Watershed – The land area that drains to or contributes water to a lake or other waterbody.

Zooplankton – Microscopic animals that float in open water and feed on bacteria, algae, and organic matter and may be consumed by fish.

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