WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

# Lake Water Quality Assessment Project

## 1989

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## EXECUTIVE SUMMARY

In 1989, Ecology added a statewide lake monitoring program to its ambient water quality monitoring network. The goals of the lake monitoring program are to identify lakes that are exhibiting water quality problems, to assess significant publicly-owned lakes by estimating the trophic status of monitored lakes, and to promote public awareness of lake ecology and protection. This program is coordinated through Ecology's Environmental Investigations and Laboratory Services Program, and in 1989 consisted of three elements: volunteer lake monitoring, a conventional parameter water quality survey of a subset of the volunteer-monitored lakes, and a toxic contaminant survey of fish tissues and sediments from nine lakes. This report presents results from the first two elements.

The greatest emphasis of the overall program is with the volunteer lake monitoring project. In 1989, volunteers participating in Washington's Citizen Lake Monitoring Project collected data from 49 lakes throughout Washington state. Each volunteer was asked to measure Secchi disk transparency and surface water temperatures at the deep water station of their lakes approximately every two weeks from mid-May through mid-October, 1989. In addition, most of the volunteers completed a survey on lake and watershed uses. Lakes included in the program cover at least 30 acres, have a public access, and most importantly, had a willing volunteer who collected data from his or her own boat. Most of the lakes monitored by volunteers are located within the Puget Sound drainage and in the northeast corner of the State (particularly Spokane and Stevens Counties).

Secchi disk transparency readings collected by volunteers ranged from 2 feet (Duck Lake, Grays Harbor County) to 78 feet (Crescent Lake, Clallam County), although typical clarity readings for lakes were within a range of 12 to 22 feet. Using Carlson's (1977) trophic state index to evaluate volunteer-collected Secchi data, of the 48 lakes monitored, 22 were oligotrophic or oligo-mesotrophic, 19 were mesotrophic or meso-eutrophic, and 7 were eutrophic. Each volunteer was given a summary report of the data they collected from their lake during 1989. These individual lake summaries are included in this report.

To supplement data collected by the volunteers, during June and September, 1989, Ecology staff surveyed 25 lakes that were being monitored by volunteers. One site at each lake was sampled; for most of the surveyed lakes, sampling occurred over the deepest site. Profile data were collected using a multi-parameter profiling instrument which measures temperature, pH, dissolved oxygen, and specific conductance. Water samples from the hypolimnion and epilimnion were analyzed for total phosphorus, ortho-phosphorus, total nitrogen, nitrate+nitrite nitrogen, and ammonia nitrogen. In addition, epilimnion samples were collected for turbidity and chlorophyll *a* analysis, and a surface fecal coliform bacteria sample was collected and analyzed. Based on the profile and nutrient data collected by Ecology from the 25 lakes, 10 of the lakes were evaluated as oligotrophic, eight as mesotrophic, and seven as eutrophic.

The methods and discussion for the Ecology-collected survey data are reported in Brower and Kendra (1990). Data from the Ecology survey are included in the individual lake summaries in this report. However, because some of the volunteers on the lakes surveyed by Ecology dropped out of the program, of the 25 lakes surveyed by Ecology, data from only 20 lakes are included in this report.

The validity of using volunteer-collected Secchi data to estimate trophic states was evaluated by comparing data collected by the volunteers with data collected by Ecology in 1989. These comparisons were favorable enough to conclude that volunteer-collected Secchi data are adequate to roughly assign trophic states for Washington lakes.

Data from the 20 lakes sampled both by volunteers and by Ecology were analyzed to evaluate the relationships between Secchi disk transparency, total phosphorus and chlorophyll *a*, and to identify monitored lakes that did not fit the observed relationships. The Secchi:phosphorus:chlorophyll relationships from the 1989 Washington lakes data were similar to the relationships found by Carlson (1977). Several lakes did not fit the observed relationships between the trophic parameters.

Because 1989 was the first year of the lake monitoring program, there were not sufficient data to adequately evaluate water quality trends within particular lakes. A comparison of data from this study to data collected in the 1970s (Bortleson *et al.*, 1976a, 1976b, 1976c, 1976d; Dion *et al.*, 1976a, 1976b, 1976c) and in 1981 (Sumioka and Dion, 1985), show that roughly half the volunteer-monitored lakes were more eutrophic, and roughly half the lakes were more oligotrophic. Because of climatic effects and sampling variability, however, trends within particular lakes should not be inferred.

Ecoregion (Omernik and Gallant, 1986) analysis of monitored lakes showed that different physical characteristics of the monitored lakes, rather than anthropogenic differences within ecoregions appeared to explain why some lakes had an unusual trophic state index (Secchi) when compared to other lakes in the same ecoregion. For both water quality trend analysis and ecoregion analysis, additional data will be needed to complete a meaningful evaluation.

The data gathered through this monitoring program have a number of uses, in addition to creating a baseline and establishing a dataset which may eventually be used to assess water quality trends. The 1989 lakes data were used to assess lakes for the State's surface water quality assessment as required under Section 305(b) of the Clean Water Act (Ecology, 1990). Also, the data were used, along with other factors, to prioritize the monitored lakes according to need for management. The ranking scheme, though still rough, appears to be in general agreement with past management funding decisions.

Because the number of volunteer lake monitoring programs is increasing, this report also discusses some of the administrative aspects of Washington's volunteer monitoring program, including development and funding, and a discussion of the successes and failures of the first year of the program.

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# INTRODUCTION

## Background

Although programs for monitoring streams and marine waters in Washington have been ongoing for many years, there has been no statewide program for assessing the water quality of Washington's lakes. Lake monitoring information has a number of uses:

* Assessing lakes. A statewide assessment of lake water is required under section 305(b) of the Clean Water Act.

* Indicating overall watershed health. Non-point source (NPS) pollution in particular (primarily sediment and nutrients) is a growing problem and is difficult to measure. A change in lake quality can be an indicator of NPS pollution in the watershed, and may identify lakes where more intensive study is needed. Lakes, as the "sump" at the bottom of a watershed, can indicate watershed health better than streams.

* Indicating early stages of cultural eutrophication and sedimentation. When a problem is detected early, prevention management (for example, source control measures, watershed management, inspection and maintenance of domestic wastewater systems, education of lake users) may protect the lake from further degradation and may avert the need for lake restoration. Restoration is often far more difficult and expensive than prevention management.

* Updating water quality standards. Many years of monitoring data will be needed before lake quality standards for trophic parameters (i.e., total phosphorus) can be developed.

* Prioritizing lakes for restoration. Lake monitoring information can be useful in prioritizing lakes according to restoration needs. Ecology's Water Quality Financial Assistance Program may use monitoring information as a component in selecting grant recipients.

* Establishing a baseline. Eutrophication is part of a natural aging process. A baseline of information is needed to begin to make the distinction between naturally eutrophic and culturally eutrophic lakes. Uses and management may depend on the history of the lake. For example, a naturally eutrophic lake may not be good for swimming; however, it may have other benefits, such as wetland habitat, that need to be protected. Lake restoration (or management) that would destroy natural wetland areas is to be avoided.

Ecology does not have the resources to assess the approximately 8000 lakes in Washington. Not only is there a large number of lakes, but because of the seasonality of biological and chemical characteristics of lentic systems, sampling to assess water quality should, ideally, be conducted at regular intervals throughout the growing season. For these reasons, a thorough assessment of every lake is not possible. However, by using volunteers in conjunction with sampling by Ecology staff, more lakes can be assessed.

**Project Overview**

Washington's Lake Water Quality Assessment Project was established in early 1989 to assess the general water quality of significant, publicly-owned lakes in Washington. "Significant, publicly-owned" lakes are defined in Washington's "1990 Statewide Water Quality Assessment (305(b)) Report" to the Environmental Protection Agency (EPA) as follows:

> "those lakes, including impoundments which meet the definition of Lake Class in the State Water Quality Standards (a mean detention time of greater than fifteen days), which have an area of 20 acres or greater within the bounds of their ordinary high water mark, support or have the potential to support the fishable, swimmable goals of the Clean Water Act and are publicly owned or have a public access point; in addition to any other lakes specifically identified as significant by the Department of Ecology."

However, to be eligible for the project, a lake was required to cover at least 30 acres and have both public access and a willing volunteer to collect monitoring data. Ecology intends to assess as many of Washington's lakes that meet the above definition as funds and the availability of volunteers allow. Because of the large number of lakes involved, and our reliance on volunteers to collect data, no formal schedule for assessing significant publicly-owned lakes has been developed.

There were three major tasks to the 1989 Lake Water Quality Assessment Project. The first was the development of a potentially long-term monitoring program using volunteers. This task is described under the Methods section of this report. The second task was a conventional parameter survey of 25 of the lakes scheduled to be monitored by volunteers. Ecology staff collected early and late growing season physical/chemical profile data and epilimnion and hypolimnion composites samples for nutrient and chlorophyll analyses at one station on each lake. Results of this task are discussed in the individual lake assessments section and presented in more detail in Brower and Kendra (1990). The third task was a toxics survey, designed to screen a small number of lakes for chemical contaminants. Ecology staff collected sportfish tissue and sediment samples from ten lakes for analysis for EPA priority pollutants, herbicides, and organophosphorus pesticides. Results of this task are discussed in the individual lake assessments section and presented in more detail in Johnson and Norton (1990).

Washington's Lake Water Quality Assessment Project was funded in 1989 by a Lake Water Quality Assessment (Clean Lakes) Grant from EPA. Additional funding from a Water Quality Management Planning (205(j)) grant continued the project until June 30, 1991. Funds have been committed from Ecology and EPA beginning July, 1991, to establish lake monitoring as a permanent part of Ecology's ambient water quality monitoring program. Also, a separate 205(j) grant will fund special projects for the program during 1991.

**Project Objectives**

The goal of this project was to assess the current water quality status of publicly-owned lakes in Washington and to develop and implement a potentially long-term volunteer monitoring program. Specific objectives were as follows:

1) Determine the trophic state of monitored lakes.

2) Assess water quality in lakes not evaluated in the last five years and determine the degree to which beneficial uses are supported.

3) Promote public awareness of lake processes and lake protection measures and foster a conservation ethic.

4) Separate lakes into ecoregions (Omernik and Gallant 1986) and identify anomalies within these regions for further investigation.

5) Determine trends once a sufficiently long period of record is established.

6) Establish a data set for analysis and dissemination.

Although most of these objectives can be addressed provisionally after a single year of data-collection, all can be met with more confidence when equipped with several years data from a continuing program.

**Lake Monitoring in Other States**

Washington's Citizen Lake Monitoring Project was patterned after other volunteer lake monitoring programs, such as those in Wisconsin, Illinois, Minnesota, Massachusetts, and Idaho, and the Municipality of Metropolitan Seattle (METRO) in King County, Washington. These programs are all similar in that they use volunteers to collect Secchi disk transparency data approximately every two weeks during summer months. However, each program differs somewhat with respect to the parameters measured by the volunteers, the approach to data analysis and presentation, or the extent of public outreach offered.

In addition to Secchi disk transparency data, most of the other volunteer lake monitoring programs have the volunteers measure surface water temperature. Others also have the volunteers measuring dissolved oxygen, pH, or sampling for chlorophyll and/or nutrients. State programs such as Wisconsin have the volunteers mail in the water samples, whereas in King County, METRO staff go to each volunteer's house twice each month to pick up water samples and drop off new sample bottles. Also, programs in New Hampshire, Florida, and Wisconsin provide equipment (such as pH meters, dissolved oxygen kits, or chlorophyll *a* filtering apparatus) to volunteers.

Analysis and presentation of data collected for volunteer lake monitoring programs generally consist of a summary narrative, and a simplified method for interpreting data for the volunteers. For example, Wisconsin assigns the transparency data into categories of "excellent", "very good", ""good", "fair", "poor", and "very poor". Most of the other programs also use graphs to show the temporal variations of the Secchi disk data. METRO uses a point system to determine the overall trophic state of a monitored lake based on Secchi disk transparency and concentrations of total phosphorus and chlorophyll *a*. METRO also uses detailed graphs to illustrate how the ranges and average values for selected parameters compare with data collected during previous years, and how the data compare to average values from the other monitored lakes. Some programs, such as Wisconsin's, rank the lakes participating in the program in order of best to worst transparency. Illinois' program uses Carlson's (1977) Trophic State Index to estimate trophic states from volunteer-collected data.

**Washington Lake Monitoring Program**

Washington's Volunteer Lake Monitoring Program incorporates selected components from these other programs. Individual touches added to the Washington program included a quality assurance component (e.g., having the volunteers collect repeat readings), making (rather than buying) Secchi disks, and identifying macrophytes and algae samples sent in by the volunteers. Presently Ecology has 1.0 FTE for project coordination and implementation, and 0.2 FTE for overseeing the program. Because of the geographic scope of the project, the number of lakes monitored and the types of parameters measured must be limited to allow for adequate supervision of and communications with the volunteers.

Based on recommendations from other state program managers, Washington's Lake Monitoring Program started with few monitoring parameters and relatively few lakes. We intend to expand the program after working out the inevitable problems. Appendix B discusses some the of the lessons learned by the coordinators of Washington's program during the first year of program implementation.

## METHODS

**Data Collection**

Volunteer Monitoring

Volunteers measured Secchi disk transparency and surface water temperatures approximately every two weeks from mid-May through mid-October, 1989, preferably between 10 a.m. and 2 p.m. Each volunteer used their own boat to get to their monitoring site. At most lakes the site was located at the deepest part of the lake. After anchoring at their sampling site, the volunteers measured water clarity by leaning over the side of their boat, lowering a 20 cm diameter limological style Secchi disk from the shady side of the boat (method for making the disks is described in Appendix C) until it was no longer visible, and then slowly raising the disk until it was just barely visible. This depth was then read from the line attached to the Secchi disk (these are marked at one-foot intervals) and recorded to the nearest 1/4 foot. The procedure was repeated during each sampling trip so that consistency between readings could be evaluated by Ecology staff (see Quality Assurance Section). If the Secchi disk hit the bottom of the lake and was still visible, or was obscured by macrophyte growth, this was indicated on the data reporting sheet.

Surface water temperatures were measured using red alcohol BCR pocket thermometers. The thermometers are marked in 1° increments, and can measure a range of 35 to 50°C. The thermometers were completely emersed about 1 foot below the water surface until the temperature equilibrated, and the temperature was quickly read and recorded. The volunteers were encouraged to attach a string to the thermometers and to wrap the string around their wrists, in order to reduce the chance of dropping the thermometers into the water. Some of the volunteers attached a bobber to the string near the thermometer, and then tied the other end of the string to their boat. This freed their hands and allowed the temperature to equilibrate while the Secchi readings were being taken.

The data reporting sheets had areas for describing the weather and water color (Appendix A). The volunteers marked which option on the sheets most closely described the weather condition. Field observations were recorded by some of the volunteers in the given space on the data reporting sheet.

Depth was measured by some of the volunteers who either lowered the Secchi disk to the bottom of their lake, or used a depth sounder if one was available. Several volunteers from the program also supplied other information about their lakes on a regular basis, such as lake height (measured from a fixed place on a dock), lake depth, algae or macrophyte species present, air temperature, or daily precipitation.

The data reporting sheets were mailed to Ecology after each sampling trip. Self-addressed, stamped envelopes were provided by Ecology for mailing in each data sheet.

A questionnaire was mailed to all volunteers in August 1989 (Appendix D). This questionnaire consisted of 26 questions on lake and watershed uses. Each questionnaire also included a map of each lake so that areas of extensive plant and algae growth, stormwater discharges, wetlands, and residential development could be drawn on the map. The purpose of the questionnaire was to collect qualitative information about the water quality problems and the aquatic plant growth for each lake. Questionnaire results were also used to help interpret Secchi depth data. For example, water color helped to evaluate whether the Secchi depth readings were affected more by water color or suspended sediments than algae growth. Also, the increase in lakeshore residential development was evaluated by comparing the number of near shore homes reported by the volunteers with numbers reported during the 1970s in Washington Water Supply Bulletin 43: Reconnaissance Data on Selected Lakes in Washington (Bortleson *et al.*, 1976a, b, c, d; Dion *et al.*, 1976 a, b, c). The volunteers were encouraged to send in plant and algae samples for identification. Algae samples were sealed in small containers and frozen before mailing, and macrophyte samples were sealed in baggies, wrapped in newspaper, and refrigerated for mailing.

Ecology Surveys

Methods used during the Ecology conventional parameter and toxics surveys are described in the reports produced for each of the surveys: Water Quality Survey of 25 'Citizen-Volunteer' Lakes in Washington (Brower and Kendra, 1990) and 1989 Lakes and Reservoir Water Quality Assessment Program: Survey of Chemical Contaminants in Ten Washington Lakes (Johnson and Norton, 1990).

**Data Analysis**

Secchi Disk Theory

This project relies heavily on the relationship between the Secchi disk depth (the maximum distance light is perceived to travel through water, reflect off a black and white disk, and return to the eye of the observer) and measures of trophic state. This relationship is based on the effect algae biovolume has on water clarity. Because algal biovolume can be measured more directly as the plant pigment, chlorophyll, increases in chlorophyll concentrations (algal biovolume) are related to decreases in Secchi depth (water clarity). As a result, Secchi depth is considered an indirect measure of trophic state. Unfortunately, there are a number of factors besides chlorophyll which affect the Secchi depth. These factors can affect both the accuracy and precision of the Secchi reading itself (independent of conditions in the water that affect clarity), as well as the Secchi-trophic relationship.

Factors which affect the accuracy and precision of the Secchi reading were first investigated by Professor P. A. Secchi in 1865. He reported that the visibility of the disk is affected by its size and whiteness, the altitude of the sun, the height of the observer, reflection and refraction of light at the surface, the presence or absence of shadow over the disk, and the clearness of the sky (Tyler, 1968). As a result, variability in weather conditions, sun angle, etc., from day to day and variations in procedures and visual sensitivity between observers will impart scatter to the empirical relationship between Secchi depth and actual water transparency. Nevertheless, Secchi depth may be confidently replicated as long as close attention is paid to proper procedures. Tilzer (1988) reported variability between inexperienced students to be relatively small (standard deviation about the mean was $\pm$ 8%) when using a viewing tube. Although the volunteers in Washington's program did not use viewing tubes, we attempted to maximize the accuracy and precision of volunteer-collected Secchi disk readings by standardizing procedures.

Ideally for the development of a relationship between chlorophyll (as a measured trophic state) and Secchi depth, only the concentration of chlorophyll would affect absorption and scattering of light. However, the Secchi-trophic relationship is also affected by water color, non-algal turbidity, and the size and shape of particles (both algal and non-algal) in the water. These characteristics will affect how light is absorbed and scattered as it passes through the water, and can vary within and between lakes. The relationship between Secchi depth and chlorophyll has other problems as well. Lorenzen (1980) showed that Secchi depth is insensitive to changes in chlorophyll at high chlorophyll concentrations ($>40$ $\mu$g/L) and is fairly insensitive anytime non-chlorophyll light attenuation ($K_w$) is large. Furthermore, the effect of changes in non-chlorophyll light attenuation on Secchi depth becomes quite dramatic when chlorophyll drops below 10 or 15 $\mu$g/L. Lorenzen (1980) recommends determining non-chlorophyll light attenuation ($K_w$) for each lake in order to evaluate the sensitivity of Secchi depth to changes in chlorophyll.

Because we do not have enough data to calculate $K_w$ for each lake and therefore cannot account for the affect of abiotic factors on Secchi depth in the volunteer-monitored lakes, our analysis of the data assumes that non-algal light attenuation was either low or was constant both within lakes (for within-lake analyses) and between lakes (for between-lake comparisons). ($K_w$ is the intercept of the linear regression relating chlorophyll *a* and the inverse of the Secchi depth (Lorenzen, 1980)). In other words, we generally assume the differences between Secchi readings are due primarily to changes in chlorophyll. Of course, professional judgment was used to dismiss occasional Secchi readings based on the qualitative observation that the change in Secchi depth resulted from a change in non-algal turbidity (for example, after a runoff event).

We acknowledge that the Secchi-trophic relationship has its limitations and does not replace chemical data when specific lake water quality questions need to be answered. Carlson (1980) and others (Davies-Colley and Vant, 1988; Lorenzen, 1980; Megard, 1980) discuss the limitations of using the Secchi disk to assess trophic state, and how these problems apply to Carlson's (1977) Trophic State Index. Carlson recommends giving his Trophic State Index (TSI) based on chlorophyll *a* greater weight than that based on Secchi depth, but declares amazement at the degree at which the two indices do agree. In spite of the mechanistic problems discussed above, there is a fairly strong empirical relationship between Secchi depth and chlorophyll. The strength of this relationship can be determined from the variance in the empirical relationship between Secchi depth and chlorophyll *a*; this quantifies the sum of non-chlorophyll effects on Secchi depth, including differences in measurement techniques.

There are many advantages to Secchi data. Secchi depth is one of the most commonly used limnological measurements; it can be collected easily, quickly, and inexpensively with a minimum of training. Results are easily understood and can be related to ordinary experience (unlike, for example, turbidity, measured "nephelometric turbidity units"). Also, Secchi depth is a direct measure of water clarity and is therefore related to aesthetic values, whether the reduction in clarity is caused by trophic or other factors. Secchi depth is an important part of most volunteer lake monitoring programs. One important goal of these programs is to monitor long-term changes in algae abundance in individual lakes. Long-term changes can often be detected by long term Secchi measurements (Edmondson, 1980). We believe Secchi depth can also provide coarse short term assessments of lake water quality, particularly when tempered with professional judgement. Nevertheless, the limitations of assessments based primarily on Secchi depth must be understood.

Trophic State Index

The Secchi depth data collected by the volunteers were used to estimate the trophic state for each lake using Carlson's (1977) TSI. The TSI is calculated from Secchi depth (SD) in meters (m) as:

$$TSI_{SD} = 10 \left[ 6 - \frac{\ln(SD)}{\ln(2)} \right]$$

where ln is the natural log. This index was developed to refine the definition and determination of trophic status for lakes. As one of several benefits (listed in Carlson, 1977), the TSI serves as a simple and useful tool for explaining to the general public the concept of trophic status and the varying degrees of severity of each trophic state.

Ecology surveys (Brower and Kendra, 1990; Coots, 1991) determined trophic state using TSI boundary values of 41 between oligotrophic and mesotrophic and 51 between mesotrophic and eutrophic as suggested by Carlson (1979). Some professional judgment was also used in the estimations of trophic status, primarily to explain discrepancies among trophic state indices calculated from different parameters (Secchi depth, chlorophyll a, and total phosphorus) and to acknowledge that there are some anomalies associated with the trophic state index calculated from Secchi depth data. For example, some of the lakes are chemically treated to kill algae and improve the water clarity. As a result, water clarity measurements will underestimate the trophic state of the treated lake. In lakes where the Secchi disk depth was occasionally deeper than the depth of the lake (and therefore unmeasurable), only readings collected when the Secchi disk did not reach the bottom were used to calculate the TSI. As a result, the average Secchi depth will be biased low, and the average trophic state will be overestimated. Also, some lakes had extensive macrophyte growth or localized algae growth, yet high open-water clarity. The productivity of these lakes would be underestimated by Secchi disk data.

Although TSIs were calculated for each of the monitored lakes, calculated indices and resulting trophic state estimations were annotated for those lakes which appeared to be affected by one or more of these anomalous conditions.

Volunteer Monitoring Data

During the course of the monitoring season we discovered that the lines attached to the Secchi disks had shrunk considerably--about one inch per foot of original length. Typically the argument against using rope on a Secchi disk is that many ropes stretch. We had prepared for this by purchasing rope which we were assured by the vendor would not stretch (Appendix C). After experimenting with some line, we found that the majority of the shrinkage occurred after the first wetting. We assumed all lines shrank equally and applied a correction of one inch per foot to Secchi data prior to analysis.

Data from lakes that had at least three valid Secchi disk readings (e.g., none of the readings hit bottom) from June through September, 1989 were included in the data analysis. In all, data from 48 lakes were used for the data analysis.

The TSI (Secchi disk) for each of volunteer-monitored lakes was calculated from the mean Secchi disk depth for June - September. The Secchi data from these four months were used because most lakes had data collected during this period, and because algal growth, water quality problems and recreational use of lakes are usually heaviest during these months. Ecology-collected Secchi data from the conventional parameter survey were included in the TSI calculations for many of the lakes that were monitored both by volunteers and by Ecology.

The trophic state was then estimated using the trophic index calculated for each monitored lake. Some professional judgment was used to assign trophic states to lakes that had a TSI borderline between trophic states. In general, oligotrophy was assigned to lakes with TSI values up to 38, oligo-mesotrophy to lakes with a TSI from 38 to 41, mesotrophy to lakes with a TSI of 41 to 49, meso-eutrophy to lakes with a TSI from 49 to 51, and eutrophy to lakes with a TSI greater than 51. Qualifiers were placed on some trophic state estimations that were based on relatively few readings (five or fewer), lakes that were treated with herbicides or were subjected to some other kind of in-lake management activity, or lakes with a known history of water quality problems (such as severe nearshore blue-green algae blooms) which were not reflected in the water clarity readings collected by the volunteers.

WQHYDRO (Aroner, 1990) was used for most regression analyses and plotting. SYSTAT version 5.0 (Wilkinson, 1988) was used to calculate summary statistics on the volunteer-collected data, to evaluate the distribution of data, to create box plots, and for multiple regression analysis. Hitchcock and Cronquist (1973), Prescott (1962), Prescott (1978), Prescott (1980), Smith (1950), Tarver (1978), and VanLandingham (1982) were used in plant identification of both volunteer-collected and Ecology-collected plant and algae samples.

Quality Assurance

The quality of the Secchi disk transparency data used during this project was assured by standardizing procedures, which were provided to the volunteers in a sampling procedures manual that included step-by step sampling methods. Also, the volunteers were trained to be consistent in the sampling with respect to sampling location, sampling technique, timing of sampling, and person collecting the readings.

Replicate Secchi disk readings collected by the volunteers on each sampling date were used to assess the ability of the volunteers to reproduce their water clarity readings. Secchi disk reading precision was evaluated in part by using the relative percent difference (RPD) between each replicate pair. The RPD is defined as the difference between the two replicates divided by their mean multiplied by 100. Replicate readings within one foot of each other or $<10\%$ RPD were considered acceptable.

Secchi data collected by volunteers were graphically compared with Secchi data collected by Ecology staff during Ecology's conventional parameter survey.

## RESULTS AND DISCUSSION

### Project Assessment

Volunteer participation, on the whole, was fairly good. The six month commitment to collect monitoring data should have yielded 12 data points for each lake; we received an average of eight per lake. Nine lakes of the 48 lakes discussed in this report had fewer than six readings. Although we were concerned about the drop-out rate among the volunteers, most of the volunteers who initially dropped out of the program never got started with the monitoring. Of the 50 lakes in the 1989 program, two of which had insufficient data for analysis, volunteers for 36 of the lakes agreed to continue monitoring in 1990. Several of those non-continuing volunteers were moving, or had changes in health or job status. We intend to improve our recruitment methods, and are planning more ways of motivating the volunteers during the sampling seasons in order to improve volunteer participation in the future. In order to get an idea of how the program could be improved from the volunteers' standpoint, the volunteers were encouraged to make suggestions. Many of the suggestions from the volunteers were anticipated (such as having the volunteers collect water samples, and providing less fragile thermometers) and were planned for the 1990 program.

Feedback from the volunteers was generally positive and indicated that the program was off to a good start.

Overall, Ecology staff are satisfied with the data gathered for the program. Although the Secchi rope shrinkage presents some problems in future trend analysis, we nevertheless have a better idea of the general water quality of many of the monitored lakes. We also have increased our understanding of public perceptions of lake water quality issues and problems. We feel that we have offered the public more opportunity to use Ecology as an information resource for lake water quality issues. As a cooperative program between Ecology and the public that uses and enjoys lakes, we feel that the first year of Washington's Citizen Lake Monitoring Project was a success.

### Characteristics and Distributions of Lakes Monitored in 1989

Physical Characteristics

The monitored lakes represent a wide range of physical characteristics. Table 1 lists the lakes monitored, altitude, volume, size, maximum and average depth, drainage area, and shoreline length for each lake.

Table 1. Physical characteristics of volunteer-monitored lakes

| LAKE | LAKE ALTITUDE (FEET) | LAKE VOLUME (ACRE-FT) | LAKE AREA (ACRES) | DEPTH MAX (FEET) | MEAN DEPTH (FEET) | DRAINAGE AREA (SQ MILES) | SHORELINE LENGTH (MILES) |
|---|---|---|---|---|---|---|---|
| BARNES | 150 | * | 14 | * | * | * | 0.00 |
| BIG | 81 | 7470 | 520 | 23 | 14 | 22.40 | 6.21 |
| BIG MEADOW | 3450 | 72 | * | * | * | * | * |
| BLACK | 3701 | 1863 | 70 | 45 | 27 | 0.90 | 2.03 |
| BLACKMANS | 140 | 798 | 57 | 29 | 14 | 0.81 | 1.47 |
| BLUE | 1093 | 21318 | 532 | 69 | 40 | 334.00 | 7.03 |
| CLE ELUM | 2223 | 520000 | 4800 | 258 | 109 | 203.00 | 19.51 |
| CLEAR | 518 | 3200 | 170 | 25 | 19 | 2.61 | 2.73 |
| CRANBERRY | 20 | 1576 | 125 | 25 | 13 | 0.61 | 2.84 |
| CRAWFISH | 4475 | * | * | 80 | 36 | * | 0.00 |
| CRESCENT | 580 | * | * | 5127 | 624 | * | 0.00 |
| CURLEW | 2333 | 39519 | 921 | 130 | 43 | 64.50 | 15.78 |
| DAVIS | 2150 | 12622 | 152 | 146 | 83 | 17.80 | 2.67 |
| DEEP | 2025 | 7203 | 210 | 49 | 34 | 48.10 | 3.50 |
| DEER | 2474 | 57000 | 1110 | 75 | 52 | 18.20 | 8.62 |
| DUCK | 10 | 3000 | 278 | 30 | 11 | 1.44 | 11.30 |
| ELOIKA | 1905 | 6018 | 662 | 15 | 9 | 111.00 | 5.91 |
| FLOWING | 526 | 3790 | 134 | 69 | 28 | 0.79 | 2.22 |
| GOODWIN | 324 | 13000 | 560 | 50 | 23 | 5.17 | 5.45 |
| GOSS | 130 | 1500 | 47 | 60 | 32 | 1.41 | 1.19 |
| ISLAND | 230 | 2246 | 108 | 31 | 21 | 0.26 | 1.74 |
| KAHLOTUS | 880 | 5140 | 380 | 24 | 14 | 167.00 | 5.34 |
| KILLARNEY (SOUTH ARM) | 385 | 230 | 24 | 15 | 9 | 0.24 | 1.25 |
| KITSAP | 156 | 4500 | 250 | 29 | 18 | 2.73 | 2.69 |
| LACAMAS | 179 | 7489 | 315 | 65 | 24 | 64.30 | 5.34 |
| LIBERTY | 2053 | 16000 | 710 | 30 | 23 | 13.30 | 4.77 |
| LONG (KITSAP CO.) | 118 | 2180 | 339 | 12 | 6 | 9.36 | 5.07 |
| LONG (THURSTON CO.) | 153 | 3900 | 330 | 21 | 12 | 8.25 | 7.08 |
| LOON | 2381 | 52000 | 1100 | 100 | 46 | 14.10 | 7.92 |
| LOUISE | 230 | 860 | 39 | 35 | 22 | 0.34 | 0.91 |
| MASON | 194 | 49000 | 1000 | 90 | 48 | 20.20 | 10.90 |
| NEWMAN | 2124 | 23000 | 1200 | 30 | 19 | 28.60 | 9.75 |
| OSOYOOS | 911 | 266000 | 5800 | 208 | 46 | 3150.00 | 29.73 |
| PACKWOOD | 2858 | 28000 | 400 | 120 | 71 | 19.20 | 4.26 |
| PATTERSON | 154 | 2500 | 190 | 19 | 13 | 3.77 | 4.60 |
| PHILLIPS | 188 | 1800 | 110 | 25 | 16 | 0.50 | 2.63 |
| SAMISH (WEST ARM) | 273 | 9100 | 130 | 140 | 71 | 3.70 | 1.80 |
| STARVATION | 2375 | 233 | 30 | 14 | 8 | 3.00 | 0.88 |
| STEILACOOM | 210 | 3500 | 320 | 20 | 11 | 89.40 | 5.70 |
| ST. CLAIR (NORTH ARM) | 73 | 5100 | 180 | 70 | 28 | 6.40 | 7.50 |
| SULLIVAN | 2583 | 267000 | 1380 | 332 | 193 | 51.20 | 8.89 |
| SUMMIT | 500 | 28000 | 530 | 100 | 53 | 2.82 | 5.61 |
| SUTHERLAND | 501 | 20800 | 369 | 86 | 57 | 7.98 | 4.92 |
| THOMAS | 3147 | 4000 | 170 | 55 | 23 | 12.70 | 3.31 |
| TIGER | 496 | 2100 | 110 | 40 | 19 | 0.70 | 2.46 |
| WENATCHEE | 1875 | 360000 | 2480 | 244 | 147 | 273.00 | 13.30 |
| WILLIAMS | 2052 | 12000 | 320 | 120 | 37 | 21.80 | 5.30 |
| WOOTEN | 407 | 1530 | 68 | 36 | 23 | 0.32 | 1.55 |

* Data not available

The altitudes of the monitored lakes ranged from 10 feet to 4475 feet, and, with the exception of Packwood Lake, all over 800 feet are located in Eastern Washington. The areas of the monitored lakes ranged from 30 to 5,800 acres. Twenty-seven are greater than 300 acres (15 of these are located in Western Washington), and only ten lakes are less than 100 acres (6 of these are located in Western Washington).

Geographical Distributions

Of the 48 lakes actively monitored by volunteers throughout the state, 28 are located in Western Washington (of which 24 are located in the Puget Sound drainage) and 20 are located in Eastern Washington (of which 13 are located in Pend Oreille, Stevens, or Spokane Counties)(Figure 1). Both of these areas have a large number of lakes, and a large number of lake associations. Also, recruitment methods may have caused the distribution of lakes monitored for the program to be biased for lakes with moderate to heavy recreational use and residential development. Because the program required that the lakes be monitored at least twice per month, few of the monitored lakes are located at higher elevations or in remote or undeveloped areas. As a result, most of the lakes in the program are monitored by people who live on a lakeshore either year-round or during most of the summer, and have a boat moored in the water to use while sampling.

Only one lake in King County was included in the monitoring program. This is because the Municipality of Metropolitan Seattle (METRO) has coordinated a citizen monitoring program within King County since 1983. To avoid duplication of effort, lakes that were already participating in the METRO program were not included in the statewide project.

The distribution of lakes with respect to Pacific Northwest ecoregions (Omernik and Gallant, 1986) is also shown in Figure 1. Of the 48 lakes in program, three are located in ecoregion 1 (Coast Range), 23 are located in ecoregion 2 (Puget Lowland), one is located in ecoregion 3 (Willamette Valley), three are located in ecoregion 4 (Cascades), four are located in ecoregion 7 (Northern Rockies), and 14 are located in ecoregion 8 (Columbia Basin). There were no volunteer-monitored lakes within ecoregions 6 (Eastern Cascades Slopes and Foothills), and 9 (Blue Mountains) probably because there are fewer public lakes with lakeshore residential development in these areas.

Trophic State Distributions

We summarized the trophic state distributions of the monitored lakes to determine how many of the monitored lakes were eutrophic, and to evaluate whether there were any relationships between physical characteristics and trophic state. However, because the monitored lakes represent a relatively small, nonrandom sample size, the following distributions should not be used to draw conclusions about lakes statewide with respect to geographic area, size, depth, etc. Trophic state indices calculated from the Secchi depth data indicate that almost half (22) of the monitored lakes had a TSI value less than 40 (Figure 2) and were estimated as oligotrophic or oligo-mesotrophic. Twenty-six of the lakes had a TSI value of 40 or higher and were estimated

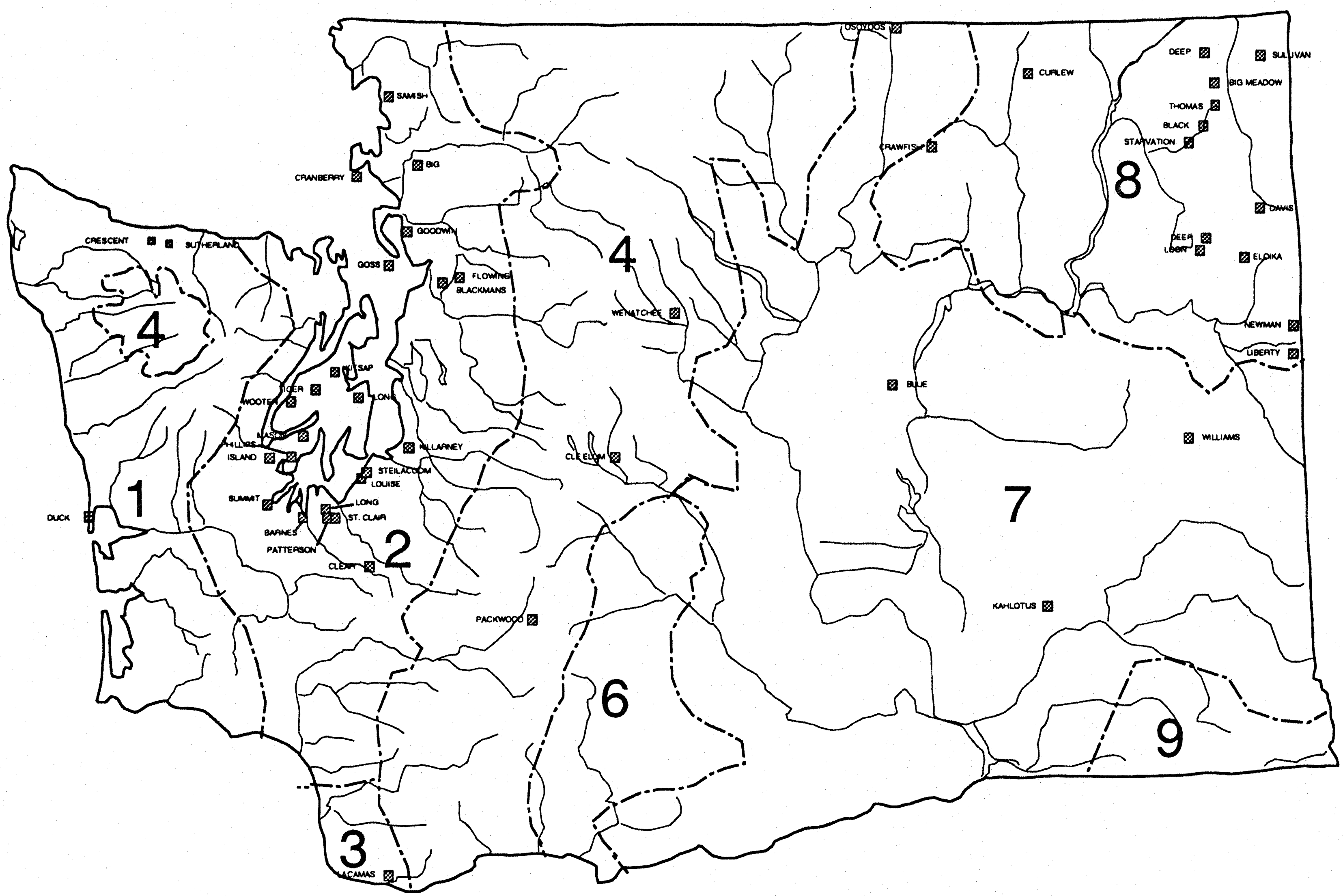



FIGURE 1. Map of Volunteer-monitored lakes with Northwest Ecoregions shown: 1-Coast Range, 2-Puget Lowland, 3-Willamette Valley, 4-Cascades, 6-Eastern Cascade Slopes and Foothills, 7-Columbia Basin, 8-Northern Rockies, and 9-Blue Mountains.

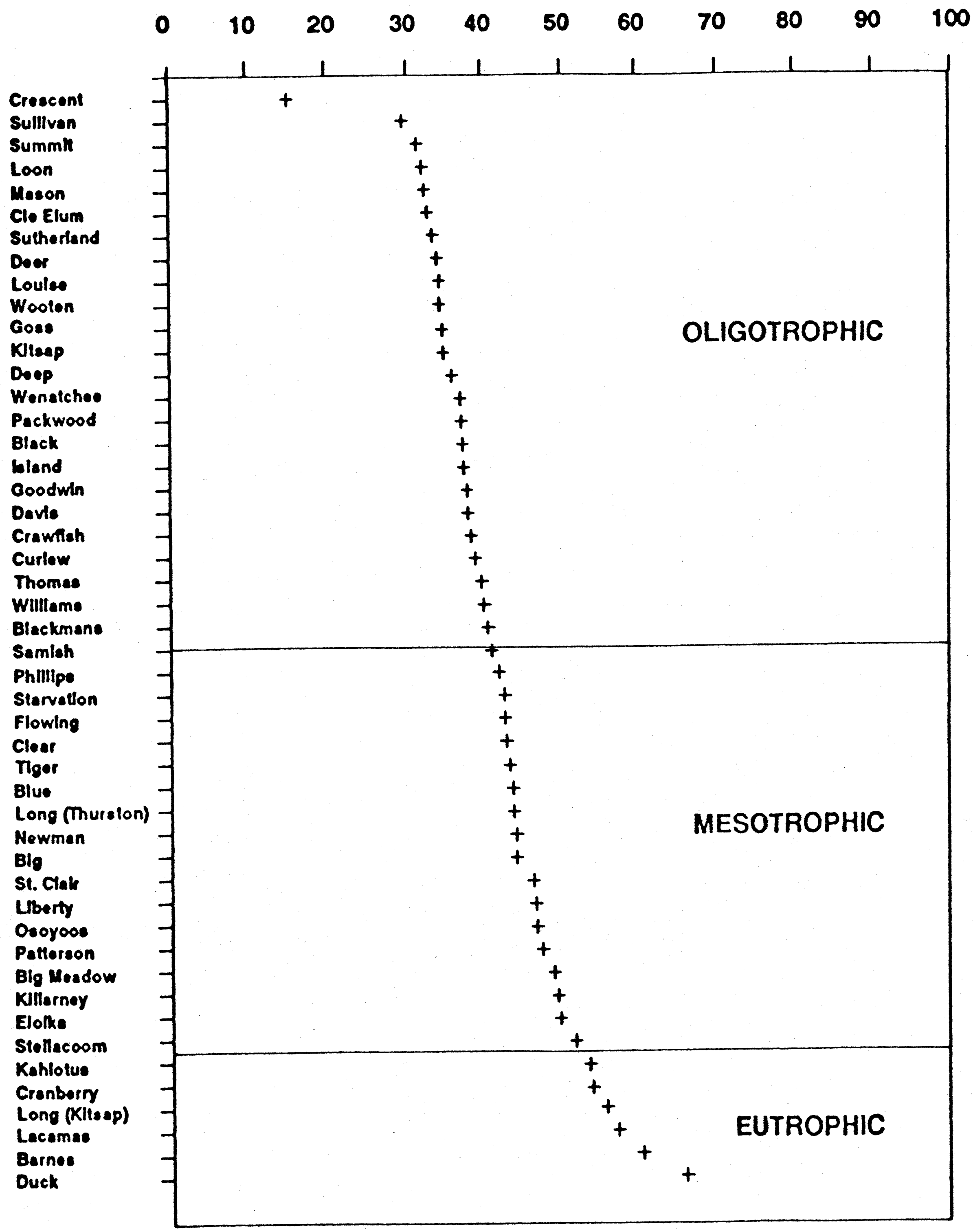



FIGURE 2. Lakes ranked in order of mean summer TSI (Secchi).

as mesotrophic, meso-eutrophic, or eutrophic. A large majority of the lakes had TSI values between 30 and 50, so that few lakes were in either extreme end of the trophic scale. Of the 20 monitored lakes in Eastern Washington, 11 were oligotrophic or oligo-mesotrophic, and one was eutrophic. Of the 28 Western Washington lakes, 11 were oligotrophic and 6 were eutrophic. The large number of oligotrophic assessments was unanticipated.

The mean depth of a lake affects a number of important lake processes such as stratification, hypolimnetic oxygen depletion, availability of nutrients from the sediments, and rooted aquatic plant growth. Because of these processes, in general a shallower lake is more likely to be eutrophic than a deeper lake. This is demonstrated in the trophic state estimations based on the Secchi disk readings; most of the lakes with a mean depth greater than 30 feet were oligotrophic or oligo-mesotrophic, and all but one of the lakes with a mean depth of less than 20 feet were mesotrophic or eutrophic. Mean depths were not available for Barnes, Big Meadow, and Crawfish Lakes.

Except for Lake Osoyoos, Curlew Lake, and Newman Lake, all lakes that cover more than 900 acres were oligotrophic. Of the seven eutrophic lakes monitored for the program, five cover between 250 and 600 acres. Of the lakes that cover less than 100 acres, one was eutrophic and three were classified as oligotrophic. Most of the lakes that cover between 100 and 200 acres were mesotrophic.

## Comparative Limnology

### Usefulness of Secchi-based Trophic State Indicators

This program relies heavily on the use of volunteer-collected Secchi disk data to assess trophic state. The Quality Assurance Section discusses the quality of volunteer-collected Secchi data compared to professionally-collected Secchi data. The Methods section discusses the advantages and potential problems of using Secchi data to assess trophic state. This section compares the trophic state assessment based on volunteer-collected Secchi data and other information available through the volunteer monitoring program to assessments based on 1989 data available from 20 of the volunteer-monitored lakes (Brower and Kendra, 1990). Although Brower and Kendra (1990) surveyed 25 lakes, volunteers from five of the lakes did not collect sufficient data to evaluate the trophic status.

The relationship between mean Secchi depth, fall chlorophyll, and spring total phosphorus trophic state indices ($TSI_{sd}$, $TSI_c$, and $TS_{tp}$ respectively) is illustrated in Figure 3. The three TSI measures differ by more than 10 units at six of the 20 lakes. Although this inconsistency between TSIs may be caused in part by low-quality Secchi data or theoretical problems with Secchi data, it may also result from basing $TSI_c$ and $TSI_{tp}$ on single samples. The lack of agreement between indices may also be caused by anomalous characteristics within the evaluated lakes (for example, nitrogen rather than phosphorus limitation). Identifying causes of a lack of agreement between indices can be quite useful when assessing in-lake conditions (Carlson, 1977).

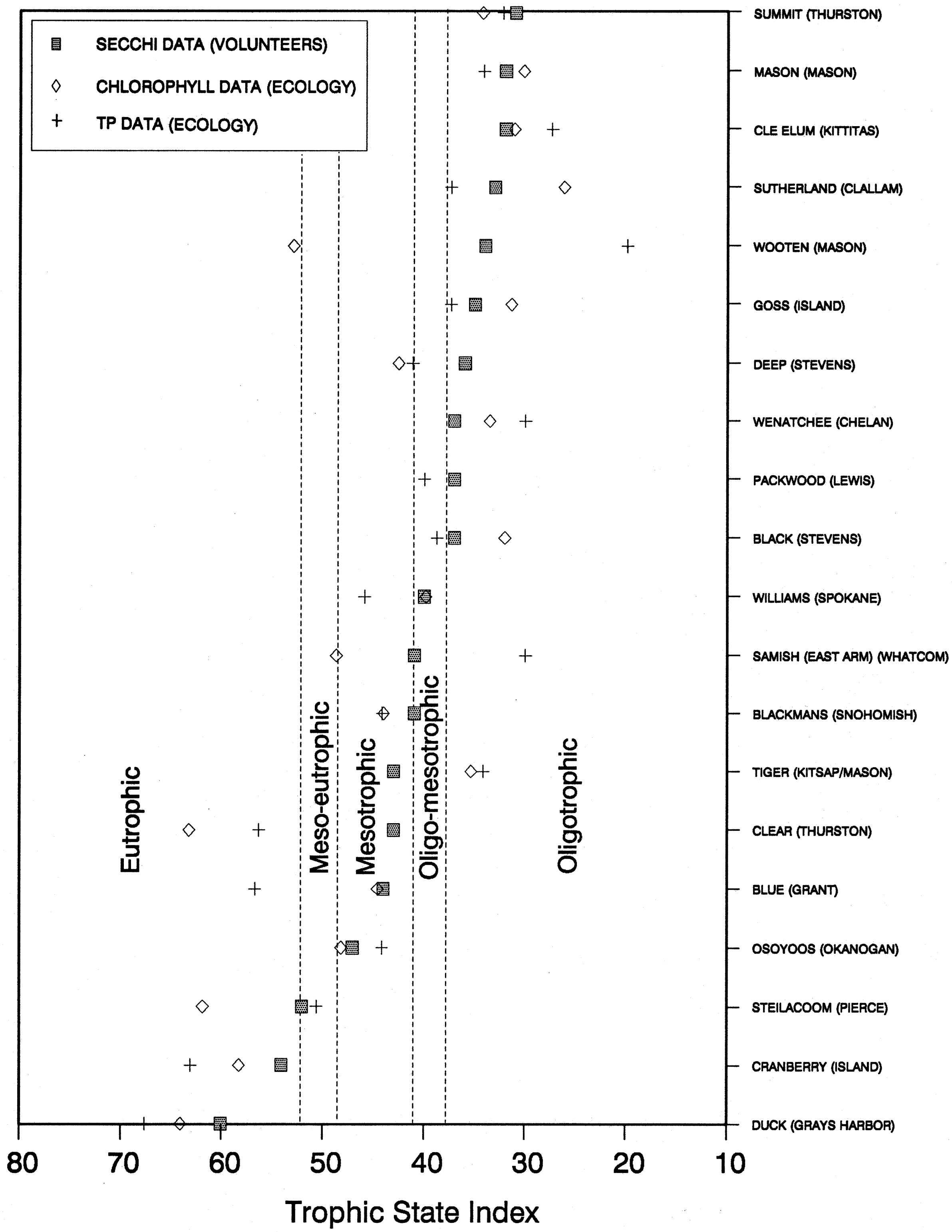



FIGURE 3. Relationship between TSI's calculated from Secchi depth, chlorophyll, and total phosphorus. Lakes are ranked by 1989 TSI (Secchi).

To evaluate the appropriateness of using Secchi data alone to estimate trophic state, the trophic states based on only $TSI_{sd}$ were compared with the trophic states in Bower and Kendra (1990), which were based on $TSI_{sd}$, $TSI_{tp}$, and $TSI_{chl}$ and were tempered with professional judgement. The two methods resulted in different trophic state assessments for only three of twenty lakes:

1) **Clear Lake.** Overall, Clear Lake was considered to be eutrophic by Brower and Kendra (1990) due to high phosphorus and high fall chlorophyll concentrations. Although volunteer Secchi readings were in the eutrophic range in the fall, the average volunteer $TSI_{sd}$ indicated mesotrophy. Clear Lake is regularly treated with algicide which increases transparency and hence Secchi depth. Therefore, we expected Secchi data to indicate a less eutrophic condition than was actually the case.

2) **Deep Lake.** Considering all factors, Deep Lake was assessed as oligo-mesotrophic by Brower and Kendra (1990) while volunteer-collected Secchi data indicated oligotrophy. In this case, the Secchi data alone may not have accurately assessed trophic state; however, only three readings were collected from this lake, all before mid-June. Sampling throughout the summer might have allowed a more accurate assessment.

3) **Tiger Lake.** Brower and Kendra (1990) assessed Tiger Lake as oligotrophic while volunteer Secchi data indicated mesotrophy. There were other indications that Tiger Lake was not oligotrophic. The water color was green and anoxic conditions were present near the bottom in both June and September. Further study is required to assess the trophic state of Tiger Lake with confidence.

Even when data from the conventional parameter study were not available, final assessments were based on more than simple Secchi readings. Comments from the volunteers, water color, geographic information, observations during field visits, and past study data were all used to refine the assessment based on Secchi disk data. Of the twenty lakes assessed in the conventional study (Brower and Kendra, 1990), only one or two would not have been placed in the same trophic category based on volunteer monitoring data alone. Although a small percentage of the 49 lakes assessed in this report may be misclassified, we feel our use of volunteer monitoring data to roughly assign trophic state is, on the whole, justified in the absence of more detailed information.

Water Quality Trends

Five years is often used as the minimum amount of data required to conduct statistical trend analyses (e.g., Taylor and Loftis, 1989), more if greater sensitivity is required. We will evaluate the possibility of formally assessing trends in 1994.

We can, however, evaluate overall differences in water quality between this study and earlier studies. Sixteen of the lakes assessed in this report were assessed in the early 1970s (Bortleson, *et al.*, 1976 a-d and Dion, *et al.*, 1976 a-c), and 41 were assessed in 1981 (Sumioka and Dion, 1985). Based on Secchi data alone, approximately half of the lakes assessed in 1989 would be considered more eutrophic and half more oligotrophic compared to trophic categories based on data from these earlier studies, indicating no net change in overall Secchi-based water quality (Figure 4). There was no apparent pattern within ecoregions; trophic states increased and decrease in approximately equal proportions compared to earlier studies.

However, trends at individual lakes should not be inferred from these differences. Observed changes in water quality based on only two or three years of data may merely be a response to assessment methods (the earlier studies are based on only two to four samples) or climatic variations. Total precipitation varied between the different studies (Table 2). Other important factors, such as solar radiation, growing season temperature, timing of precipitation events, etc., were not evaluated.

Secchi:Chlorophyll:Phosphorus Relationships

The relationships between Secchi disk depth, chlorophyll *a*, and phosphorus were evaluated because our water quality assessments, which are based on volunteer-collected Secchi data, assume a relationship between Secchi data and trophic state. (Trophic state is more directly assessed by measuring chlorophyll and phosphorus -- see the section on Secchi Disk Theory). All of the data used in these analyses, except the volunteer-collected Secchi depths, are from Brower and Kendra (1990). Specifically, we wanted to a) confirm that our results were similar to those of Carlson (1977), b) identify which relationships are strongest, particularly with respect to volunteer-collected data, and c) identify specific lakes that do not fit the relationships observed.

This project was not designed to allow detailed assessments of nutrient-chlorophyll-Secchi disk dynamics at any particular lake. With only two nutrient and chlorophyll samples per lake, explanations for why a lake does not fit a particular model should be considered conjecture.

Chlorophyll explained much of the differences in Secchi depth between lakes (Figure 5). Packwood Lake was excluded from the analysis because it is influenced by glacial runoff which would affect Secchi depth. A logarithmic relationship was used, rather than the inverse relationship suggested by the theoretical model (Carlson, 1977; Megard, 1980; Lorenzen, 1980), because the residuals of the inverse regression violated the assumption of equality for variances. In addition, Carlson's (1977) TSI is based on a logarithmic relationship.

Table 2. Climatic data from Seattle and Spokane (EarthInfo, Inc., 1990). Temperatures are daily averages, snow and precipitation are annual totals.

| Parameter | Period of Record | 1971 | 1972 | 1973 | 1974 | 1981 | 1989 |
|---|---|---|---|---|---|---|---|
| Station: SEATTLE TAC WSCMO AP | | | | | | | |
| Temp, Min ( o F) | 44 | 44 | 44 | 44 | 45 | 45 | 45 |
| Temp, Max ( o F) | 59 | 57 | 58 | 59 | 60 | 60 | 60 |
| Snow (in.) | 12.59 | 25.80 | 22.20 | 4.00 | 13.50 | 1.10 | 14.20 |
| Precip. (in.) | 38.04 | 43.21 | 48.36 | 35.04 | 37.87 | 35.40 | 34.69 |
| Station: SPOKANE WSO AP | | | | | | | |
| Temp, Min ( o F) | 38 | 37 | 37 | 39 | 37 | 38 | 37 |
| Temp, Max ( o F) | 58 | 57 | 57 | 59 | 58 | 58 | 57 |
| Snow (in.) | 44.84 | 54.40 | 31.30 | 44.00 | 39.60 | 20.00 | 45.20 |
| Precip. (in.) | 16.01 | 18.48 | 13.53 | 17.11 | 16.04 | 14.91 | 14.71 |

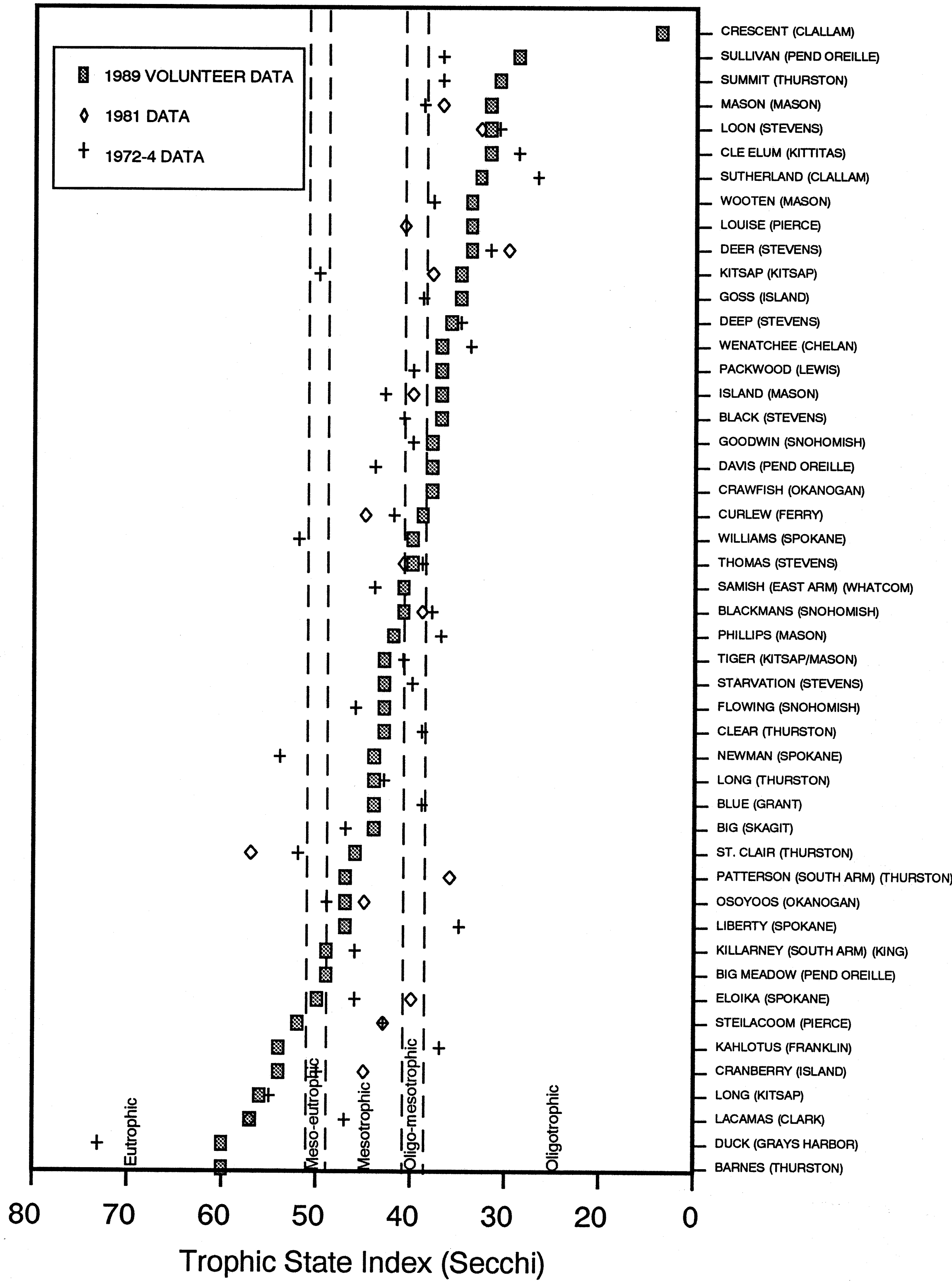



FIGURE 4. TSI calculated from Secchi depth for early 1970's, 1981, and 1989 (this study). Lakes are ranked by 1989 TSI (Secchi).

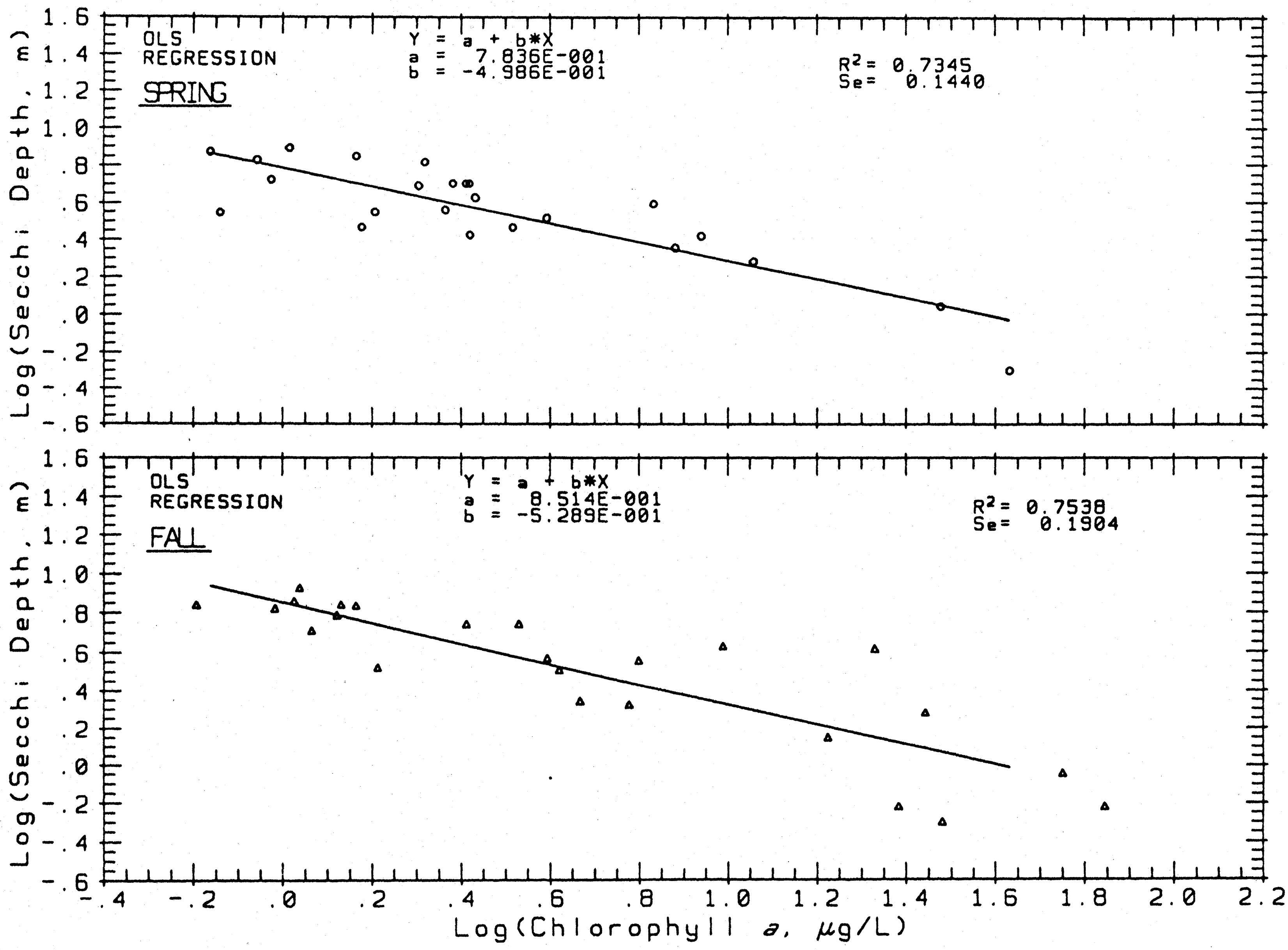



FIGURE 5. Regression of Secchi depth and chlorophyll from spring and fall conventional parameter sampling (Data source: Brower and Kendra, 1990).

The relationships between Secchi disk depth and chlorophyll *a* found in the 24 lakes studied by Brower and Kendra (1990),

$$\text{Spring: } \log SD = 0.78 - 0.50 \log Chl$$
$$(r^2=0.73,\ n=24)$$

and

$$\text{Fall: } \log SD = 0.85 - 0.53 \log Chl$$
$$(r^2=0.75,\ n=24)$$

were very similar to each other and to that which was found in Carlson's study. Carlson's regression equation, which included lakes from across the United States, was

$$\log SD = 0.89 - 0.68 \log Chl$$
$$(r^2=0.86,\ n=147).$$

The average non-chlorophyll light attenuation coefficients ($K_w$) were low and indicate that, on average, chlorophyll was the major factor affecting Secchi depth, an important assumption in using Secchi data to estimate trophic state. Average non-chlorophyll light attenuation coefficients ($K_w$) for the 24 lakes were 0.14 in the spring and 0.20 in the fall. Unfortunately, this average relationship tells us little about whether or not any particular lake may violate this assumption. The "Secchi Disk Theory" section discusses the affect of non-algal light attenuation on the sensitivity of Secchi depth to changes in chlorophyll. The reported attenuation coefficients cannot be calculated from the above logarithmic relationships and so were based on the theoretical model of the inverse of Secchi depth and chlorophyll *a*; as such, they should be considered approximate.

Because algae production, and hence chlorophyll, is most often limited by phosphorus, we expected a relationship between spring (pre-stratification, pre-growing season) total phosphorus and mean summer chlorophyll *a* (spring phosphorus and mean summer chlorophyll are thought to be more representative of average trophic state than concentrations at other times). However, the relationship between the log of spring epilimnetic total phosphorus and the mean chlorophyll *a* concentration was not particularly strong ($r^2=0.49$) (Figure 6). This relationship was based on all 25 lakes where conventional parameter sampling was conducted. The small number of data points and especially the availability of only two chlorophyll values (spring and fall) may be partly responsible for the low amount of variance explained by the equation. Also, in some cases, spring sampling did not occur until after stratification and the beginning of the growing season. Another explanation, however, is that not all lakes (or not all algae species within an assemblage--see Smith, 1982) are phosphorus limited. A multiple regression of mean

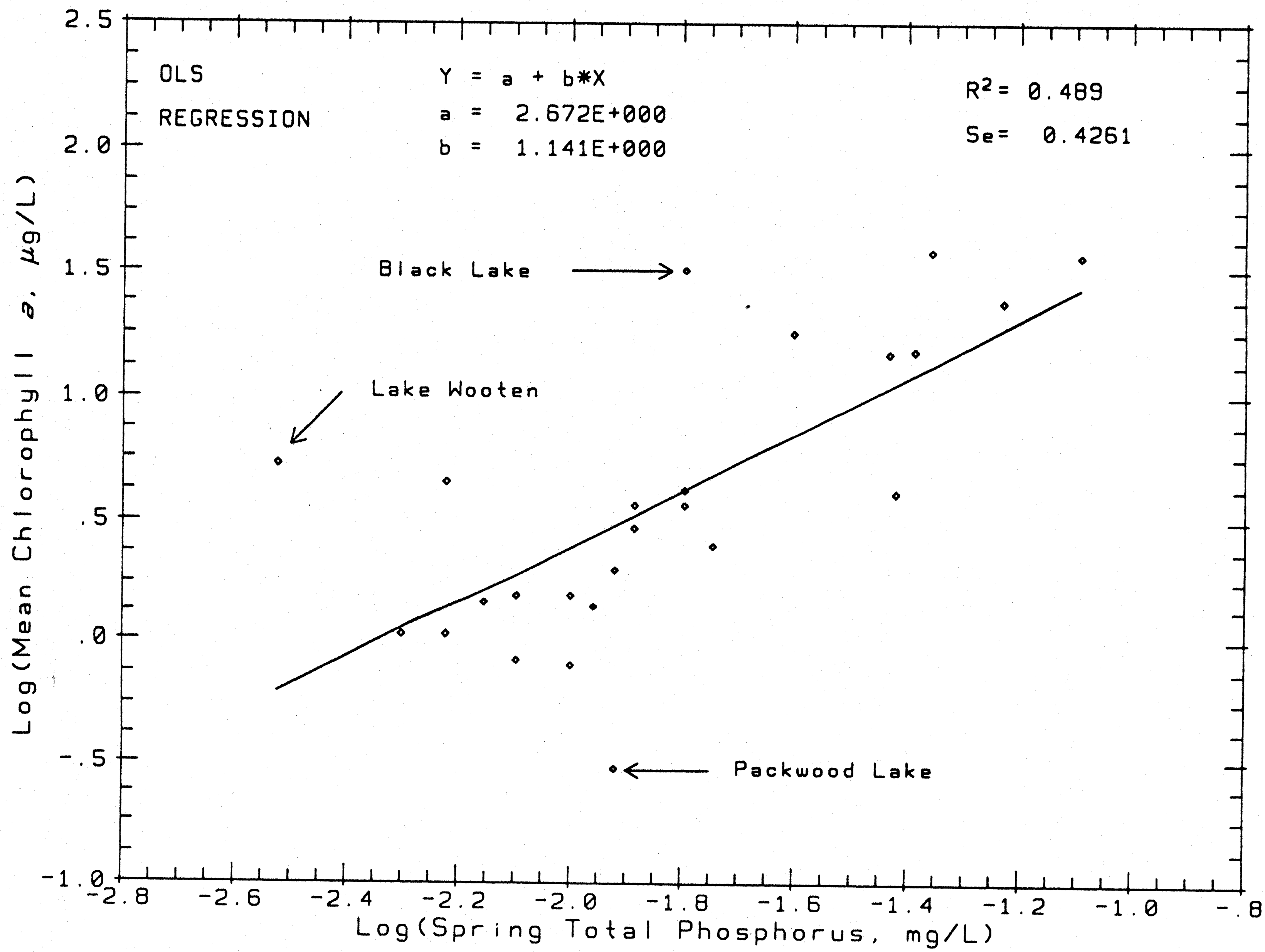



FIGURE 6. Regression of chlorophyll and spring total phosphorus from spring and fall conventional parameter sampling (Data source: Brower and Kendra, 1990).

chlorophyll *a* vs. spring total phosphorus and spring total nitrogen yielded an r-squared of 0.68 with both nitrogen and phosphorus being significant ($P < 0.01$). This suggests that nitrogen plays an important role in determining chlorophyll concentrations in these lakes.

Because phosphorus influences chlorophyll and chlorophyll influences Secchi depth (and all three are related to trophic state), Secchi depth should be related to phosphorus. The logarithmic relationship between average volunteer-collected Secchi depth and spring epilimnetic total phosphorus (Figure 7) was not as strong as that between Secchi depth and chlorophyll. This was expected because Secchi disk theory links Secchi depth directly with chlorophyll and only indirectly with phosphorus through the relationship between phosphorus and chlorophyll. Figure 7 is based on 19 lakes: the 20 where both volunteer monitoring data and conventional survey data are available, excluding Packwood Lake, where glacial meltwater would be expected to interfere with Secchi depth relationships.

One of the major strengths of a volunteer monitoring program is that volunteers living on or near a lake are able to easily collect more frequent measurements than could Ecology staff. The importance of frequent measurements is demonstrated in the correlations between volunteer-collected Secchi depth and other measures of trophic state (Table 3). These correlations were better than correlations with Ecology-collected Secchi data. This is because the volunteer data was an average of several measurements while Ecology Secchi depths were based on a single sample.

Several lakes do not behave as predicted in the relationships illustrated in Figures 5-7. Duck Lake did not fit the Secchi depth:phosphorus relationship (Figure 7) as well as other lakes. Duck Lake also did not fit the Secchi depth:chlorophyll model well in either spring or fall. The data point was below the regression line in all cases indicating the Secchi depth was shallower than expected given the phosphorus and chlorophyll concentrations. However, Duck Lake did fit the chlorophyll:phosphorus model and adding nitrogen to the model did not improve the fit for Duck Lake, which suggests the lake was not nitrogen limited. Duck Lake is a coastal marshy lake and Secchi depths may have been influenced by water color or non-algal turbidity. Caution should be used when employing Secchi depths to assess trophic state in Duck Lake.

Packwood Lake was not included in the Secchi depth models because it is fed by glacial meltwater. However, Packwood Lake was well below the regression line in Figure 6, indicating clorophyll was much lower than expected given the phosphorus concentration. However, Packwood Lake has a fairly low residual when nitrogen was included in the chlorophyll:phosphorus model. This and the low TN:TP ratios reported by Brower and Kendra (1990) support a conclusion that Packwood Lake is nitrogen limited.

Lake Wooten fit the Secchi depth:chlorophyll model fairly well but both Lake Wooten and Black Lake (Thurston County) had higher than expected chlorophyll given their phosphorus concentrations (Figure 6). (We had no volunteer information on Black Lake so it was not included in the Secchi depth:chlorophyll model.) In Lake Wooten, reported ortho-phosphorus

Table 3. Significant ($p < 0.05$) Pearson correlation coefficients (r) for mean volunteer-collected Secchi disk data and conventional data collected by Ecology staff.

| Secchi, Volunteer Spring | Secchi Volunteer | Secchi Ecology Spring | Phosph. Ecology Fall | Phosph. Spring | Chlorophyll Fall | |
|---|---|---|---|---|---|---|
| Secchi, Volunteer | 1.000 | | | | | |
| Secchi, Ecology, Spring | 0.832 | 1.000 | | | | |
| Secchi, Ecology, Fall | 0.862 | 0.534 | 1.000 | | | |
| Phosphorus, Spring | -0.763 | -0.577 | -0.689 | 1.000 | | |
| Phosphorus, Fall | N.S. | N.S. | N.S. | N.S. | 1.000 | |
| Chlorophyll, Spring | -0.695 | -0.610 | -0.614 | 0.908 | N.S. | 1.000 |
| Chlorophyll, Fall | -0.701 | N.S. | -0.802 | 0.770 | 0.560 | 0.703 |

N.S. = Not Significant

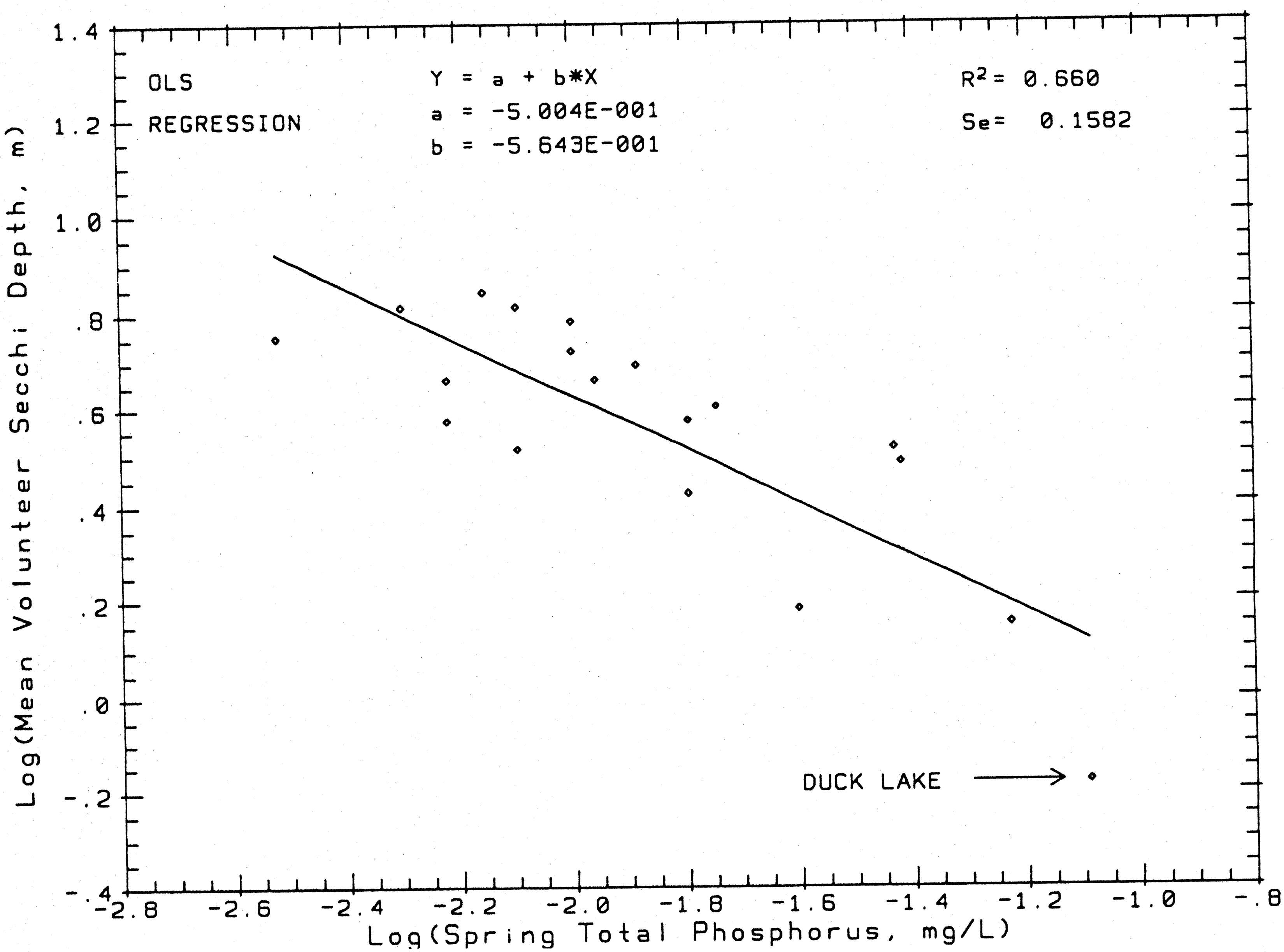



FIGURE 7. Regression of volunteer-collected Secchi depth and spring total phosphorus. Phosphorus data is from spring conventional parameter sampling (Data source: Brower and Kendra).

was twice the total phosphorus indicating a data error of sufficient magnitude to explain the poor fit. For Black Lake, the poor fit cannot be explained by either non-algal light attenuation or limitation by something other than phosphorus. Spring chlorophyll concentrations were relatively low and the lake stratified and experienced anoxic conditions in the hypolimnion in the fall. Given this, one possible explanation for the poor fit of Black Lake to the chlorophyll:phosphorus model is that as the algae cells circulated through the epilimnion and passed near the metalimnion, they obtained nutrients from hypolimnetic entrainment or upwelling and hence were able to reach greater concentrations than could be supported by epilimnetic phosphorus alone. Another explanation is that our sample chlorophyll concentration was higher than the lake-wide average due to the clumpy distribution of algae.

Ecoregion Analysis.

Omernik and Gallant (1986) divided the Pacific Northwest into 15 areas (8 in Washington) based on similarities in land use, land surface form, potential natural vegetation, and soils. In theory, water bodies within an ecoregion would have similar water quality or potential water quality. In actuality, though, water quality will differ within an ecoregion in lakes of varying types and origins. For example, artificially-created reservoirs (e.g., Sullivan Lake and Lake Cle Elum), reclaimed wetlands (Duck Lake), and chemically-treated lakes (Clear Lake, Lake Louise, Steilacoom Lake) may not have water quality similar to "natural" lakes in their respective ecoregions. Nevertheless, the variance in water quality measures within ecoregions should be less than the variance between ecoregions. This section attempts to identify volunteer-monitored lakes where Secchi depth does not conform to Secchi depths in other lakes within the same ecoregion. Unfortunately, only ecoregions 2 (Puget Sound Lowlands) and 8 (Northern Rockies), have much data, and as a consequence, unusual results are more difficult to detect. Also, dissimilarity only identifies a lake as having unusual (compared to other lakes in the ecoregion) Secchi disk depths, and not necessarily as having unusual trophic states. Secchi depths may be unusual because of reasons not related to trophic state, for example, the measurement may be affected by high suspended sediment. The most we can say about these lakes may be that they require further study to assess water quality with confidence.

There was little difference between ecoregions with respect to Secchi depth (Figure 8, top). Although ecoregion 1 (Coast Range) had significantly ($P<0.05$) different Secchi depths than other ecoregions, only three lakes were monitored in that ecoregion. Interestingly, the lake with the highest overall water clarity (Lake Crescent) and a lake with extremely low water clarity (Duck Lake) are both in ecoregion 1. Only one lake was outside the expected range of data for its ecoregion. That lake, Sullivan Lake, had particularly good (deep) Secchi depths compared to other lakes in ecoregion 8.

We also identified unusual average Secchi disk depths by performing a multiple linear regression to predict Secchi depth given various physical attributes from each lake. The physical parameters used were altitude, area, volume, shoreline length, maximum depth, mean depth, drainage area, residential development, shoreline development index, drainage area to surface

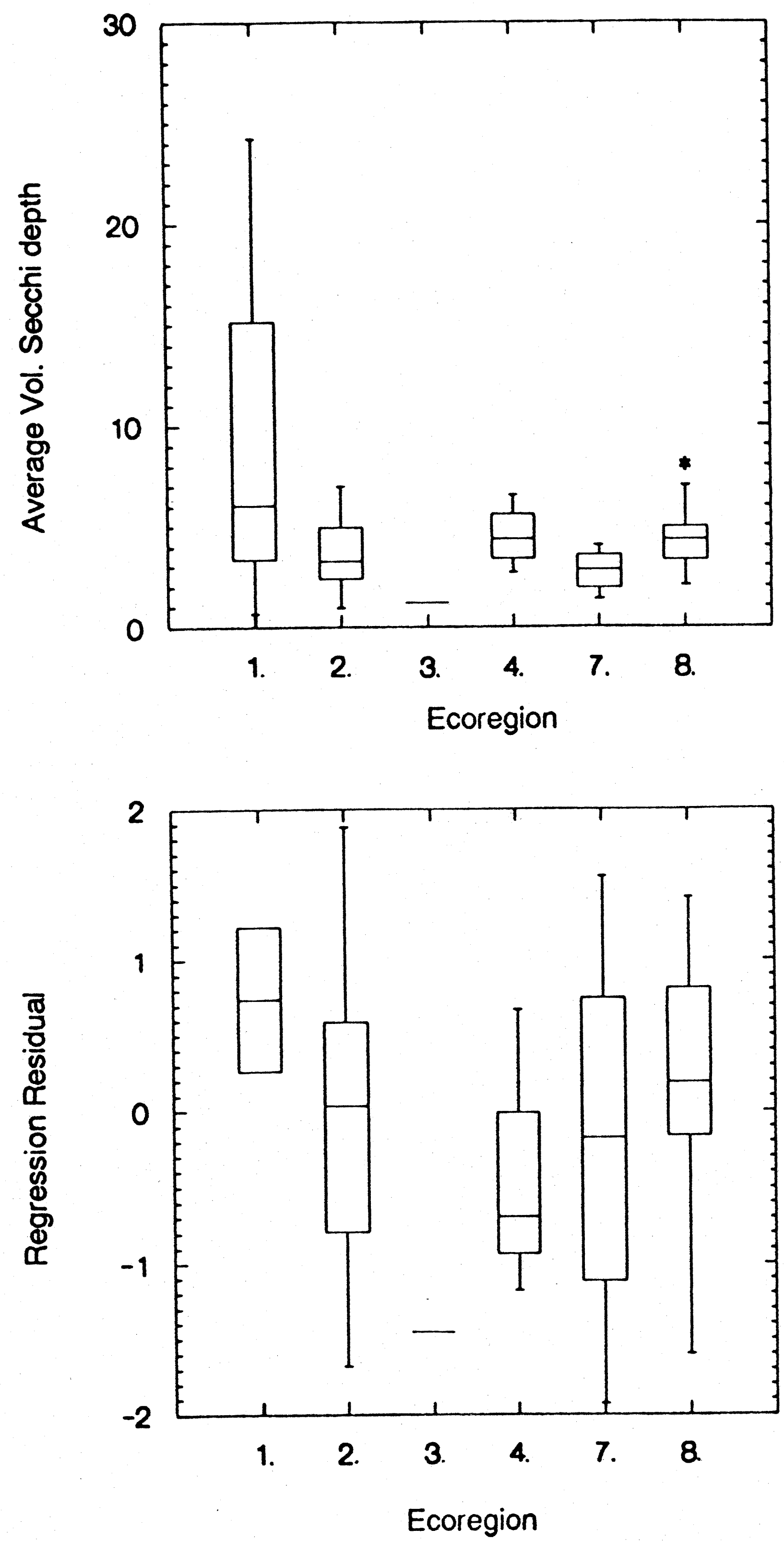



FIGURE 8. Box plots of volunteer-collected Secchi depths and regression residuals by ecoregion (see text).

area ratio, and relative depth. This procedure removes the overall affect of the listed parameters on Secchi depth. When the residuals from this regression were compared by ecoregion, there were no significant differences between ecoregions ($P > 0.10$) and no lake stood out as unusual (Figure 8, bottom). In other words, differences in Secchi depths between ecoregions can be explained by physical characteristics. Based on this analysis, at least, we do not need to suspect anomalous data or an unusual nutrient source to explain atypical within-ecoregion Secchi readings.

Finally, a second multiple regression was conducted on all lakes using significant variables from the above list as determined by a step-wise regression ($P < 0.15$ to enter, $P > 0.15$ to remove). Variables included in the regression were shoreline length, mean depth, drainage area, residential development, shoreline development index, and relative depth ($r^2 = 0.66$). Using this procedure, two lakes had Studentized residuals that fell outside the range of about 95% of all residuals from the same population. Lake Wenatchee had lower Secchi depths than predicted by the physical variables listed. The section on individual lakes, written prior to these analyses, warns of using Secchi data alone to assess Lake Wenatchee due to strong and frequent winds on the lake. Blue Lake (Grant County) had Secchi depths deeper than would be predicted given its physical characteristics. The reasons for this are unknown.

**Priority Ranking of Lakes**

EPA's Clean Lakes Program's objectives are to "provide maximum recreational and environmental benefits to as many people as possible" (EPA 1988). EPA urges states to consider criteria such as public access, the number of people that will benefit, the degree to which high-quality lakes may be threatened in the future, as well as the water quality of the lake in determining which lakes most urgently need help. This section is an attempt to rank lakes based on more than simply water quality.

One possible use of such a ranking would be as an aid in making management funding decisions, particularly in cases where funding is awarded on a strict priority basis. At present, however, funding for lake restoration projects is awarded each year in response to applications for Centennial Clean Water Funds (CCWF)--a competitive grant process requiring sponsorship by a public entity, 25% local matching funds, and public access. Application by Ecology for additional dollars from federal Clean Lakes funds is generally made only in cases where a CCWF project exists or is expected to be funded. This ensures the availability of the required match for the federal funds. In other words, because of the matching requirements, the placement of a potential project on the CCWF list becomes the driver for the awarding of federal grant monies, rather than a statewide priority list. Although the rankings in Table 4 may not be used by Ecology to seek out and directly fund high priority projects, it may be useful as a selection criteria in the awarding of CCWF grants. The list may also indicate to Ecology where to encourage local officials to apply for a CCWF grant (Kim McKee, personal communication).

Table 4 shows lakes in the volunteer monitoring program roughly prioritized according to need for protection/restoration. The overall score was determined by ranking lakes according to the average of the three category ranks (lake significance, susceptibility to eutrophication, and current trophic status). Each category rank was determined by ranking lakes according to several variables descriptive of that category, averaging the ranks, and then ranking the lakes according to the average.

The variables descriptive of each category were chosen based on their availability and our opinion that they are important in determining management priorities. The "Lake Significance" ranks were derived by averaging ranks according to area, estimated populations within 30 miles (based on OFM, 1989), number of other accessible lakes within 30 miles (from a 1:500,000 map), and number of homes along the shoreline. Each variable except number of lakes within 30 miles, was ranked in descending order; that is, for example, the larger the lake area, the lower the numerical value given the lake rank. In the case of the number of lakes within 30 miles, lakes with more nearby lakes were considered less significant and so were given higher ranks (i.e., ranked in ascending order). A lake with a low rank is considered to be more critical for protection than one with a high rank, based on the variables evaluated.

The "Susceptibility to Eutrophication" category ranks were derived by averaging ranks according to lake volume, shoreline development index, density of homes along the shoreline, drainage area to lake area ratio, and relative depth. (The shoreline development index indicates how winding the shoreline is; the relative depth indicates how deep the lake is compared to its surface area.) Each variable was ranked in descending order except for lake volume and relative depth which were ranked in ascending order. In general, the greater the volume, the less likely a lake is to become eutrophic and the higher (farther from one) its rank should be; similarly, the greater the relative depth (the deeper a lake is for its area) the less likely it is to become eutrophic.

The "Current Trophic State" category ranks were derived by averaging ranks according to percent littoral macrophytes, total phosphorus concentrations (both from Bortleson, *et al.*, 1976 a-d, and Dion, et al., 1976 a-c), and trophic state index (TSI) based on volunteer secchi readings (this project). Each variable was ranked in descending order; that is, for example, the greater the trophic state (i.e., the more eutrophic the lake), the lower the rank.

As an example, Duck Lake ranked 26th in lake area, 17th in number of homes along the shoreline, 32nd in population within 30 miles, and was tied for first (and therefore given a rank of 1.5) in the number of nearby lakes. The average of these ranks is 19.125, which was the 12th lowest average in the lake significance category. Similarly, Duck Lake placed 14th and 1st in the other two categories for an average category rank of 9.0. Because 9.0 is the lowest average category rank of the lakes evaluated, Duck Lake was given an overall score of 1.0.

The listing of a lake as "high priority" does not necessarily signify a requirement for management attention. This ranking scheme does not differentiate between natural

Table 4. Rankings of 1989 Volunteer Monitoring Program lakes proposed for use as a tool in setting lake management priorities. These ranking should be tempered with professional judgement (see text).

| Lake (County) | Management | Sign. of Lake | Suscep. to Eutroph. | Current Trophic Status | Overall Score |
|---|---|---|---|---|---|
| High Priority Lakes | | | | | |
| DUCK (GRAYS HARBOR) | H | 12.0 | 14.0 | 1.0 | 1.0 |
| NEWMAN (SPOKANE) | A | 1.0 | 7.5 | 20.0 | 2.0 |
| LONG (KITSAP) | C | 18.0 | 3.0 | 8.0 | 3.0 |
| LIBERTY (SPOKANE) | C | 2.0 | 16.0 | 13.5 | 4.0 |
| ELOIKA (SPOKANE) | A | 19.0 | 10.0 | 4.5 | 5.0 |
| KAHLOTUS (FRANKLIN) | | 26.0 | 7.5 | 3.0 | 6.0 |
| BIG (SKAGIT) | C | 14.5 | 5.0 | 18.0 | 7.0 |
| OSOYOOS (OKANOGAN) | | 24.0 | 6.0 | 12.0 | 8.0 |
| STEILACOOM (PIERCE) | H | 20.5 | 1.0 | 21.0 | 9.0 |
| S. PATTERSON (THURS) | C | 30.0 | 4.0 | 10.0 | 10.0 |
| Medium Priority Lakes | | | | | |
| ST. CLAIR (THURSTON) | | 17.0 | 11.0 | 16.5 | 11.0 |
| LONG (THURSTON) | C | 16.0 | 2.0 | 32.0 | 12.0 |
| CURLEW (FERRY) | A | 11.0 | 23.0 | 19.0 | 13.5 |
| DEER (STEVENS) | | 3.0 | 21.0 | 29.0 | 13.5 |
| BLUE (GRANT) | | 25.0 | 15.0 | 15.0 | 15.0 |
| MASON (MASON) | | 7.0 | 13.0 | 38.0 | 16.0 |
| KILLARNEY (KING) | H | 39.5 | 9.0 | 11.0 | 17.0 |
| LACAMAS (CLARK) | A | 37.0 | 18.0 | 7.0 | 18.0 |
| PHILLIPS (MASON) | | 31.0 | 12.0 | 24.0 | 19.0 |
| STARVATION (STEVENS) | | 45.0 | 17.0 | 6.0 | 20.0 |
| THOMAS (STEVENS) | | 34.0 | 19.0 | 16.5 | 21.5 |
| KITSAP (KITSAP) | C | 20.5 | 27.0 | 22.0 | 21.5 |
| BARNES (THURSTON) | | 46.0 | * | 2.0 | 23.0 |
| WILLIAMS (SPOKANE) | | 29.0 | 32.5 | 13.5 | 24.0 |
| SAMISH (WHATCOM) | | 14.5 | 38.0 | 23.0 | 25.0 |
| WENATCHEE (CHELAN) | | 5.0 | 31.0 | 40.0 | 26.0 |
| GOODWIN (SNOHOMISH) | C | 8.0 | 26.0 | 43.0 | 27.0 |
| CRANBERRY (ISLAND) | | 43.0 | 30.0 | 4.5 | 28.0 |

A = Active (Phase I or II)
C = Completed (Phase I or II)
H = Regularly treated with algicides or herbicides
* = No data

Table 4. Continued.

| Lake (County) | Management Status | Sign. of Lake | Suscep. to Eutroph. | Current Trophic Status | Overall Score |
|---|---|---|---|---|---|
| Medium Priority Lakes (cont.) | | | | | |
| BIG MEADOW (PEND OREILLE) | | 47.0 | 22.0 | 9.0 | 29.0 |
| SUTHERLAND (CLALLAM) | | 9.0 | 25.0 | 45.0 | 30.0 |
| BLACKMANS (SNOHOMISH) | | 27.0 | 28.0 | 25.0 | 31.0 |
| CLEAR (THURSTON) | H | 33.0 | 24.0 | 28.0 | 32.0 |
| DEEP (STEVENS) | | 39.5 | 20.0 | 26.0 | 33.0 |
| Low Priority Lakes | | | | | |
| LOON (STEVENS) | | 6.0 | 44.0 | 44.0 | 34.0 |
| SUMMIT (THURSTON) | | 13.0 | 40.0 | 42.0 | 35.0 |
| CLE ELUM (KITTITAS) | | 10.0 | 39.0 | 47.0 | 36.0 |
| CRESCENT (CLALLAM) | | 4.0 | 47.0 | 48.0 | 37.0 |
| FLOWING (SNOHOMISH) | | 22.0 | 42.0 | 37.0 | 38.0 |
| GOSS (ISLAND) | | 36.0 | 32.5 | 33.5 | 39.0 |
| TIGER (KITSAP/MASON) | | 35.0 | 34.0 | 33.5 | 40.0 |
| ISLAND (MASON) | | 38.0 | 35.0 | 30.0 | 41.0 |
| DAVIS (PEND OREILLE) | | 32.0 | 41.0 | 31.0 | 42.0 |
| BLACK (STEVENS) | | 44.0 | 36.0 | 27.0 | 43.0 |
| PACKWOOD (LEWIS) | | 28.0 | 45.0 | 35.5 | 44.0 |
| LOUISE (PIERCE) | H | 41.0 | 29.0 | 39.0 | 45.0 |
| SULLIVAN (PEND OREILLE) | | 23.0 | 46.0 | 46.0 | 46.0 |
| WOOTEN (MASON) | | 42.0 | 37.0 | 41.0 | 47.0 |
| CRAWFISH (OKANOGAN) | | 48.0 | 43.0 | 35.5 | 48.0 |

A = Active (Phase I or II)
C = completed (Phase I or II)
H = Regularly treated with algicides or herbicides
* = No data

eutrophication. In fact, protection of some "low-priority" lakes just beginning to experience priority" lakes that may be naturally eutrophic. In addition, only the 48 lakes active in the 1989 monitoring program were included in the ranking. Table 4 should be used as a broad guideline only and tempered with professional judgement. An appropriate use of the rankings would be as a tie-breaker between two management proposals of equal merit.

Lakes listed in table 4 are divided into "high", "medium", and "low" priority categories. These division lines were based primarily on best professional judgement. Eight of ten "high priority" lakes, 7 of 18 "medium priority" lakes, and one "low priority" lake are receiving or have received management attention. "Management attention" is defined here as receiving EPA grant money for Phase I (study) or Phase II (implementation) work or being regularly treated with herbicides. This ranking scheme seems to be in general agreement with past management funding decisions.

Obviously, receiving management attention does not necessarily shift a lake out of the "high priority" category. This is because while water quality (and therefore the "current trophic status" rank) may improve, most management actions will not affect the "susceptibility to eutrophication" and "significance" ranks.

There are several ways these rankings could be improved. For example, including current nutrient data, importance as a fishery, importance as a drinking water source, as well as other variables would refine this list. Using a TSI based on more than one year's data would also improve the assessment. There are three areas of particular importance missing from this ranking scheme:

1) A trend assessment. A deteriorating lake should take priority over a stable lake, other things being equal. This information is not yet available for most lakes.

2) A meaningful evaluation of macrophyte problems. Some lakes have low phosphorus concentrations and good Secchi depth measurements and yet have serious macrophyte problems. This is particularly true of lakes infested with eurasian milfoil (*Myriophyllum spicatum*). These lakes may be in desperate need of management but are unlikely to be near the top of Table 4.

3) Weighting of variables. Weighting each variable according to its relative importance in determining need for management would also improve the rankings. For example, spring phosphorus concentrations may be considered more important than trophic state based on Secchi readings. Because we wanted to avoid imparting our own biases on the ranking, all variables were weighted equally for this report. In the future, weighing factors may be applied after consultation with lake management professionals.

4) Forecasts. Anticipated changes in the lake or its watershed (such as heavy development pressures), could affect water quality and the lake's management priority.

5) Assessment of management potential. As discussed earlier, it may not be cost effective or even desirable to "restore" naturally eutrophic lakes. Also, some watershed uses may be more easily managed than others.

## Questionnaire Results

Of the 48 active volunteers, 44 completed and returned the questionnaires. A summary of results from the 44 questionnaires is in Table 5.

Most of the lakes have a moderate to heavy amount of residential development along the shoreline. Twenty of the monitored lakes have 40 or more houses per mile of shoreline. Most of the lakes are used for fishing, swimming, and boating and most of the lakeshores are being developed further for residences.

In the water quality problem ranking section, it was apparent that most of the volunteers perceived some kind of water quality problem in their lake. Only six of the monitored lakes were cited by their volunteer as having no water quality problems. Because not all volunteers ranked each water quality problem, it was difficult to evaluate their overall perceptions. Of the 38 lakes responding to the survey that were perceived by the volunteer as having water quality problems, weeds were identified as being a problem in 66% (25 lakes). Suspended sediments were a problem in 32% (12 lakes), lake level in 34% (13 lakes), garbage, debris and leaves in 5 lakes, fish kills in 3 lakes, and rough fish (non-game species) in three lakes.

## Quality Assurance

Of the 484 total data sheets returned by the volunteers, 12 readings (2.8%) did not include duplicate readings. Eight of these readings are from one lake (Patterson Lake, Thurston County). In addition, 18 readings could not be evaluated because the Secchi disk depth was not valid (from either hitting the lake bottom, or disappearing in weeds). Therefore, quality assurance evaluations were based on 454 data records for which there were both replicate and valid records.

Overall, 84% of the replicate readings collected by the volunteers had a relative percent difference (RPD) of less than 5%. However, 19 data records (3.9% of the 454 records evaluated for quality assurance) were not considered to be within acceptable limits. Four of the data records are from lakes with Secchi readings of less than 10 feet and the replicate reading is not within 1 foot. Of the Secchi readings greater than 10 feet, 15 were not considered acceptable because the replicate readings were not within 10%. Of these 15 readings, six were from one lake (Mason Lake, Mason County). The data from these 19 records are reported, but are flagged to indicate the data are questionable.

TSI's based on Secchi depths collected by volunteers agreed remarkably well with those collected by Ecology staff at lakes Ecology studied in more detail (Brower and Kendra, 1990) (Figure 9). In all cases but two, the average volunteer-based TSI was either with one or two TSI units of an Ecology-based TSI or between the spring and fall Ecology-based TSI's. In those two lakes (Williams and Duck) the differences were small.

Table 5. Summary of results form 44 questionnaires completed by volunteer.

| | Number of Responses | % of Responses |
|---|---|---|
| **Recreational Uses** | | |
| Fishing | 44 | 100.0 |
| Boating | 32 | 72.7 |
| Swimming | 41 | 93.2 |
| Canoeing | 42 | 95.5 |
| Jet Skiing | 29 | 65.9 |
| Sailing | 35 | 79.5 |
| Aesthetics | 40 | 90.9 |
| Picnicking | 32 | 72.7 |
| Camping | 27 | 61.4 |
| Hiking/Walking | 28 | 63.6 |
| Waterfowl Hunting | 11 | 25.0 |
| **Public Facilities** | | |
| Picnic Tables | 28 | 63.6 |
| State Parks | 5 | 11.4 |
| Camping | 24 | 54.5 |
| Pit Toilets | 15 | 34.1 |
| Flush Toilets | 19 | 43.2 |
| Showers | 11 | 25.0 |
| Parks | 13 | 29.5 |
| Beaches | 17 | 38.6 |
| **Boating Restrictions** | | |
| No Motor Boats Allowed | 4 | 9.1 |
| No Restrictions at All | 15 | 34.1 |
| **Lake Water Uses** | | |
| Drinking/Domestic | 16 | 36.4 |
| Municipal | 0 | 0.0 |
| Industrial | 1 | 2.3 |
| Irrigation | 14 | 31.8 |
| **Current Watershed Uses** | | |
| Logging | 21 | 47.7 |
| Agriculture--Crops | 20 | 45.5 |
| Animal Grazing | 15 | 34.1 |
| Industry | 3 | 6.8 |
| Residential Development | 32 | 72.7 |
| **Historical Watershed Uses** | | |
| Logging | 35 | 79.5 |
| Agriculture | 21 | 47.7 |
| Mining | 8 | 18.2 |
| Lake or Wetlands Dredging | 8 | 18.2 |
| Shoreline Alteration | 17 | 38.6 |

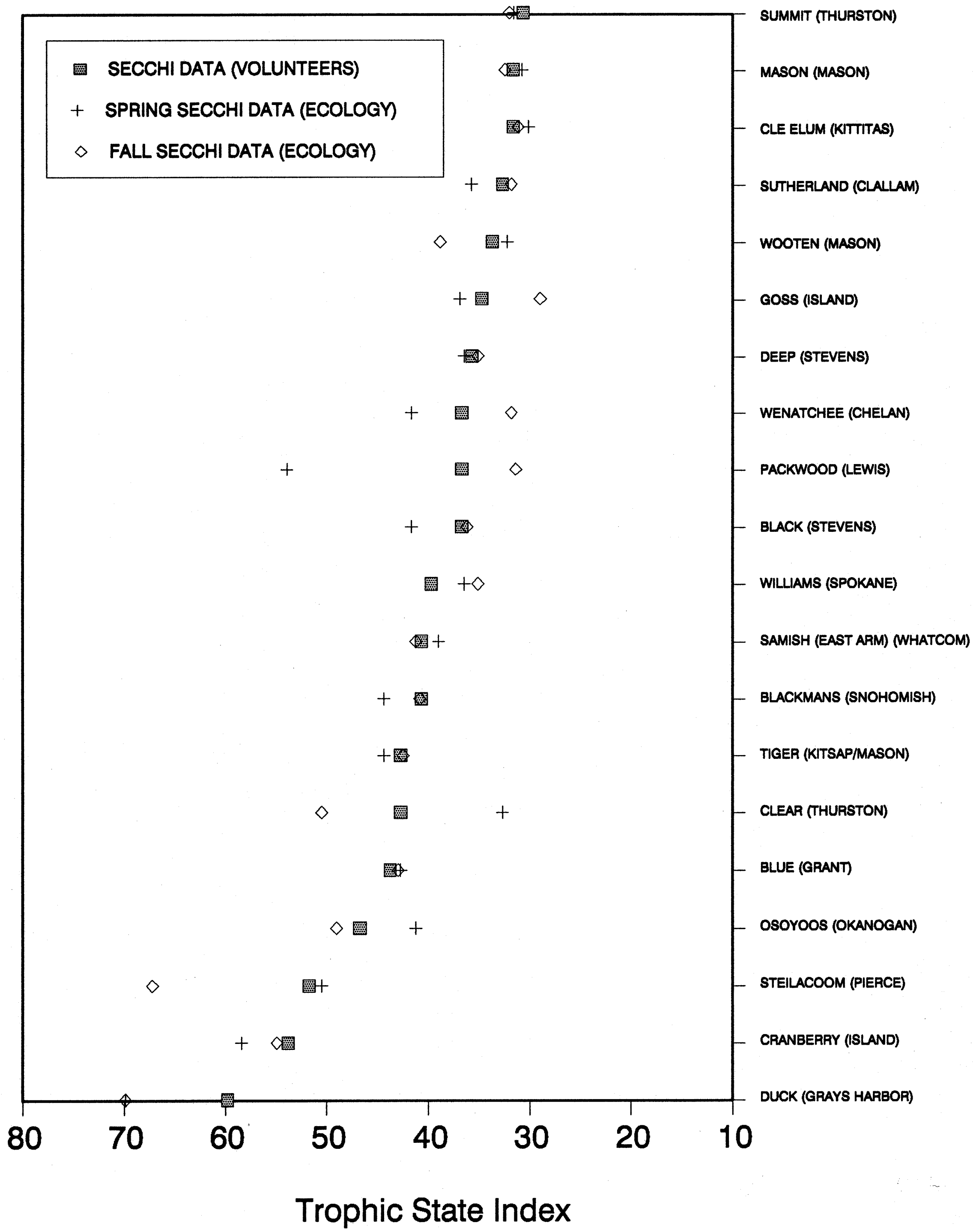



FIGURE 9. Comparison of volunteer-collected Secchi-based TSI with spring and fall TSI from the conventional parameter study (Brower and Kendra, 1990).

Figure 9 demonstrates not only that volunteers can collect Secchi data comparable to professionally-collected data, but also the importance of sampling more frequently than once in the spring and once in the fall. The Ecology TSI's are often widely separated due to seasonal changes in water clarity making an overall TSI determination difficult. The volunteer TSI was based on an average of Secchi depths collected during the growing season. The observation that volunteer-collected Secchi data is superior to single samples collected by professionals can be quantified by examining the correlation coefficients between Secchi depth and variables measured by Ecology staff (Table 3). Correlation coefficients between the mean volunteer Secchi depth and spring total phosphorus and spring chlorophyll (-0.763 and -0.695, respectively) were better than those between Ecology Secchi depths and those variables.

Quality Assurance plans for the 1990 program included measuring the Secchi disks ropes used by the volunteers to account for shrinkage, taking duplicate Secchi readings with the volunteers during site visits, and continuing to have the volunteers take two Secchi readings each time they sample. We also recruited a second volunteer for some of the lakes monitored in 1990, in order to compare within lake variability of volunteer-collected data.

**Individual Lake Assessments**

The individual lakes assessments are listed alphabetically by lake. These assessments were written for the volunteers, who, in early December 1990, each received the summary for the lake they monitored, as well as a brief description of how the assessments were made, how their lake compared to others in the program, and a glossary. (See Appendix D.)

Trophic state estimations were based on Secchi disk readings collected from June through September, 1989. Data interpretation was based mainly on the Secchi depth graphs, water color, and any past data on the lakes that were available. All data collected by the volunteers are reported, although comments and observations made by the volunteers are summarized or abbreviated.

Although lake water quality varies from year to year, these assessments are based primarily on one growing season of data (results from previous studies were considered when available). One of the major factors affecting annual variations is weather. During 1989, annual precipitation was about 8% lower in Spokane and 9% lower in Seattle compared with historical precipitation data (Table 2). Temperatures were also not unusual, except for an extremely cold period in early January. Nevertheless, lake levels are reported to have been very low in Eastern Washington (Ken Merrill, WA Department of Ecology, personal communication) perhaps as a result of unusual timing of precipitation events (for example, a rain-on-snow event) or as a carryover from previous low-precipitation years. Water level, which affects lake volume, littoral area exposed to light, exposure of shoreline sediments, etc., can have a pronounced affect on water quality. An evaluation of these affects is beyond the scope of this report.

Barnes Lake -- Thurston County

Barnes Lake is located three miles south of Olympia. It drains to Percival Creek and Budd Inlet. It is an urban lake that receives some runoff from Interstate 5. About 95% of the lakeshore is developed for residences and some private facilities. The lake may not have a public access, but was included in the project because of the considerable community interest.

| | |
|---|---|
| Size (acres) | 14 |
| Maximum Depth (feet) | * |
| Mean Depth (feet) | * |
| Lake Volume (acre-feet) | * |
| Drainage Area ($miles^2$) | * |
| Altitude (feet) | 150 |
| Shoreline Length (miles) | * |

*information not available

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 60 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated remarks |
|---|---|---|---|---|---|---|
| 06/11 | 1330 | Gr-Br | Sunny | 22.0 | 5.50 | Lots of algae (gray-green, slight yellow) on bottom of most of lake. |
| 06/18 | 1200 | Gr-Br | P Cloudy | 23.0 | 4.58 | Lily pads have moved from center of lake to shore areas. Lilies are white. |
| 06/25 | 1230 | Gr-Br | Sunny | 24.0 | 4.81 | Algae mats floating on water (A first). Lilies: 5% yellow, 95% white. |
| 07/11 | 1200 | Gr-Br | P Sunny | 21.0 | 4.35 | Lilies enclosed more of east shore area. |
| 07/16 | 1245 | Brown | P Cloudy | -- | 3.67 | |
| 07/23 | 1415 | Brown | Sunny | 21.0 | 3.21 | Heron sighted at lake. |
| 07/30 | 1330 | Brown | Cloudy | -- | 2.75 | |
| 08/06 | 1417 | Brown | Sunny | -- | 2.75 | Water level is down. |
| 08/13 | 1200 | Gr-Br | P Cloudy | 20.0 | 2.29 | |
| 08/20 | 1245 | Brown | P Cloudy | 19.0 | 1.83 | Water level is down. More dry leaves on water lily. |
| 08/27 | 1200 | Brown | Sunny | -- | 2.75 | |
| 09/03 | 1413 | Brown | Sunny | 20.0 | 1.83 | |
| 09/17 | 1235 | Brown | P Sunny | 17.0 | 1.83 | Edge of lake now mud and dying lily pads. |

The water clarity gradually decreased over the summer with the lowest water clarity occurring from mid- to late August. The water color was consistently brown or green-brown throughout the sampling period.

## Summary of Questionnaire Results and Information from the Volunteer

The questionnaire on lake and watershed uses was not returned. The following are from the volunteers' remarks. Lily pads are abundant in the lake and cover a considerable portion of the lake surface. One volunteer reported that 95% of the lilies have a white flowers (water lily;

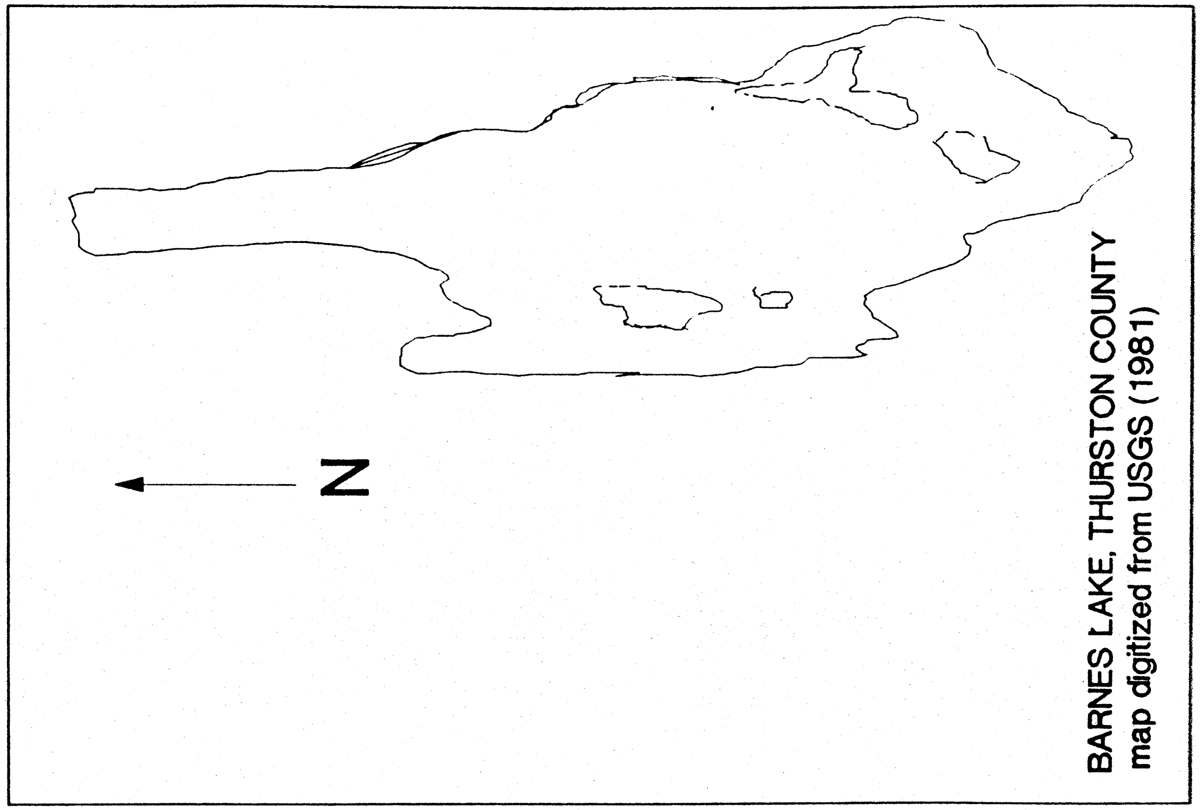
*Nymphaea odorata*) and about 5% have yellow flowers (pond lily; *Nuphar polysepalum*). Lilies started to turn brown and dry up in August. The water level lowered considerably over the course of the summer. Floating algae mats were noted for the first time this summer.

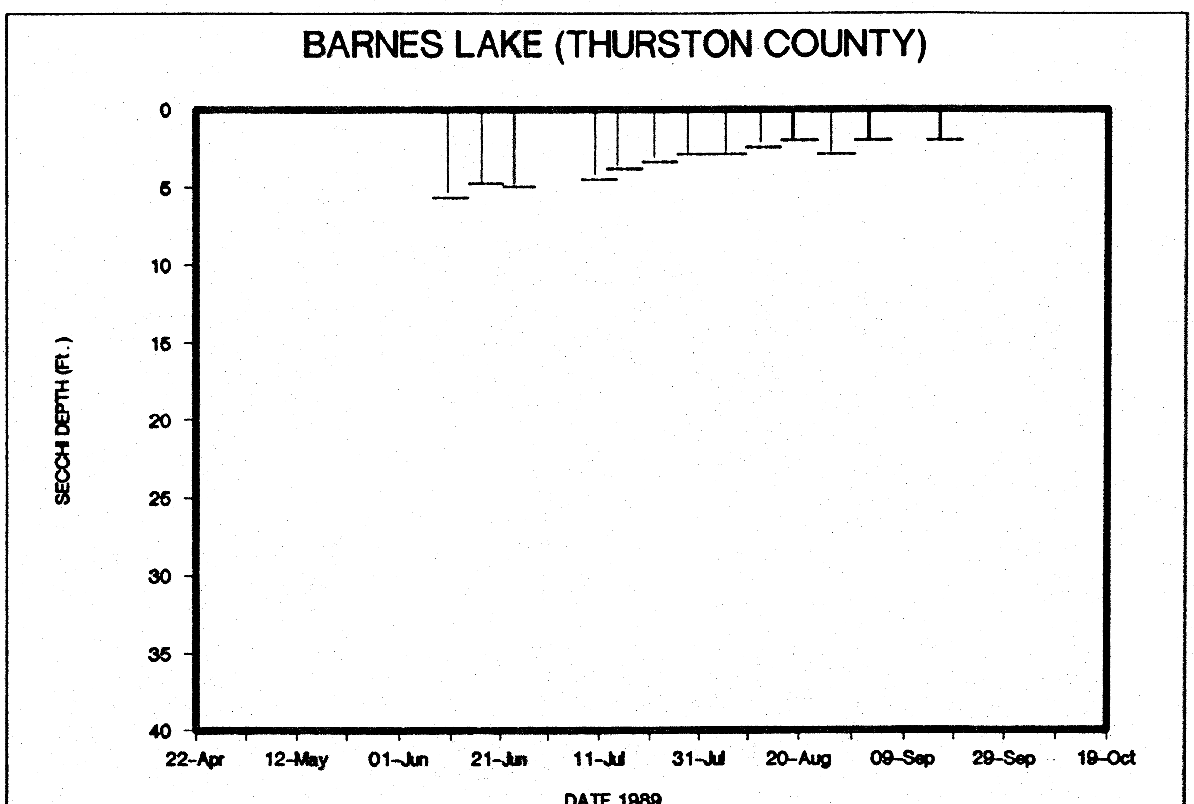
Summary of Other Available Information

No other information was available for Barnes Lake.

Comments

Barnes Lake is one of the smaller and shallower lakes in the program and had some of the lowest water clarity readings, even compared to other small shallow lakes in the program such as Lake Killarney and Starvation Lake. Many of the lakes in the program with an average depth of less than 20 feet are eutrophic. However, because Barnes Lake is so much smaller than most of the lakes in the program, it is not surprising that the only lake in the program that had lower average water clarity than Barnes Lake was Duck Lake, which is a reclaimed wetland.


N
BARNES LAKE, THURSTON COUNTY
map digitized from USGS (1981)


BARNES LAKE (THURSTON COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Big Lake -- Skagit County

Big Lake is located five miles southeast from Mount Vernon. It is 2.75 miles long. Nookachamps Creek is both the inlet and the outlet, and drains to the Skagit River.

| | |
|---|---|
| Size (acres) | 520 |
| Maximum Depth (feet) | 23 |
| Mean Depth (feet) | 14 |
| Lake Volume (acre-feet) | 7470 |
| Drainage Area (miles$^2$) | 22.4 |
| Altitude (feet) | 81 |
| Shoreline Length (miles) | 6.21 |

| | |
|---|---|
| Trophic State: | mesotrophic |
| Mean Trophic State Index: | 44 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/13 | 1700 | Bl-Gr | Sunny | 16.0 | 12.83 | Lake somewhat choppy due to speed boats and light wind. |
| 06/03 | 1525 | Bl-Gr | Sunny | 20.5 | 13.75 | Encountered a lot of power boat traffic. |
| 06/22 | 1500 | Bl-Gr | -- | 17.5 | 11.00 | Very windy. We had to take reading about 1/4 mile south of the usual location. |
| 07/02 | 1810 | Green | Cloudy | 18.0 | 5.96 | Raining, rough water. Major growth of lily pads at south end of lake. |
| 07/13 | 1605 | Green | Sunny | 21.0 | 10.08 | Windy; relatively calm water. |
| 07/29 | 1800 | Green | P Sunny | 21.0 | 11.00 | Some clouds and wind. |
| 08/15 | 1620 | Green | Cloudy | 21.0 | 11.00 | |
| 08/28 | 1730 | Green | P Cloudy | 22.0 | 9.17 | |
| 09/07 | 1700 | Bl-Gr | Sunny | 19.0 | 7.33 | |

The water color was green or blue-green throughout the sampling period. The low clarity reading during early July was more likely from rough weather conditions than from algal growth. As a result, it is probable that water clarity remained fairly stable from mid-June through mid-August. As would be expected, algal growth increased from late August to September.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Big Lake is used for fishing, boating, swimming, and camping. Floatplanes land on the lake. There is one resort, a college recreation facility, and a golf course on the lakeshore; all three are located at the northern (and deeper) half of the lake. Water is withdrawn for drinking and other domestic uses and for irrigation. Currently the watershed is used for logging and crop agriculture, and residential development of the lakeshore is occurring. There are 241 houses on the lakeshore, and 90-95% of these houses are occupied year-round. The lakeshore is partially sewered. The lake is stocked with rainbow trout, and according to the volunteer, the bass and trout fishing has been good in 1989. The southern end of the lake (around the inlet) is 40 - 50 acres of wetlands that support wildlife. There is local concern that the wetlands need to be protected from development. Weed growth in the lake is thick and in areas they grow to the water surface.

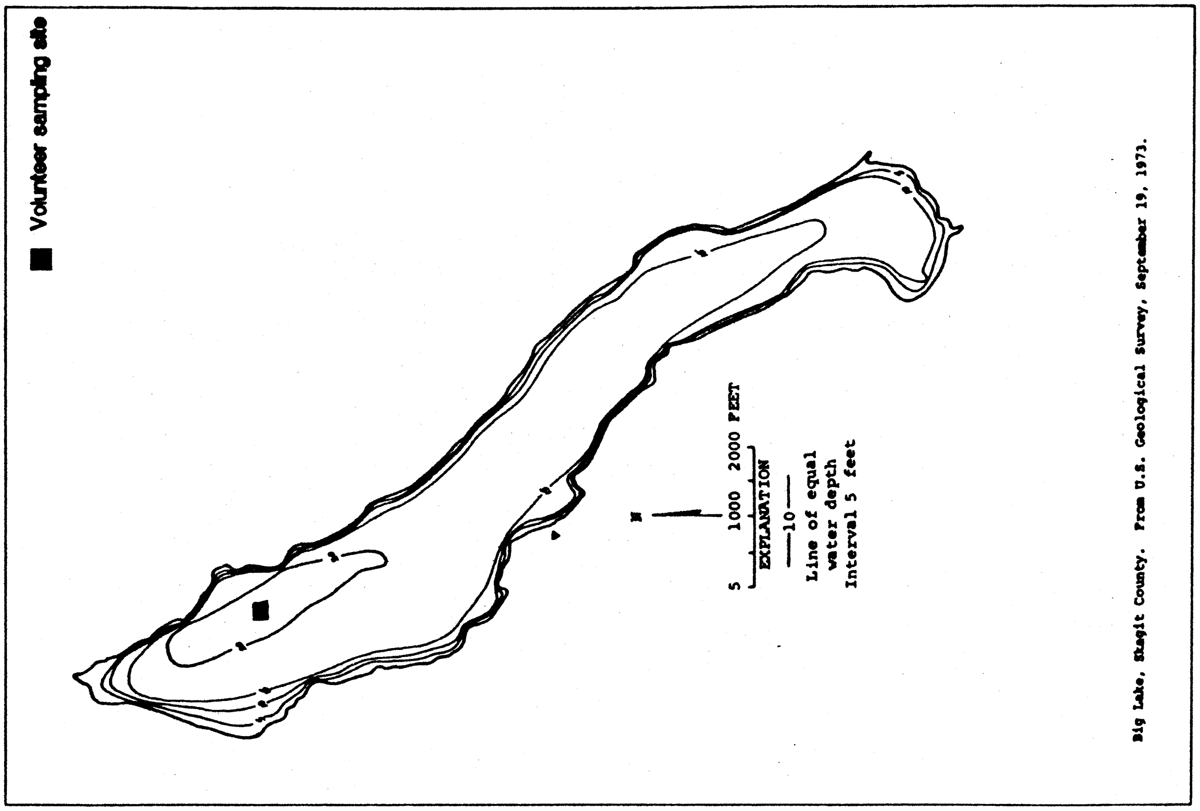
Areas thick with weeds are at the north end of the lake, near the public boat launch, and the wetland area at the south end of the lake near the inlet. There are yellow-flowering lilies, white-flowering lilies, and pink-flowering lilies in the lake, mostly at the south end. In the wetlands there are cattails, reeds, grasses and willows. The volunteer noted that the lake quality appeared to improve after the sewer was installed, and is concerned about possible water quality effects from motor boats on the lake.

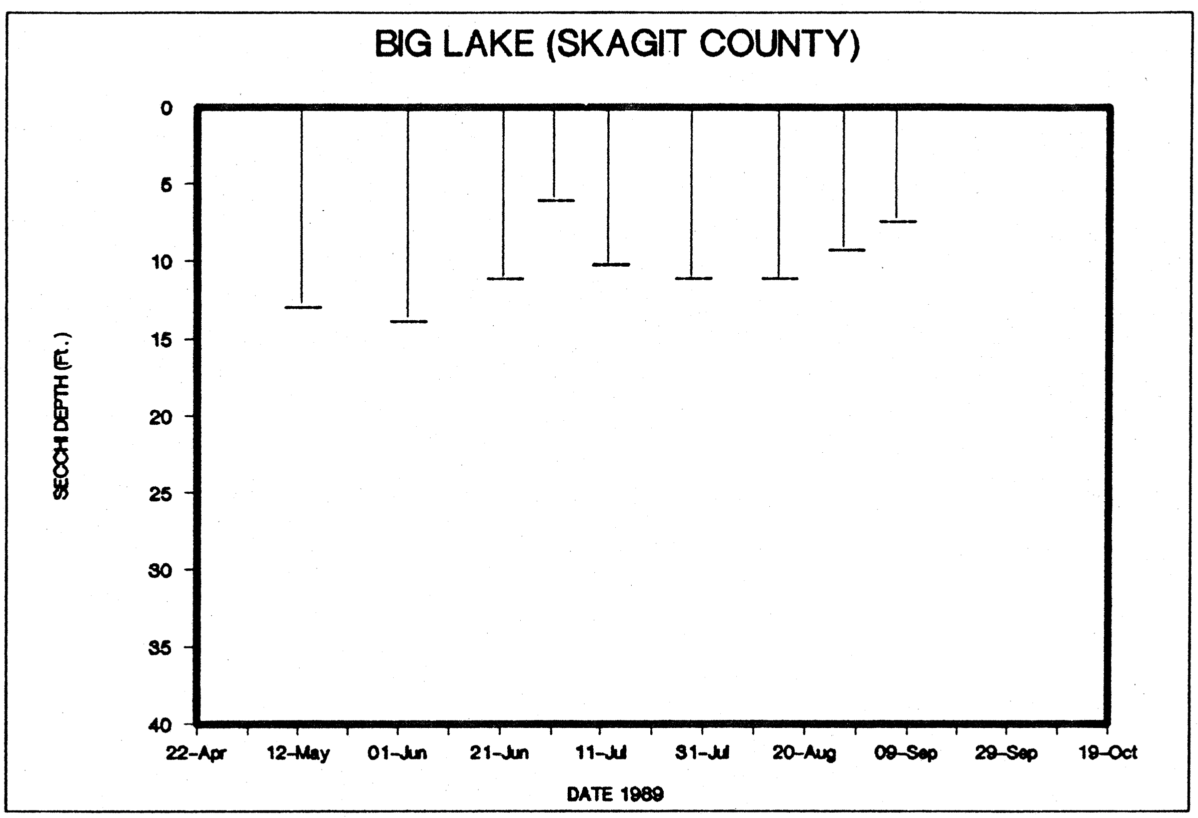
## Summary of Other Available Information

In 1973 there were 179 nearshore homes (Bortleson *et al.*, 1976), so residential development along the shore of Big Lake has increased since 1973. Data collected from Big Lake in 1973 show total phosphorus concentrations and Secchi disk transparency in the range of mesotrophic lakes (Bortleson *et al.*, 1976).

## Comments

Compared to other lakes in the program, Big Lake is relatively shallow. This would make it more prone to water quality problems that result from sediment stirring. Warmer water temperatures, increased sunlight and nutrients stirred from the sediments may well contribute to water clarity reduction during the summer months.


Volunteer sampling site
5 1000 2000 FEET
EXPLANATION
—10—
Line of equal
water depth
Interval 5 feet
N
Big Lake, Skagit County. From U.S. Geological Survey, September 19, 1973.


BIG LAKE (SKAGIT COUNTY)
SECCHI DEPTH (FT.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Big Meadow Lake -- Pend Oreille County

Big Meadow Lake lies in a peat area about 20 miles northeast from Colville at the head of Meadow Creek. It drains westerly to the south fork of Deep Creek and ultimately to the Columbia River. It was dammed in the mid-seventies and enlarged from its original size of about four acres to its present size of about 72 acres.

| | |
|---|---|
| Size (acres) | 72 |
| Maximum Depth (feet) | 23 |
| Mean Depth (feet) | 7.2 |
| Lake Volume (acre-feet) | 512 |
| Drainage Area (miles$^2$) | * |
| Altitude (feet) | 3450 |
| Shoreline length (miles) | * |

*information not available

| | |
|---|---|
| Estimated Trophic State: | meso-eutrophic |
| Mean Trophic State Index: | 49 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/01 | 1220 | Gr-Br | P Cloudy | 13.0 | 7.79 | A little chop on the surface. |
| 05/15 | 1110 | Gr-Br | Sunny | 15.0 | 9.85 | Breezy. |
| 05/31 | 1235 | Gr-Br | P Cloudy | 17.5 | 11.00 | Light breeze about 10 mph. |
| 06/13 | 1342 | Gr-Br | P Cloudy | 23.0 | 6.87 | Breeze about 10 mph. Hazy sun. |
| 06/28 | 1237 | Gr-Br | P Sunny | 21.0 | 5.96 | Hazy sun. Wind very calm. |
| 07/14 | 1300 | Gr-Br | Sunny | 24.5 | 6.42 | The floating island reappeared. USFS campground is being developed. |
| 07/27 | 1130 | Green | Sunny | 24.0 | 8.02 | Breeze 7 - 10 MPH |
| 08/11 | 1210 | Gr-Br | Sunny | 22.0 | 8.25 | Bright day. Breeze about 5 - 10 mph from east. Over 2" rain in last 2 days. |
| 08/25 | 1230 | Gr-Br | Cloudy | 19.0 | 6.87 | New aeration system installed today to prevent winter fish kill. |
| 09/08 | 1222 | Gr-Br | P Cloudy | 18.0 | 6.65 | East wind 5 - 10 mph. 1 - 3 Inch chop on water. |
| 09/22 | 1245 | Gr-Br | Sunny | 15.5 | 8.25 | East wind 5 - 10 mph. Slight chop. Need new thermometer. |
| 10/03 | 1415 | Gr-Br | Sunny | 13.5 | 8.94 | Breezy, slight chop. |

Algal growth briefly affected water clarity during June and late August/early September. The water color was green-brown throughout the sampling period.

Summary of Questionnaire Results and Information From the Volunteer

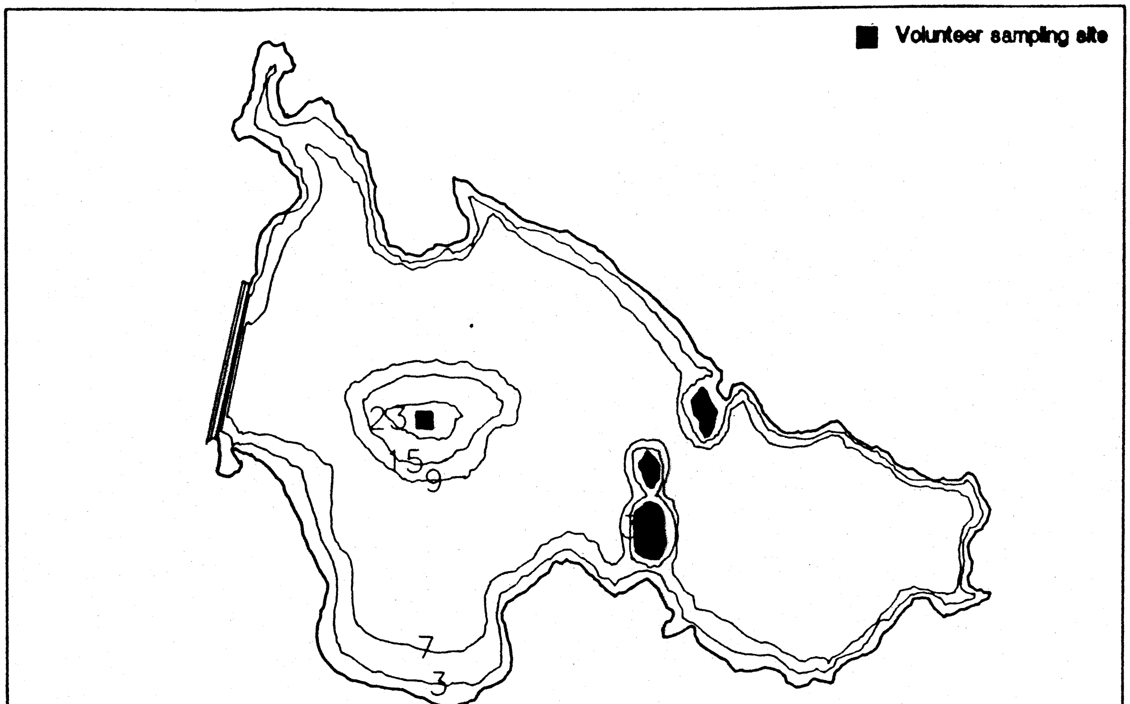
The following information is from the volunteer's remarks and questionnaire responses. Big Meadow Lake is used for fishing, picnicking, camping and waterfowl habitat. There are no houses on the lake. The Forest Service is developing a campground at the lake. Fish are stocked in the lake. The worst water quality problem identified by the volunteer is the winter kill of fish that occurs in January - February. The Game Department installed an aeration system on August 25, 1989, to prevent the fish kills. The entire lake has submerged weeds except for the areas of the original lake. Open areas about seven feet deep have floating-leaved type weeds.

Summary of Other Available Information

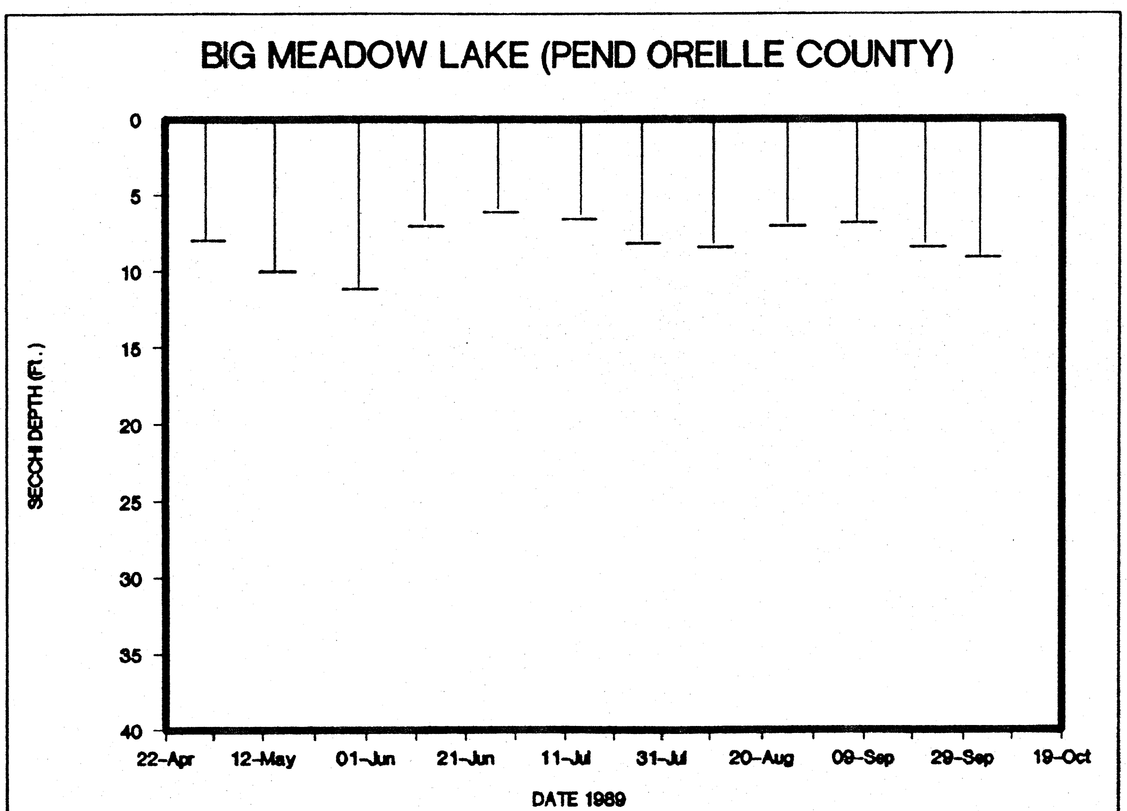
Big Meadow Lake was originally four acres in size, and was enlarged in the 1970s by damming Meadow Creek.

Comments

Big Meadow Lake is more eutrophic than other northeastern Washington lakes of similar size that were monitored for the program (Black Lake and Crawfish Lake are both estimated to be oligotrophic and cover 70 and 80 acres, respectively). Nutrients leached from the soils and vegetation when the lake was enlarged, and nutrients released from decaying fish after a winterkill may have contributed to the enrichment of the lake.




Big Meadow Lake, Pend Oreille County.
Digitized from USGS 1982 topographic map



Black Lake -- Stevens County

Black Lake is located about 12.5 miles east from Colville. It is 4800 feet long. The main inflow is intermittent, and flows into the north end of the lake. Black Lake drains via Gap Creek southeasterly to the Little Pend Oreille River.

| | |
|---|---|
| Size (acres) | 70 |
| Maximum Depth (feet) | 45 |
| Mean Depth (feet) | 27 |
| Lake Volume (acre-feet) | 1863 |
| Drainage Area (miles$^2$) | 0.90 |
| Altitude (feet) | 3701 |
| Shoreline Length (miles) | 2.03 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 38 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/02 | 1130 | Brown | P Cloudy | 10.0 | 8.7 | Lake thawed last week; water is murky, lake level high. Beaver dam at outlet. |
| 05/18 | 1030 | Brown | P Cloudy | 12.5 | 11.92 | The ice has been off lake about three weeks; some dirt remains in the water. |
| 06/02 | 0930 | Brown | Sunny | 18.0 | 17.42 | (Water color noted as brown-clear.) |
| 07/05 | 1000 | Brown | Sunny | 18.0 | 17.42 | Some wind. Readings same as month ago. |
| 07/16 | 1030 | Blue | P Cloudy | 22.0 | 13.75 | Windy - probably reduced visibility. |
| 08/06 | 1530 | Blue | Sunny | 25.0 | 16.04 | Nice day. We should be taking some serious water tests. |
| 09/27 | 1000 | Brown | Sunny | 16.0 | 18.33 | Calm and clear. (Water color noted as clear brown.) |
| 10/17 | 1100 | Brown | Sunny | 12.0 | 12.83 | The lake "turned over" in past two weeks; color was brown and visibility dropped. |

The water clarity was lowest from April through May. Although other higher elevation lakes in Eastern Washington experienced low water clarity during May because of spring algal growth, the volunteer in Black Lake noted suspended sediments in the water from the recent thaw.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Black Lake is used for fishing, swimming, canoeing/rowing, sailing/wind surfing, picnicking, camping, hiking, cross-country skiing and, while the lake is frozen, snowmobiling and golf. The water is withdrawn for drinking and other domestic uses. There is one resort (with camping) on the lakeshore. Currently the watershed is used for logging and tree farm operation, and residential development is occurring along the lakeshore. There are 26 houses on the lakeshore; only three are occupied year-round and all have on-site wastewater disposal systems. Homeowners rake weeds from their lakeshore areas. There is a beaver dam and a wetland area at the north end at the inlet. The worst water quality problem, in the opinion of the volunteer, is the increasing amount of weeds during the summer. The volunteer is also concerned about fecal coliform bacteria contamination and giardia.

Photos and aquatic weed descriptions were sent in by the volunteer. Most of the shoreline is ringed with reeds and grasses, and there are scattered weeds that reach the surface up to 20 - 40 feet offshore. Photos show submerged species (*Elodea*) of aquatic plants, floating-leaved pond weeds (*Potamogeton*) and pond lily (*Nuphar*), and emergent species of cattail, reeds, and grasses.

Results of Intensive Sampling/Summary of Other Available Information

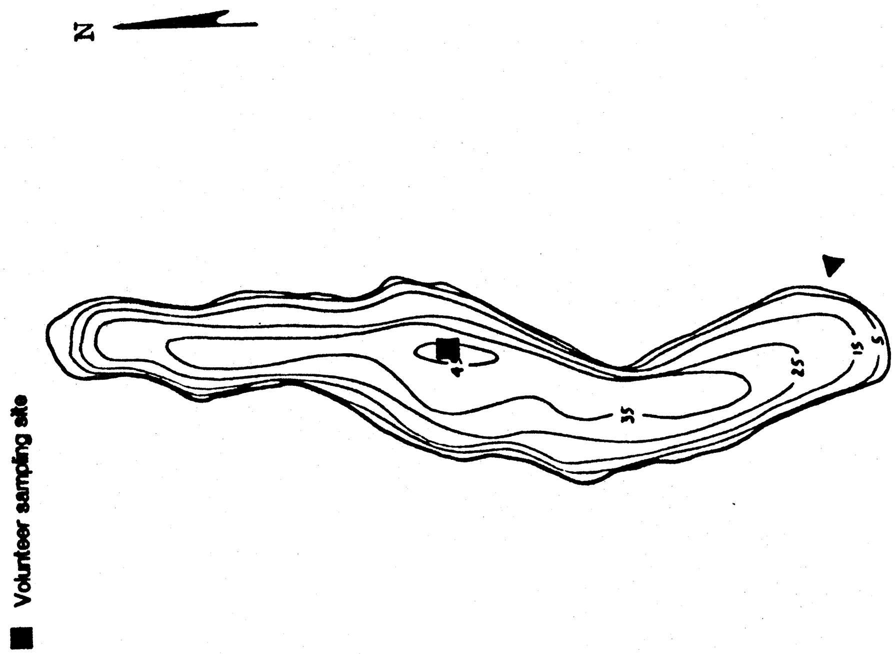
Intensive survey data from 1989 indicate that Black Lake is most likely oligotrophic because the lake has relatively high Secchi disk values and relatively low epilimnetic concentrations of total phosphorus and chlorophyll *a*. The low concentrations of dissolved oxygen in the hypolimnion and prolific aquatic plant growth in Black Lake would not normally be associated with an oligotrophic lake. However, compared to the other 24 lakes monitored by Ecology in 1989, Black Lake had very low nutrient concentrations.

The concentrations of dissolved oxygen in the hypolimnion were very low on both sampling dates. Low dissolved oxygen concentrations (0.4 mg/L at 30 feet) were also reported in 1974 (Dion *et al.*, 1976), indicating that this is not a new phenomenon. Low dissolved oxygen concentrations occur from the bacterial decomposition of organic material (such as plants, algae, and woody debris, at the bottom of the lake. Decaying vegetation would also result in the brown and clear-brown water color that is probably the namesake of the lake, as well as the color noted by the volunteer during most of the sampling period. An olive color noted in September was likely the result of an increase in algal growth; this is supported by the slightly elevated chlorophyll *a* concentration and reduced Secchi visibility. Aquatic plants covered 90 - 95% of the shoreline with scattered patches offshore.

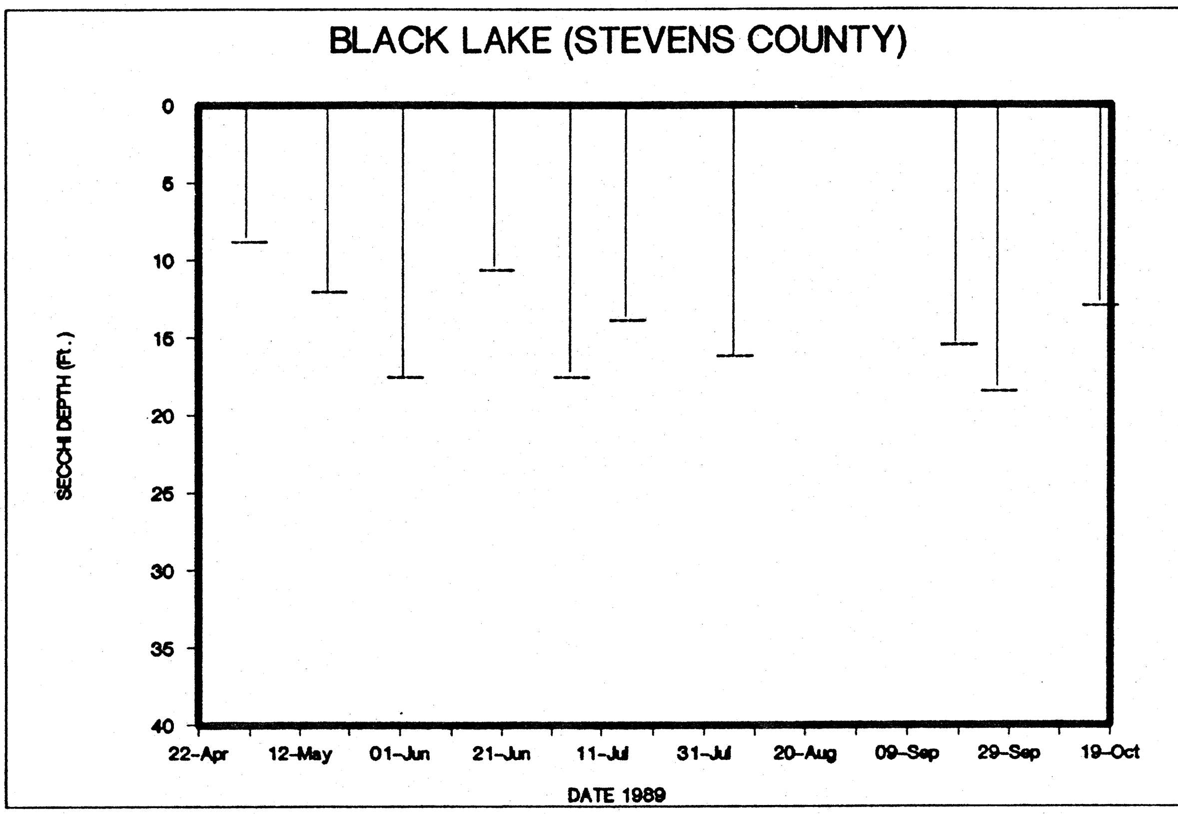
Comments

Compared to other lakes monitored in the program, the water quality of Black Lake is very good considering its size, amount of plant growth, and lack of dissolved oxygen in the hypolimnion.

Fecal coliform bacteria samples, a concern of the volunteer, were collected by Ecology during June and September, 1989, and the results did not indicate a bacteria problem in the lake. However, it should be noted that samples were collected from the surface at the center of the lake and not from nearshore areas where counts may be higher.




Black Lake, Stevens County. From Washington Department of Game, March 31, 1949.



Blackmans Lake -- Snohomish County

Blackmans Lake is located one mile north from Snohomish. A perennial stream flows into the lake from the north. Blackmans Lake drains to the Snohomish River. Motor boats are not allowed on the lake.

| | |
|---|---|
| Size (acres) | 57 |
| Maximum Depth (feet) | 29 |
| Mean Depth (feet) | 14 |
| Lake Volume (acre-feet) | 798 |
| Drainage Area (miles$^2$) | 0.81 |
| Altitude (feet) | 140 |
| Shoreline Length (miles) | 1.47 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 41 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/18 | 1717 | Bl-Gr | P Cloudy | 17.2 | 11.00 | |
| 05/02 | 1700 | Blue | Sunny | 20.0 | 15.58 | |
| 05/16 | 1630 | Brown | Cloudy | 20.6 | 14.67 | |
| 09/05 | 1625 | Blue | Sunny | 21.7 | 14.67 | |
| 09/19 | 1600 | Blue | Sunny | 20.0 | 14.21 | Water plant life starting to float to surface. |
| 10/17 | 1730 | Blue | Sunny | 15.6 | 11.92 | |

The data gap makes it difficult to interpret the graph. However, spring and fall algal blooms likely resulted in the decreased water clarity during April and October.

Summary of Questionnaire Results and Information From the Volunteer

The questionnaire on lake and watershed uses was not returned.

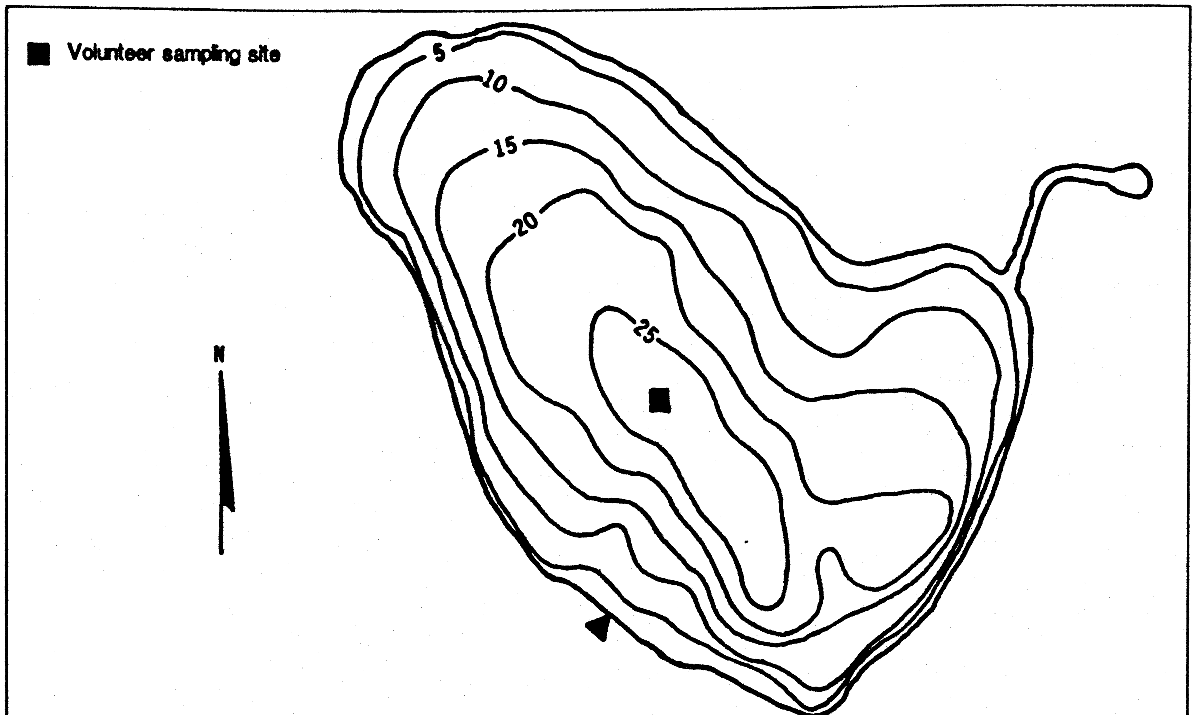
Results of Intensive Sampling/Summary of Other Available Information

Intensive survey data from 1989 show that Blackmans Lake is mesotrophic, based on moderately high water clarity and moderately low concentrations of total phosphorus and chlorophyll *a*. An increase in dissolved oxygen concentration and pH at three meters during June indicate that there may have been increased algal growth at this depth. Because some types of algae cannot grow in intense sunlight at the surface, and because nutrients are often more abundant near the hypolimnion, algae sometimes "bloom" at lower depths. During both the June and September sampling dates, the lake was stratified and there were very low dissolved oxygen concentrations in the hypolimnion. Low oxygen concentrations (0.6 mg/L) were also noted in the hypolimnion in 1973 (Bortleson *et al.*, 1976), so this is not a new phenomenon. Macrophytes cover approximately 25% of the shoreline; water lilies were found along the southeast corner and the northern perimeter.

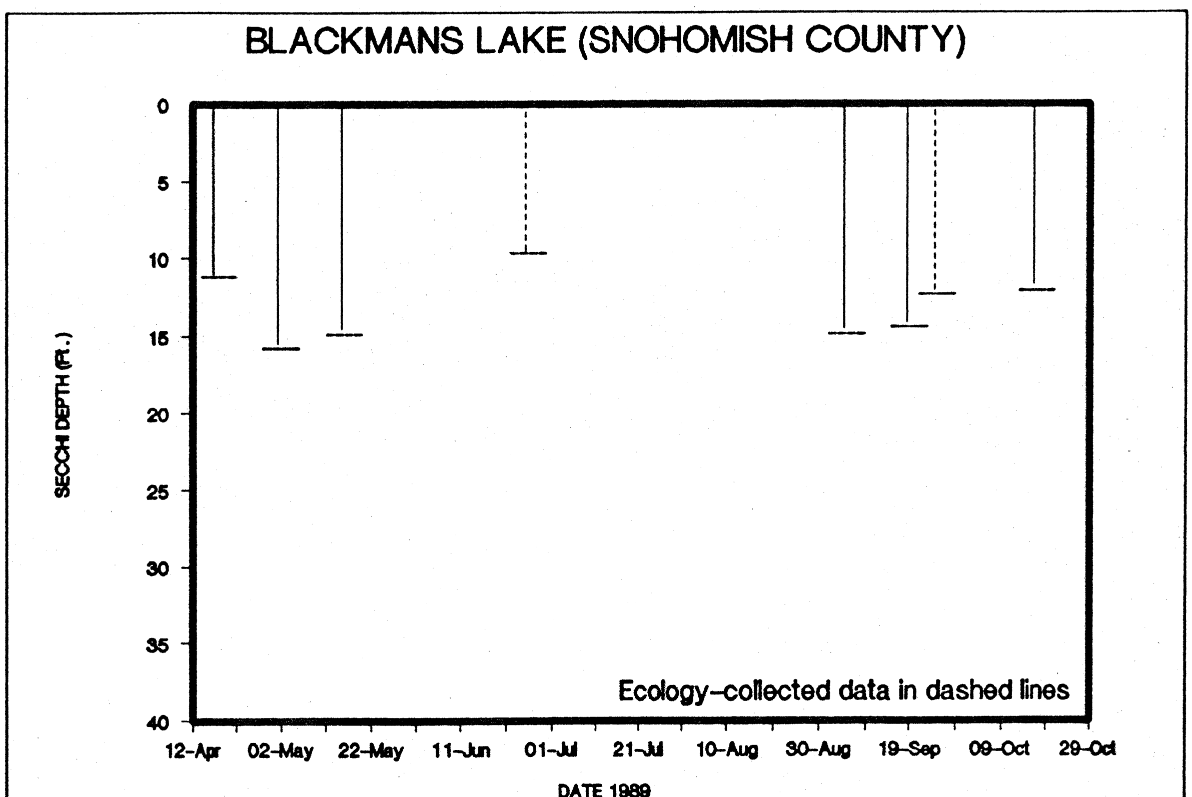
The Everett Herald reported on June 26, 1989 about the controversial issue of banning waterfowl feeding at Blackmans Lake. According to the article, the University of Washington may be studying the regional waterfowl and goose population, and local governments are expected to follow up by setting manageable waterfowl population levels. Another article in the same issue states, "Residents near Blackman's Lake in Snohomish recall thick mats of algae last summer and fear similar conditions could trigger a fish kill this summer."

Comments

Compared to all lakes sampled in the program, including other urban lakes (such as American Lake and Lake Steilacoom), Blackmans Lake had extremely high fecal coliform levels (36 and 37 organisms/100 mL). Considering that the fecal coliform sample was collected from the center of the lake, it is probable that fecal coliform bacteria levels were considerably higher nearshore and may have exceeded the state standard. The Lake Class standard for fecal coliform bacteria is a geometric mean of 50 organisms/100 mL. Fecal coliform samples collected in 1973 were similarly high; of three fecal coliform samples collected on August 3, 1973, the highest value was 36 colonies/100 mL (Bortleson *et al.*, 1976).




Blackmans Lake, Snohomish County. Photo taken May 13, 1973.
Bathymetric map from U.S. Geological Survey, July 18, 1973.



Blue Lake -- Grant County

Blue Lake is located about 11 miles north of the City of Soap Lake, and adjacent and southwest from Park Lake. It is fed by Park Lake via Park Lake Creek and drains to Lenore Lake. The inflow is intermittent. Blue Lake is a natural lake in the lower Grand Coulee. It receives heavy recreational use. There is a wetland at the south end of the lake.

| | |
|---|---|
| Size (acres) | 532 |
| Maximum Depth (feet) | 69 |
| Mean Depth (feet) | 40 |
| Lake Volume (acre-feet) | 21,318 |
| Drainage Area (miles$^2$) | 334 |
| Altitude (feet) | 1093 |
| Shoreline length (miles) | 7.03 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 44 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/12 | 1738 | -- | Sunny | 15.0 | 18.63 | |
| 06/10 | 1800 | Blue | Sunny | 20.5 | 14.97 | Big weed growth at south end of lake. Dangerous to boaters and skiers. Noxious Weed Board called. |
| 06/23 | 1800 | Blue | P Sunny | 19.0 | 10.24 | Fishing in this lake is the worst in years! |
| 07/13 | 1100 | Bl-Gr | Sunny | 22.0 | 7.33 | Algae bloom on lake. |
| 07/28 | 1730 | Bl-Gr | Sunny | 24.0 | 9.62 | Temp taken at 5': 24 degrees. Light wind. Reading approx. 200 Yards from shore. |
| 08/29 | 1745 | Bl-Gr | P Sunny | 23.0 | 8.94 | Broke the thermometer. |

The water clarity was greatest during May and decreased over the summer as algae grew. The water color was blue in the early summer, changing to blue-green as the water clarity decreased.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Blue Lake is used for fishing, boating, jet skiing, picnicking, camping, and hiking. There are three resorts, a park, and 18 houses on the lakeshore. All the houses are occupied year-round and use on-site wastewater disposal systems. The lake water is used for irrigation only. Currently the watershed is used for animal grazing, and the lakeshore is being developed further for residences. The shoreline has been altered in the past. There are some restrictions on water skiing. The lake has been treated in the past with rotenone; the last time was in 1987. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, were weeds and algae blooms that are especially a concern during June and July. The volunteer also reported that RV trailers camp illegally along the highway for long periods, presumably emptying holding tanks onsite.

## Blue Lake -- Grant County

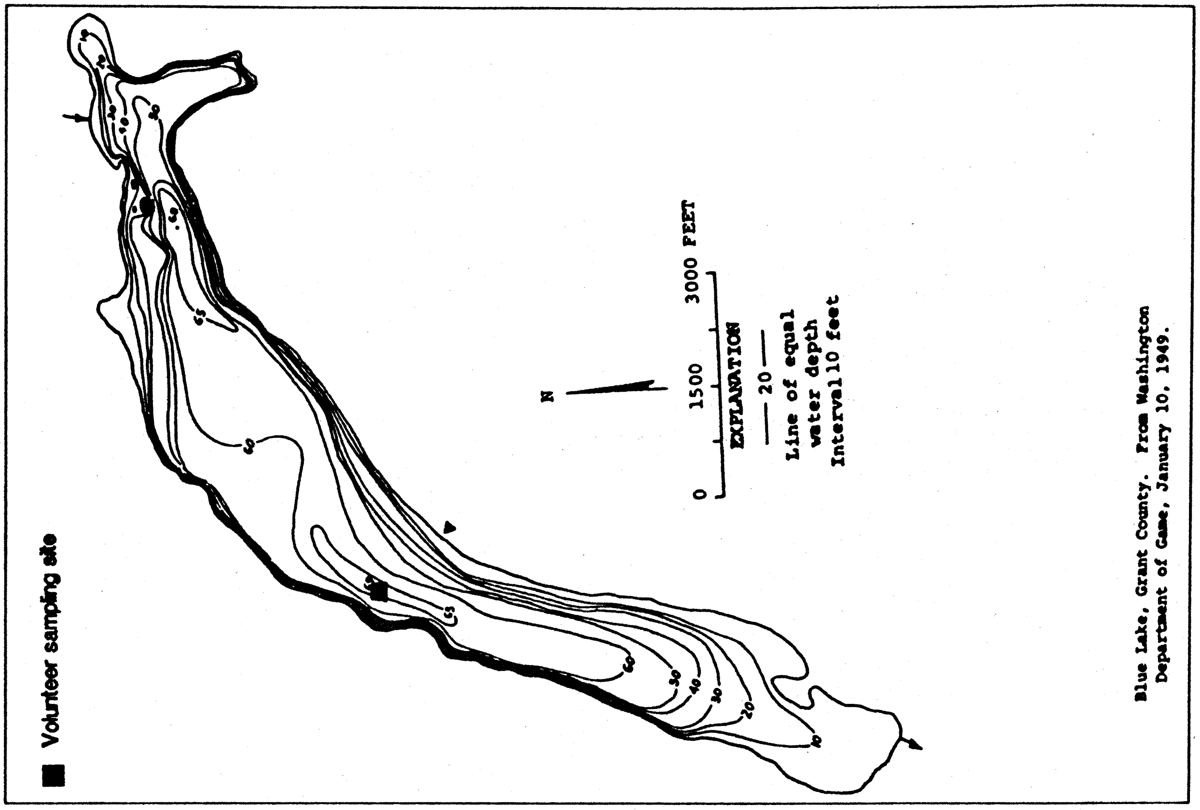
### Results of Intensive Sampling/Summary of Other Available Information

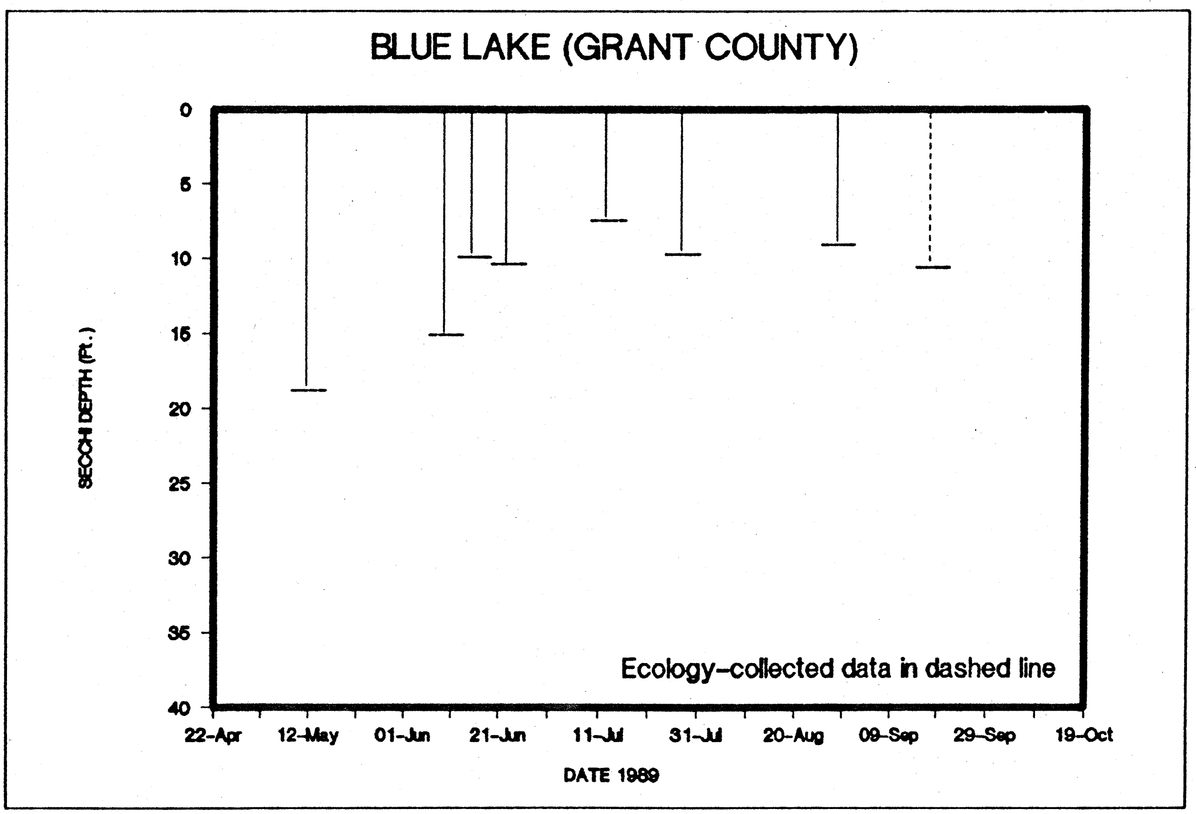
Because of high winds during the June sampling, Blue Lake was not sampled at its deepest site. The lake was sampled further north in an area about 7.5 meters deep. So that data from both sampling dates could be compared, the same location was revisited on the September sampling date.

Blue Lake is most likely mesotrophic because it has moderately high Secchi disk readings and epilimnetic concentrations of chlorophyll *a*. However, the concentration of total phosphorus in the epilimnion was very high during June (the concentration was more characteristic of a eutrophic lake than a mesotrophic lake), and probably contributed to the heavy growth of algae during July that was noted by the volunteer. In both June and September, 1989, dissolved oxygen concentrations were depleted near the bottom of the lake. In 1974 the USGS surveyed Blue Lake at its deep site and reported Secchi disk transparency and concentrations of total phosphorus that are characteristic of mesotrophic lakes, and noted very few emersed plants (Dion *et al.*, 1976). Compared to other lakes sampled for the program, Blue Lake had relatively high pH and specific conductivity from the surface to the bottom which likely results from the surrounding geology.

### Comments

The water clarity of Blue Lake was comparable to the water clarity of other Eastern Washington lakes located in areas with similar land uses and geology such as Williams Lake and Newman Lake. These lakes also have the potential for gradually accelerating water quality problems because of high recreational use and dense areas of trailers or homes using on-site wastewater disposal systems.


Volunteer sampling site
N
0 1500 3000 FEET
EXPLANATION
— 20 —
Line of equal water depth
Interval 10 feet
Blue Lake, Grant County. From Washington Department of Game, January 10, 1949.


BLUE LAKE (GRANT COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed line
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Cle Elum Lake -- Kittitas County

Cle Elum Lake is located 7.3 miles northwest from Cle Elum. The lake is an artificial irrigation reservoir created by damming the Cle Elum River in 1932; the dam extended a small natural lake north about 7.5 miles. The total stage capacity at elevation 2240 feet is 436,900 acre feet. Inlets include the Cle Elum River and numerous small streams. The inflow is perennial. Cle Elum Lake drains via the Cle Elum River to the Yakima River.

| | |
|---|---|
| Size (acres) | 4800 |
| Maximum Depth (feet) | 258 |
| Mean Depth (feet) | 109 |
| Lake Volume (acre-feet) | 520,000 |
| Drainage Area (miles$^2$) | 203 |
| Altitude (feet) | 2223 |
| Shoreline Length (miles) | 19.51 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 32 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/26 | 1000 | Bl-Gr | P Sunny | 9.0 | 19.25 | |
| 06/07 | 1345 | Bl-Gr | Sunny | 15.0 | 17.42 | |
| 06/29 | 1400 | Bl-Gr | Cloudy | 15.0 | 25.66 | |
| 07/14 | 1215 | Bl-Gr | Sunny | 18.0 | 22.00 | |
| 08/03 | 1100 | Bl-Gr | Sunny | 19.0 | 22.91 | |
| 08/19 | 0948 | Bl-Gr | P Sunny | 19.0 | 18.33 | Lake level dropped; boat ramp is no longer usable. Last report for the season. |

There was a lot of variation between readings, and although clarity decreased somewhat over the course of the summer there did not seem to be any obvious algae bloom. This may have been due to the drastic change in lake level over the course of the summer and subsequent entrainment of exposed sediments.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Cle Elum Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a USFS campground with 39 units on the lakeshore. Logging is the major activity in the watershed. Residential development is also occurring on the lakeshore. There are presently about 30 houses on the lake; three are occupied year-round and all use septic systems. No fish are stocked in the lake. Because the lake is used as a storage reservoir, the lowering water level results in the boat ramp being unusable after July. Rough waters from high evening winds limit boating.

Cle Elum Lake -- Kittitas County

Results of Intensive Sampling/Summary of Other Available Information

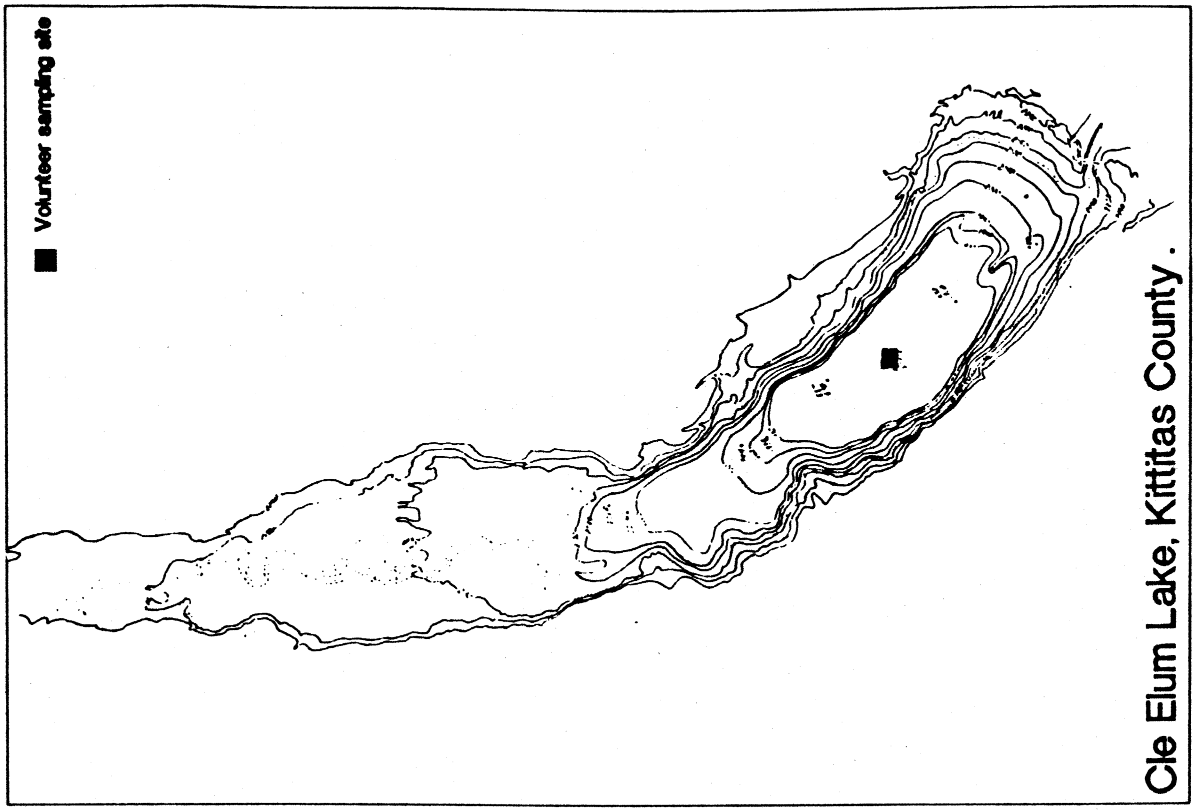
Cle Elum Lake is oligotrophic because it has relatively high Secchi disk values and low epilimnetic concentrations of chlorophyll *a*. The most noteworthy observation from the data was that the total phosphorus concentration was considerably, and unexpectedly, higher in September than in June. Compared with the other 24 lakes sampled by Ecology, total phosphorus concentrations in Cle Elum Lake were the second lowest in June and the second highest in September. During the June sampling, several observations were made: there was a fresh clearcut northeast of the lake inlet, a large area of the lake was covered with floating wood chips, the water color was yellow-brown and silt from erosion was observed in the water. The June water samples were collected from an area of the lake that was relatively clear of sediments and wood chips; by September, the phosphorus adsorbed onto the suspended sediments and woody debris could have been distributed throughout the lake by the heavy winds the area receives. It is also possible that as the lake level lowered significantly over the course of the summer, nutrients in the water were concentrated and exposed sediments with their associated phosphorus were entrained into the water.

The dissolved oxygen concentrations were extremely high (supersaturated) from surface to bottom during both June and September. The dissolved oxygen concentrations of most of the other lakes monitored by Ecology staff dropped below 10 mg/L in the hypolimnion. It should be noted that the Hydrolab profile graphs do not give a full representation of the lake's profile, since the lake has a maximum depth of 260 feet, and the Hydrolab used by Ecology staff has a 50 meter (164 feet) cable on it.

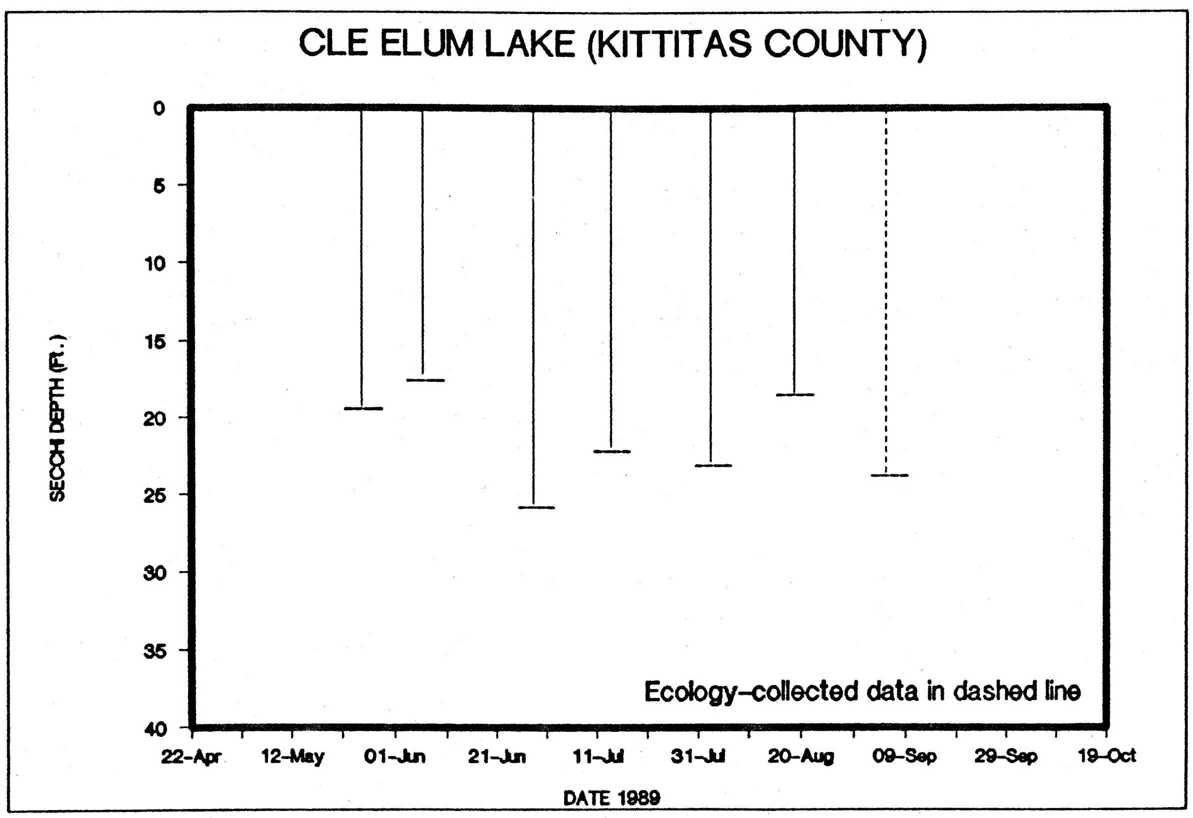
The USGS surveyed the lake in 1974 and reported Secchi disk transparency and concentrations of total phosphorus that are characteristic of oligotrophic lakes; also reported were logs floating in the southeast area of the lake (Dion *et al.*, 1976).

Comments

The high total phosphorus concentration during September is troublesome. The lowering of the lake level exposes sediments which may become entrained into the water column. Sediments may carry adsorbed nutrients into the water column and also decrease the water clarity. Other phosphorus sources could be present also.



Volunteer sampling site
Cle Elum Lake, Kittitas County.

CLE ELUM LAKE (KITTITAS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989
Ecology-collected data in dashed line

Clear Lake -- Thurston County

Clear Lake is located ten miles southeast from Yelm, in the Bald Hill region. It drains northerly to Toboton Creek and the Nisqually River. The inflow is perennial.

| | |
|---|---|
| Size (acres) | 170 |
| Maximum Depth (feet) | 25 |
| Mean Depth (feet) | 19 |
| Lake Volume (acre-feet) | 3200 |
| Drainage Area (miles$^2$) | 2.61 |
| Altitude (feet) | 518 |
| Shoreline length (miles) | 2.73 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic* |
| Mean Trophic State Index: | 41 |

* See Results of Intensive Monitoring and Comments sections

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/03 | 1300 | Blue | Sunny | 19.0 | * | Light algae bloom. Algae appeared almost white; probably dying off. |
| 05/16 | 1315 | Blue | P Cloudy | 20.0 | * | Algae bloom gone, high density of zooplankton, probably daphnia. Fishing still excellent. |
| 05/26 | 1400 | Blue | Cloudy | 18.0 | * | Some algae present but very clear. |
| 06/16 | 1130 | Blue | P Sunny | 22.0 | * | Very light algae growth in water. Windy, cool temp, and rain over past week. |
| 06/23 | 0830 | Green | Sunny | 22.0 | 21.08 | Slight algae bloom, zooplankton visible. |
| 07/06 | 1330 | Green | Sunny | 23.0 | 9.17 | Algae bloom - water color brownish-green. |
| 07/18 | 0900 | Bl-Gr | P Cloudy | 22.5 | 15.12 | Extensive bloom last week; lake was treated with $CuSO_4$ and it is clearing up now. |
| 07/24 | 1330 | Green | Sunny | 24.0 | 4.81 | Water is green in color but I'm not able to see individual algae cells. |
| 07/31 | 0900 | Green | Cloudy | 23.0 | 6.87 | Very cloudy, water still is green, very fine species of algae. |
| 08/10 | 1200 | Green | Sunny | 24.0 | 19.25 | Windy; water is clearing up very nice. |
| 08/17 | 0830 | Green | Cloudy | 23.0 | 15.58 | Very cloudy, water appears very clear. |
| 08/24 | 1400 | Green | Cloudy | 23.0 | 11.92 | Water color is clear green. Very cloudy, algae growth is slowly increasing. |
| 08/30 | 1000 | Green | Cloudy | 22.5 | 8.71 | A filamentous algae bloom is beginning. |
| 09/05 | 1130 | Green | Cloudy | 22.0 | 11.92 | Water color is clear green. Still a slight algae growth occurring. |
| 09/13 | 0830 | Green | Sunny | 22.0 | 6.42 | Strong bloom; normal for this time of year. |
| 09/20 | 1300 | Green | Sunny | 22.0 | 4.58 | Very strong algae bloom, no zooplankton. |
| 09/29 | 1330 | Blue | P Sunny | 21.5 | 9.17 | Last Friday bloom was extensive. |
| 10/04 | 1400 | Green | P Cloudy | 20.0 | 6.87 | Algae still growing. Harder to see individual cells. Water color still green. |
| 10/13 | 1400 | Green | Cloudy | 18.0 | ** | Water green-brown, no surface scum. Visibility was taken off dock at Longmire beach. |
| 10/19 | 1400 | Green | Sunny | 18.0 | 4.58 | Algae bloom still growing. |
| 10/25 | 1500 | Green | P Sunny | 16.0 | ** | Still murky with algae bloom. Lots of daphnia again off dock at Longmire beach. |
| 10/31 | 1400 | Green | Cloudy | 14.0 | 5.96 | Algae growth is still strong. |

* - Secchi hit bottom.
** - Reading not taken from deep site.

Clear Lake -- Thurston County

The lake was very clear at the beginning of the sampling season, and the bottom of the lake was visible. A series of algae blooms occurred, beginning in late June. The worst algae blooms occurred during late July and mid- to late September. Water clarity increased in early August and then decreased steadily through October.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Clear Lake is used for fishing, swimming, canoeing/rowing, sailing/wind surfing, picnicking, camping, and hiking. There is one resort and five boat ramps along the lakeshore. There is a speed limit (5 MPH) for motor boats. Currently the watershed is used for logging and tree farming, and residential development is occurring on the lakeshore. There are seven houses on the lakeshore; all the rest are located behind a buffer strip 100 - 150 feet from the shore. All houses use on-site wastewater disposal systems. The lake has been treated with chemicals since the 1960s to control weeds and algae. Copper sulfate, rotenone, Endothall and Sonar have been used. The lake was chemically treated in 1989 to control weeds and algae. Fish are stocked in the lake.

In the opinion of the volunteer, algae growing over the entire lake is the number one water quality problem, followed by weeds. Blue-green algal blooms are especially bad in early July. The volunteer does not consider weeds a problem when they are controlled in the swimming areas. Master's thesis work done by the volunteer concluded that internal loading of phosphorus from sediments triggers the blue-green algal blooms.

Results of Intensive Monitoring/Summary of Other Available Information

There was little agreement between the trophic state index values calculated from Secchi disk transparency, total phosphorus and chlorophyll *a* data collected in 1989. However, values calculated using the June total phosphorus data and all data from September, as well as obvious algal blooms occurring in the lake, indicate that Clear Lake is eutrophic.

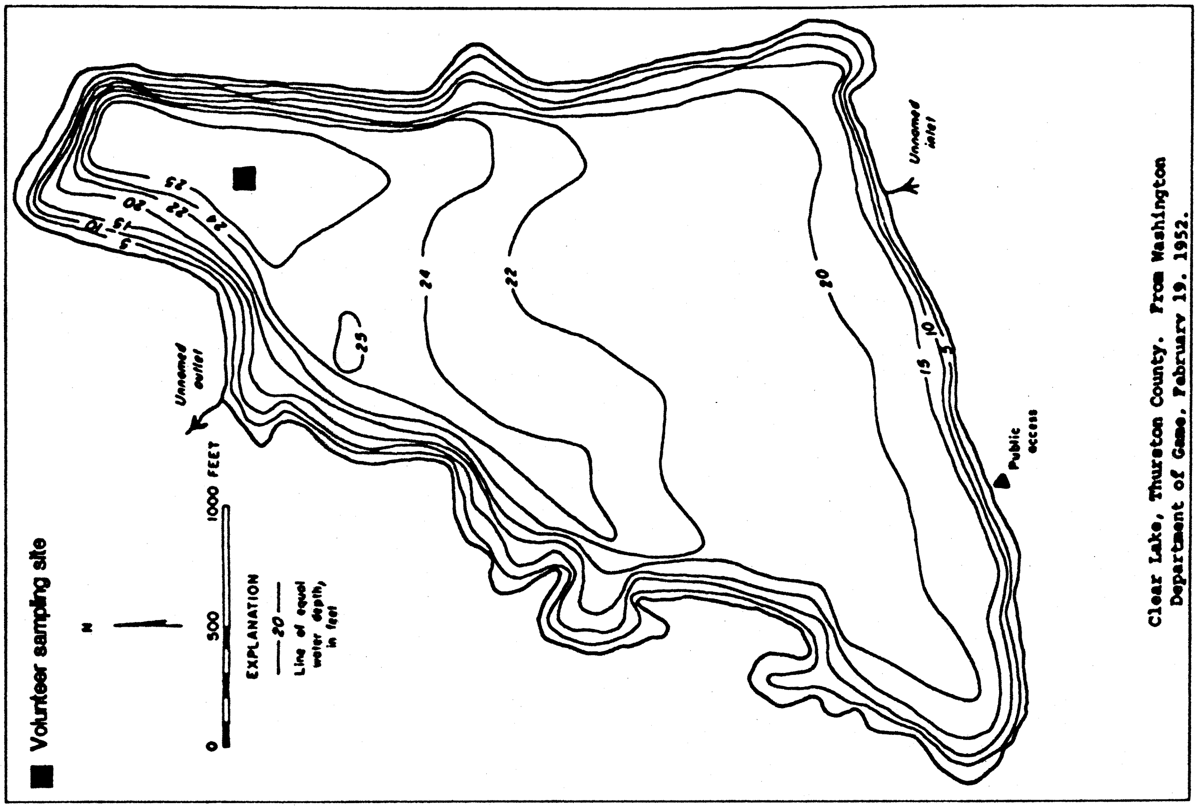
From June to September, concentrations of all nutrients increased dramatically, Secchi depth decreased and dissolved oxygen concentrations in the hypolimnion were depleted. Very low dissolved oxygen concentrations in Clear Lake have also been reported in 1968 (Lee, 1969) and 1971 (Bortleson *et al.*, 1976). During September, a surface bloom of the blue-green algae *Anabaena* was observed,which likely caused the dramatic increase in turbidity and chlorophyll *a* in the epilimnion. Compared to other lakes monitored for the program, Clear Lake had some of the highest orthophosphorus and ammonia levels on both sampling dates.

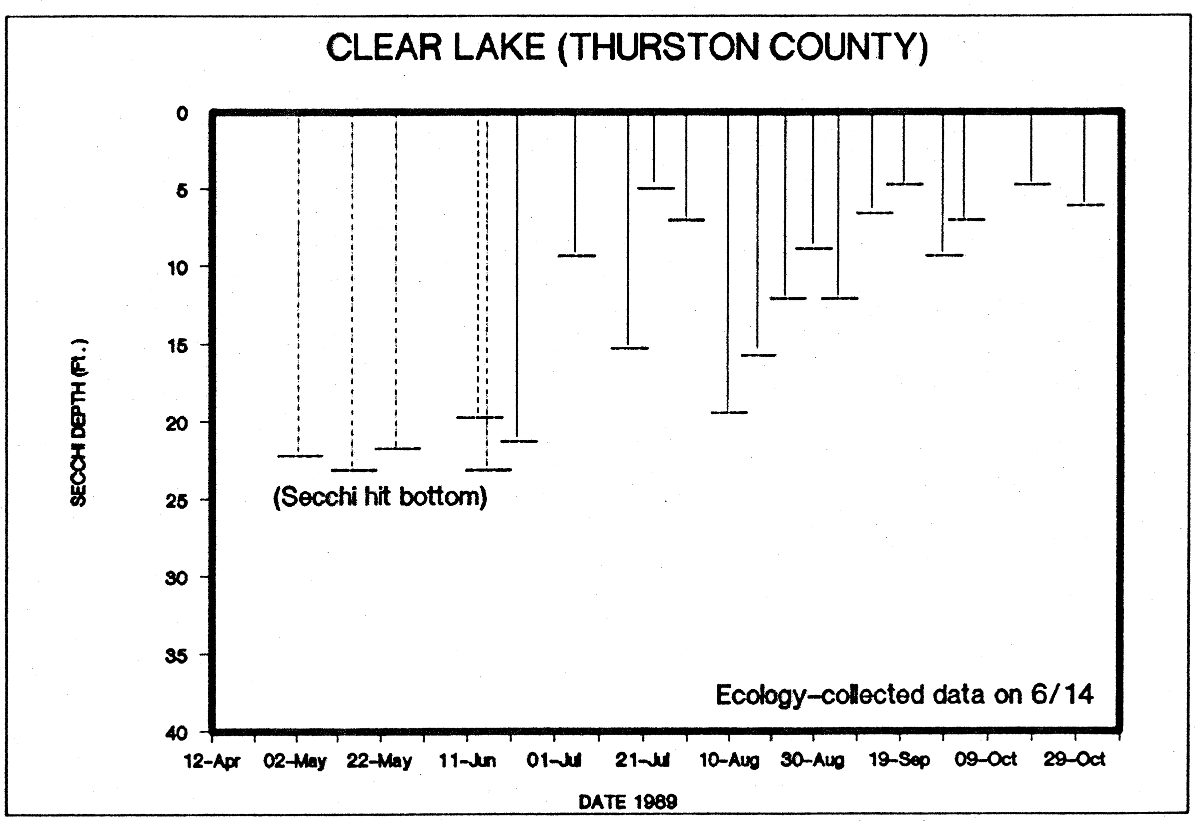
Comments

Lake Steilacoom in Pierce County is about the same size as Clear Lake and also has received long-term chemical treatments to control aquatic plants and algae. In comparison, Clear Lake has much better water clarity but considerably higher total phosphorus concentrations than Lake

Steilacoom. Lake Steilacoom receives urban and residential runoff whereas Clear Lake is probably affected by logging, tree farms, and residential runoff. The total phosphorus concentrations in Clear Lake are sufficient to support an even greater algae population than was seen during the 1989 sampling season.

Water quality variance records with Ecology show that on June 6 and 21, 1989, Clear Lake was treated with Aquathol, Endothall and Sonar to control pondweed and milfoil. On July 6, 7 and 13 the lake was treated with copper sulfate to control algae. These treatments, by altering the amount of algae that grow in the water, directly affect the water clarity as measured by the Secchi disk. Because of this, the Secchi disk data collected by the volunteer underestimate the trophic state of the lake and future estimates of trophic status should be based on chemical as well as transparency data. However, a long-term Secchi disk data record can be used to document and compare the severity of the algae blooms that occur in the lake.


Volunteer sampling site
N
0
500
1000 FEET
EXPLANATION
20
Line of equal water depth, in feet
Unnamed outlet
Unnamed inlet
Public access
24
22
20
25
15
10
5
Clear Lake, Thurston County. From Washington Department of Game, February 19, 1952.


CLEAR LAKE (THURSTON COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
(Secchi hit bottom)
Ecology-collected data on 6/14
12-Apr
02-May
22-May
11-Jun
01-Jul
21-Jul
10-Aug
30-Aug
19-Sep
09-Oct
29-Oct
DATE 1989

## Cranberry Lake -- Island County

Cranberry Lake lies in Deception Pass State Park, at the north end of Whidbey Island. The inflow is intermittent and the lake drains to Rosario Strait. The lake stage is stabilized by a dam. No motor boats are allowed on the lake.

| | |
|---|---|
| Size (acres) | 125 |
| Maximum Depth (feet) | 25 |
| Mean Depth (feet) | 13 |
| Lake Volume (acre-feet) | 1576 |
| Drainage Area (miles$^2$) | 0.61 |
| Altitude (feet) | 20 |
| Shoreline Length (miles) | 2.84 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 54 |

### Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 06/02 | 1400 | Brown | Sunny | 23.0 | 6.42 | Lake full of algae. |
| 06/18 | 1305 | Brown | P Sunny | 19.5 | 3.67 | |
| 07/02 | 1700 | Brown | P Cloudy | 22.0 | 4.58 | |
| 07/22 | 1400 | Green | Sunny | 24.0 | 6.87 | Clumps of algae on surface, but water seemed clearer and not as brown as before. |
| 08/06 | 1800 | Brown | Sunny | 26.0 | 5.73 | Algae is gone except for a few brownish clumps near shore. |
| 08/27 | 1800 | Brown | Sunny | 23.5 | 4.12 | |
| 09/17 | 1430 | Brown | Sunny | 23.0 | -- | Dropped Secchi disk overboard. Light algae growth on sides of lake. |

The water clarity was consistently low throughout the sampling period. The water color was brown the whole summer except during a heavy algae bloom. A long-lasting algae bloom occurred from late June through early July. No pattern in algal growth is apparent.

### Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Cranberry Lake is used for fishing, swimming, canoeing/rowing, picnicking, camping, and hiking. There are small hobby farms with goats and cows located in the watershed. There are no houses on the lakeshore. Fish are stocked in the lake. The north end of the lake is trees, brush, and large rocks. The south side of the lake is all wetlands. The worst water quality problems, in the opinion of the volunteer, are suspended sediments and algal blooms. Algae growth is mainly around the wetland area at the south side of the lake.

Cranberry Lake -- Island County

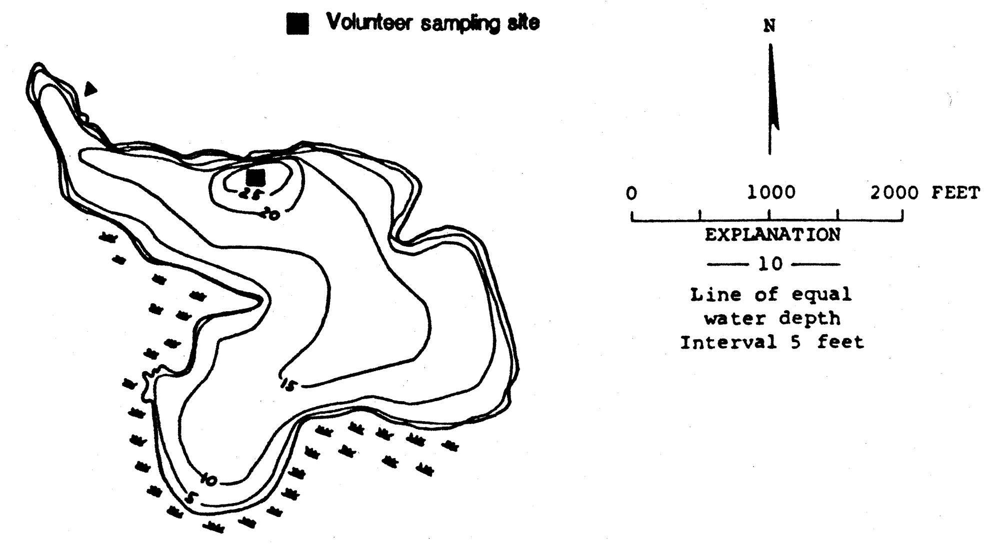
Results of Intensive Sampling/Summary of Other Available Information

Cranberry Lake is eutrophic, indicated by the low Secchi disk readings and the high epilimnetic concentrations of total phosphorus and chlorophyll *a*. Other eutrophic characteristics of the lake include the depletion of dissolved oxygen at the bottom of the lake; the smell of hydrogen sulfide from hypolimnion samples collected during September; the large clumps of the blue-green algae *Aphanizomenon* observed during June; and during September, dying algae made the water smell like rotting hay and appear yellow-brown in color. Compared to data collected during 1974 (Bortleson *et al.*, 1976), Secchi disk transparency and concentrations of total phosphorus were worse in 1989 than in 1974. Trophic state indices calculated from 1981 data (Sumioka and Dion, 1985) show that based on Secchi depth, total phosphorus and chlorophyll *a*, Cranberry Lake was much more eutrophic in 1989 than in 1981.

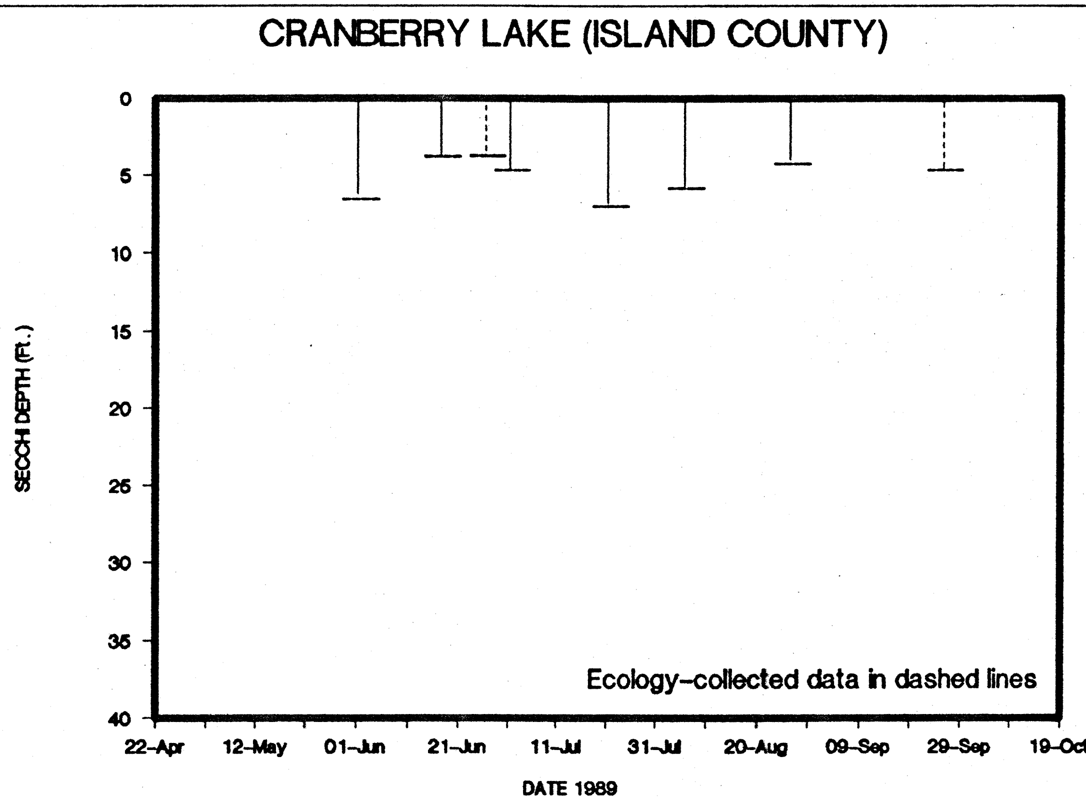
Comments

Compared to other lakes monitored for the program, the water temperatures and the nutrient concentrations (especially for total phosphorus) are very high in Cranberry Lake. There were six lakes in the program that had lower water clarity than Cranberry Lake. Although algal growth in most Northwest lakes is limited by the concentrations of phosphorus in the water, the phosphorus concentrations in Cranberry Lake are so high relative to the concentrations of nitrogen, that algal growth during the fall may be limited by other factors such as nitrogen, light or temperature. Additional input of nitrogen into the lake could result in greater algal growth and lower water clarity during the fall.

Although the Secchi disk data underestimate trophic state somewhat when compared to the index values calculated from the total phosphorus and chlorophyll *a* data, a continued record of water clarity measured by a Secchi disk can be used to document the severity of the algal blooms occurring in the lake.




Cranberry Lake, Island County. From Washington Department of Game, July 23, 1950.



Crawfish Lake -- Okanogan County

Crawfish Lake is located 15 miles northeast from Omak, and 8.5 miles north from Disautel. It drains intermittently to the east to Lost Creek and the West Fork of the Sanpoil River. The north half of the lake is on USFS land, and the south half is on the Colville Indian Reservation.

| | |
|---|---|
| Size (acres) | 80 |
| Maximum Depth (feet) | 36 |
| Mean Depth (feet) | * |
| Lake Volume (acre-feet) | * |
| Drainage Area (miles$^2$) | * |
| Altitude (feet) | 4475 |
| Shoreline Length (miles) | * |

*information not available

| | |
|---|---|
| Estimated Trophic State: | oligo-mesotrophic |
| Mean Trophic State Index: | 38 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/14 | 0930 | Green | P Sunny | 14.0 | 9.40 | Slight wind, some snow around lake yet. |
| 05/29 | 1100 | Bl-Gr | Sunny | 12.0 | 10.31 | Raining very hard the last 3 days, snowed 1/2 inch overnight, melted now. |
| 06/11 | 1300 | Green | P Sunny | 20.0 | 13.75 | |
| 06/25 | 1300 | Green | Sunny | 19.0 | 19.25 | 75 degrees. Nice day, partly cloudy. |
| 07/22 | 1700 | Bl-Gr | Sunny | 22.0 | 20.16 | Unable to take sample earlier due to high winds. |
| 07/29 | 1400 | Bl-Gr | Sunny | 23.0 | 18.79 | Sunny, hot, clear day. |
| 08/12 | 1400 | Green | Sunny | 21.0 | 11.00 | Lake green and cloudy, unable to see as deep as in the past |
| 08/20 | 1300 | Bl-Gr | P Sunny | 19.0 | 10.54 | |
| 09/04 | 1020 | Gr-Br | Sunny | 16.0 | 8.71 | Heavy rains with lots of runoff 2 days earlier. |
| 10/08 | 1145 | Bl-Gr | Sunny | 13.5 | 10.54 | No data for September. |
| 10/22 | 1030 | Bl-Gr | P Cloudy | 9.0 | 10.08 | |

The water clarity was lowest during May, most likely from spring runoff. Algal growth decreased water clarity during August.

Summary of Questionnaire Results and Information from the Volunteer

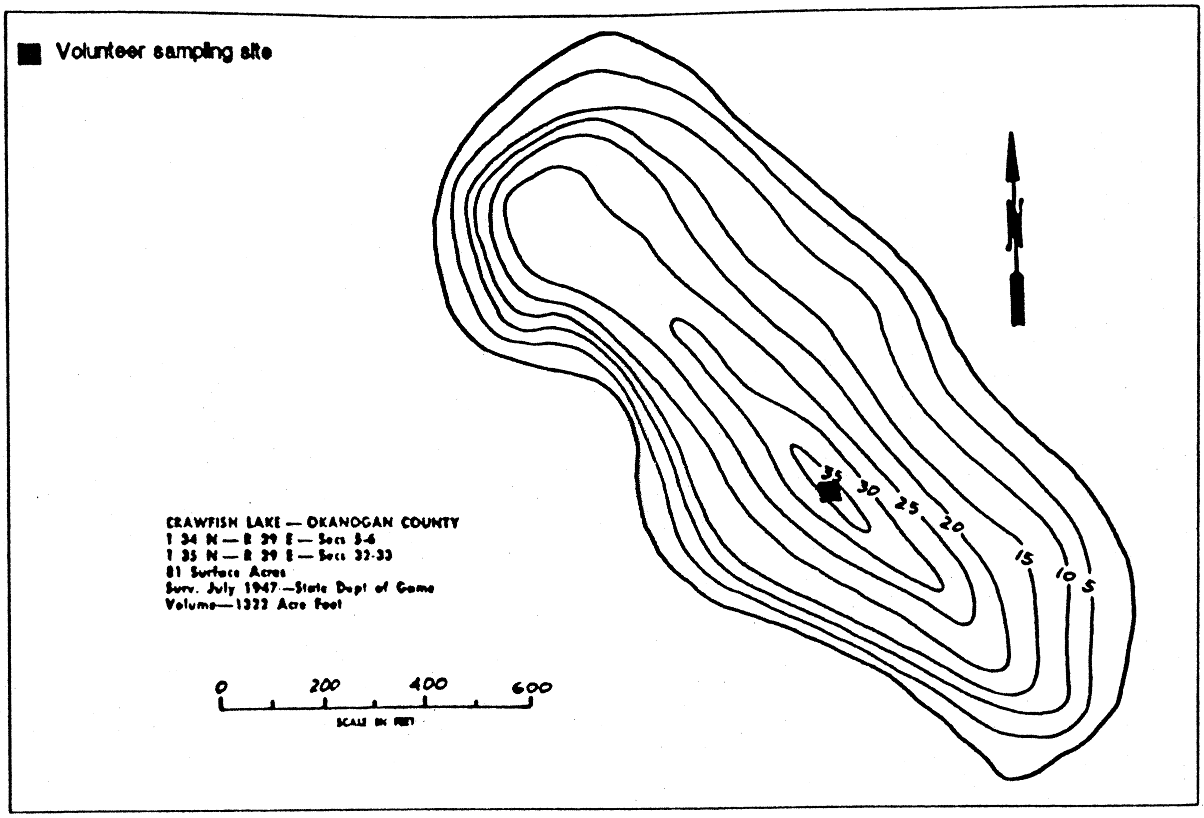
Crawfish Lake is used for fishing, swimming, boating, picnicking, camping, hiking, and waterfowl hunting. There is a USFS campground and a state park on the lakeshore. Presently there are no land use activities within the watershed, but in the past the watershed has been logged. There are 41 cabins on the lakeshore, although none are occupied year-round. Due to the size of the lake, motor boats are used only for fishing. There is ice on the lake from October through April. The lake was treated with rotenone in the fall of 1988, and fish are stocked in the lake. The crawfish population has decreased noticeably in recent years. The worst water quality problem, in the opinion of the volunteer, is dead fish during April and May following winterkill. The volunteer noted that pit privies and gray water systems may possibly affect the lake quality. There are submerged weeds near the cabins on the reservation. The wetland at the north end of the lake covers about three acres, and the wetland at the south end of the lake (on the reservation) covers about two acres.

Crawfish Lake -- Okanogan County

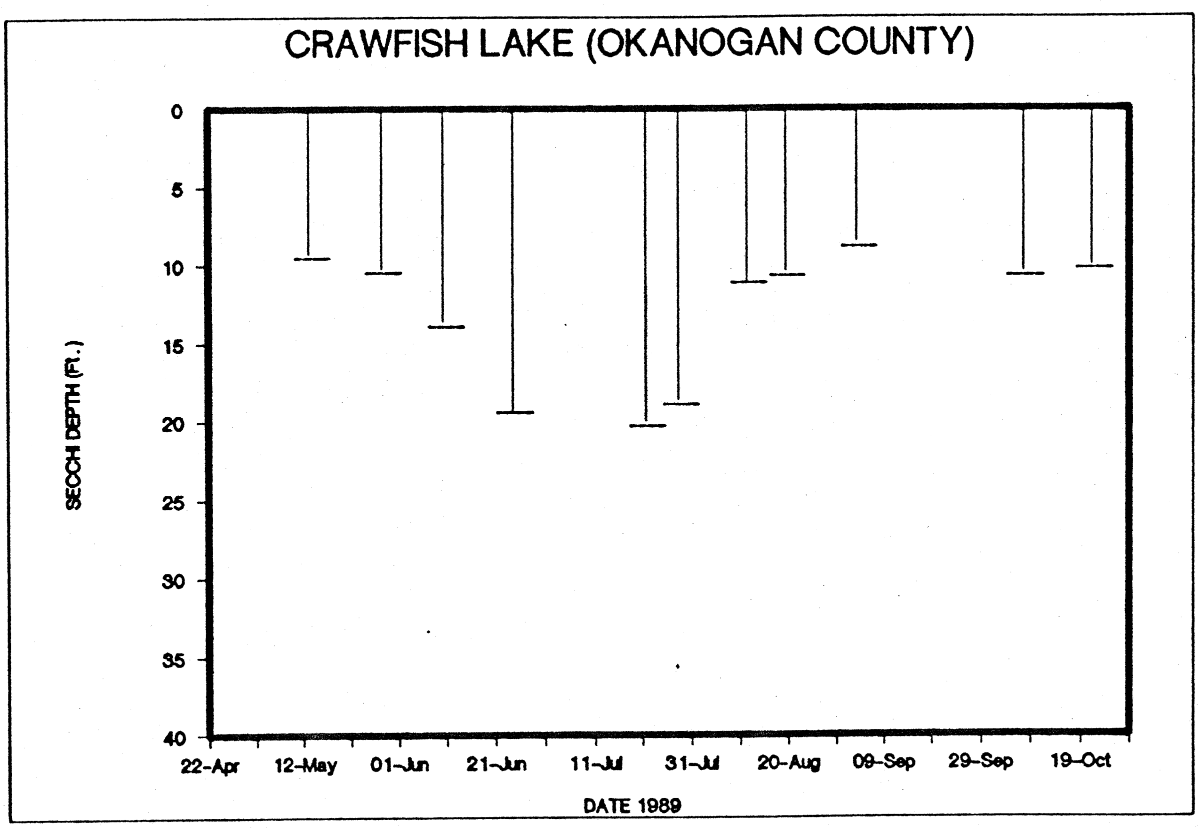
Comments

Crawfish Lake was the highest elevation lake monitored for the program. Like other high elevation lakes in Eastern Washington monitored for the program, the water clarity was lowest during May following spring thaw.

Although the mean trophic state index could suggest that Crawfish Lake is oligotrophic, an oligo-mesotrophic estimate is reported because of the winterkill problem cited by the volunteer.



Volunteer sampling site
CRAWFISH LAKE — OKANOGAN COUNTY
T 34 N — R 29 E — Secs 5-6
T 35 N — R 29 E — Secs 32-33
81 Surface Acres
Surv. July 1947 —State Dept of Game
Volume—1322 Acre Feet
0
200
400
600
35
30
25
20
15
10
5

CRAWFISH LAKE (OKANOGAN COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Crescent Lake -- Clallam County

Crescent Lake is located 14 miles west from Port Angeles. It is 8.5 miles long. Several inlets flow into the lake, including Barnes, Smith, Aurora, Lapoel, Cross, and Eagle Creeks. Crescent Lake drains via Lyre River to the Strait of Juan de Fuca. There is a precipitous shoreline except at both ends. It is the third largest natural lake in Western Washington. Beardslee trout are found only in Crescent Lake.

| | |
|---|---|
| Size (acres) | 5127 |
| Maximum Depth (feet) | 624 |
| Mean Depth (feet) | * |
| Lake Volume (acre-feet) | * |
| Drainage Area (miles$^2$) | * |
| Altitude (feet) | 580 |
| Shoreline Length (miles) | * |

*information not available

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 15 |

Volunteer - Collected Data

Station 1

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 07/17 | 1030 | Bl-Gr | P Cloudy | 17.5 | 67.00 | Overcast, ripples, hard to see disc. Slight breeze, boat drifting. |
| 08/04 | 1050 | Bl-Gr | Sunny | 19.0 | 80.00 | No wind. |
| 08/23 | 1230 | Bl-Gr | Sunny | 19.0 | 80.00 | |
| 09/15 | 1120 | Bl-Gr | Sunny | 19.0 | 89.00 | Smooth water surface and few ripples. |

Station 2

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 07/17 | 1030 | Bl-Gr | P Cloudy | 17.5 | 65.00 | Overcast, ripples, slight breeze. |
| 08/04 | 1050 | Bl-Gr | Sunny | 19.0 | 70.00 * | No wind. |
| 08/23 | 1230 | Bl-Gr | Sunny | 19.0 | 68.00 * | |
| 09/15 | 1140 | Bl-Gr | Sunny | 19.5 | 77.00 | Slight breeze causing rope to descend at an angle. |

* Limits for quality assurance test were exceeded for this data point.

Water clarity was lowest during July and increased through September. Volunteers monitored two stations on the lake (see map). The water clarity at Station 1 was somewhat better than at Station 2. Although there are not enough readings to evaluate patterns in algal growth, the readings indicate that Crescent Lake is ultra-oligotrophic.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteers' remarks and questionnaire responses. Crescent Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, hiking, and scuba diving.

Crescent Lake -- Clallam County

There are three resorts and three boat ramps on the lakeshore as well as trails in both National and County Parks. There is a decibel/noise restriction for motor boat use. Lake water is withdrawn for drinking and other domestic uses. Currently the lakeshore is being developed for residences. Historically, shoreline alteration, logging and mining occurred in the watershed. There are about 96 houses on the lakeshore, and about 14 of these are occupied year-round.

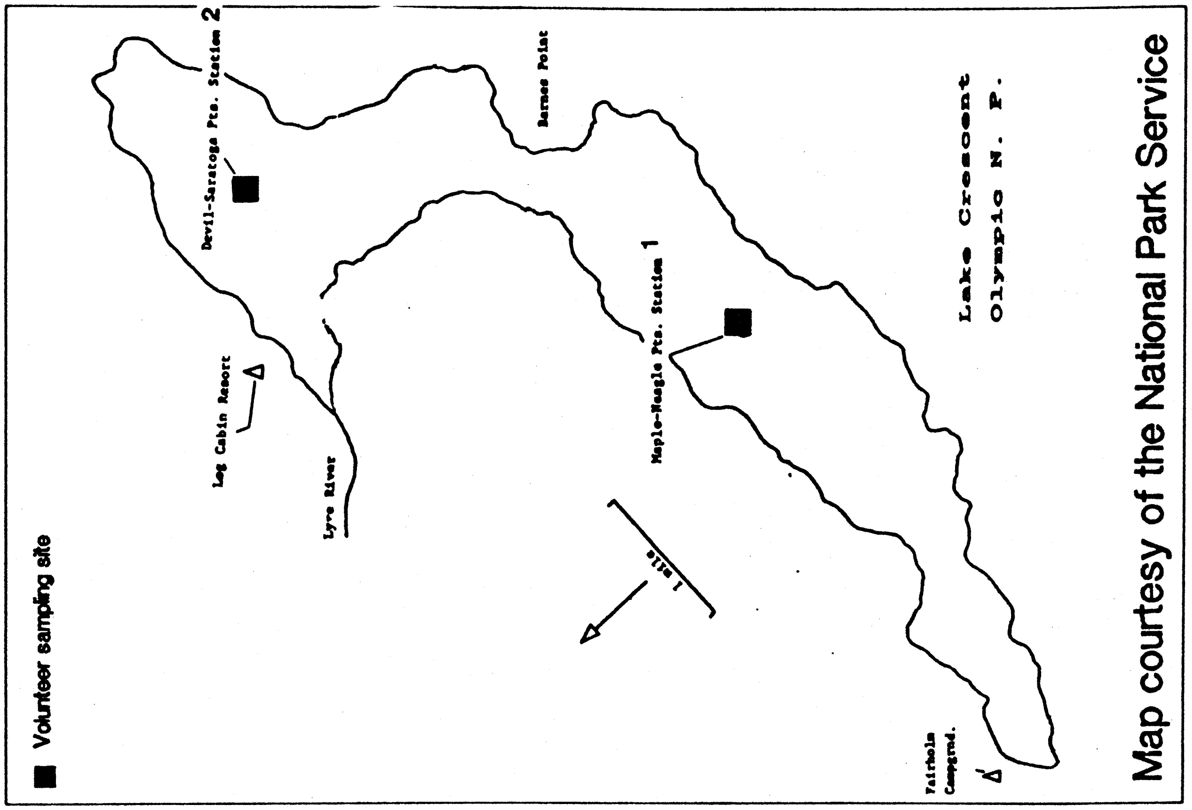
The lakeshore is partially sewered. Many storm drains flow into the lake (around 30). Fish are not stocked, and there are no water quality problems in the lake.

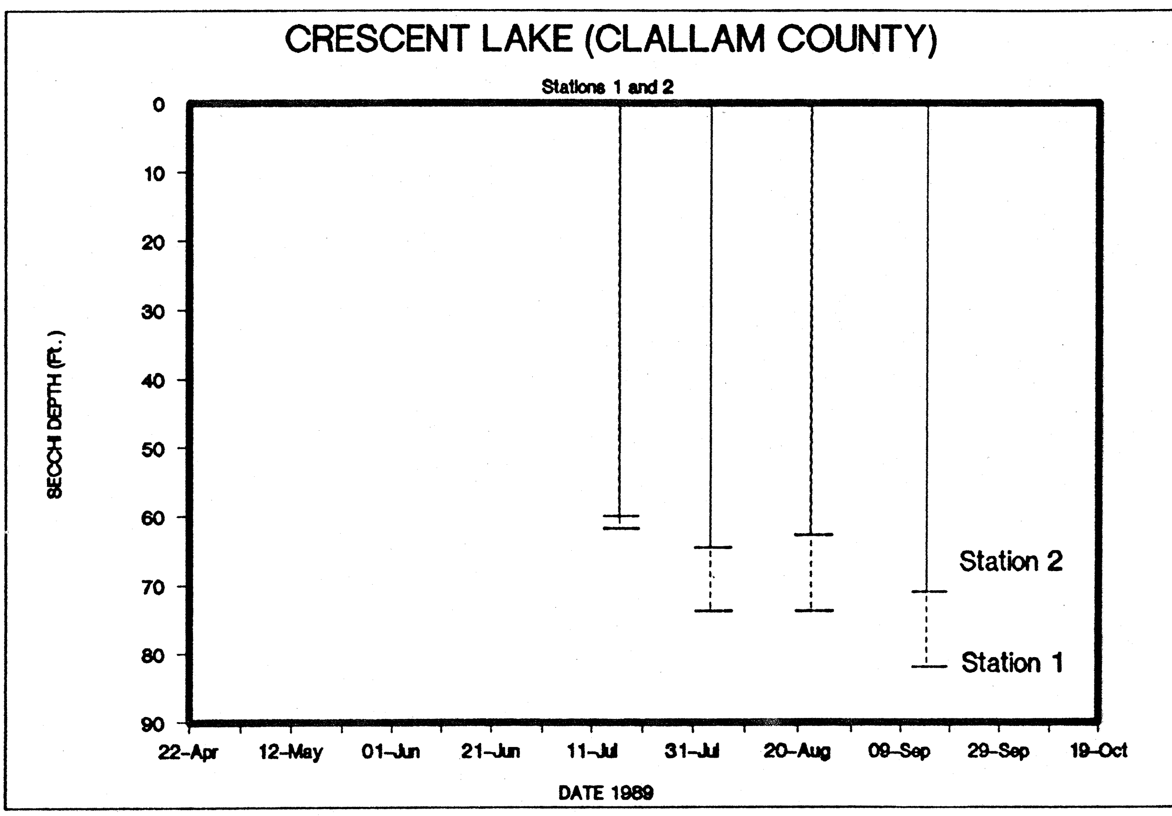
Intensive Monitoring Results/Summary of Other Available Information

During 1989, Ecology surveyed ten lakes for potentially toxic metals and organic compounds in sportfish tissue and sediments (Johnson and Norton, 1989). Lake Crescent was chosen as a reference lake for the survey because it is removed from any significant sources of chemical contamination. One of the sediment samples collected off Fairholm had the highest chromium concentration (215 mg/Kg) of all the sediment samples collected for the lakes. This may be related to the high sand content of this sample, and is probably more indicative of local mineralogy than chemical contamination. Fish tissue analyses detected 5.2 μg/Kg DDE and 0.6 μg/Kg DDD in cutthroat trout. These levels are not unusual and are well within levels considered acceptable for human consumption (Johnson and Norton, 1990).

Comments

Secchi disk readings were considerably deeper than readings collected from all other lakes in the program; water clarity measurements from Lake Crescent ranged from 67 to 89 feet, whereas readings from most other lakes ranged from 5 to 25 feet. Crescent Lake is ultraoligotrophic, meaning that it is a very unproductive lake with respect to algal growth. The U.S. National Park Service periodically monitors the lake and reports average readings of 20 meters.


Map courtesy of the National Park Service
Lake Crescent
Olympic N. P.
Volunteer sampling site
Barnes Point
Log Cabin Resort
Lyre River
1 mile


CRESCENT LAKE (CLALLAM COUNTY)
Stations 1 and 2
SECCHI DEPTH (Ft.)
0
10
20
30
40
50
60
70
80
90
Station 2
Station 1
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Curlew Lake -- Ferry County

Curlew Lake is located 4.8 miles from Republic. It is a natural lake, and water level fluctuations were stabilized by a three foot dam built in 1926. The lake is 4.8 miles long. There are four islands, totaling 20 acres, that are not included in the reported acreage. Inlets include Herron, Mires, Barrett, and Trout Creeks, and the Sanpoil River. The Sanpoil River divides in high water periods at Torboy, and one branch flows northerly to Curlew Lake and the Kettle River, and the other branch flows south to FDR Lake. Curlew Lake drains via Curlew Creek to the Kettle River.

| | |
|---|---|
| Size (acres) | 921 |
| Maximum Depth (feet) | 130 |
| Mean Depth (feet) | 43 |
| Lake Volume (acre-feet) | 39,519 |
| Drainage Area (miles$^2$) | 64.50 |
| Altitude (feet) | 2333 |
| Shoreline Length (miles) | 15.78 |

| | |
|---|---|
| Estimated Trophic State: | oligo-mesotrophic* |
| Mean Trophic State Index: | 39 |

* See Comments section

Volunteer-Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/30 | 1000 | Green | Sunny | 17.0 | 19.71 | |
| 06/20 | 0930 | Green | P Sunny | 21.0 | 16.96 | High wind drift - couldn't hold boat over deeps. |
| 07/17 | 0900 | Green | P Cloudy | 25.0 | 11.46 | |
| 08/15 | 1900 | Green | P Cloudy | 22.0 | 16.96 | Slight wind chop after stormy night with rain. |
| 09/16 | 1000 | Green | P Cloudy | 20.0 | 11.00 | First cool day after hot spell. |
| 10/15 | 1030 | Brown | P Sunny | 12.0 | 18.10 | Much surface debris. Heavy algae bloom has subsided. |

The water clarity was greatest during late May. As algae growth increased over the summer the water clarity decreased, so that water clarity was lowest during mid-July and September. The water color was mostly green throughout the sampling period.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Curlew Lake is used for fishing, swimming, boating, picnicking, camping, hiking, and waterfowl hunting. There are four resorts, a state park, and five boat ramps on the lakeshore. The lake water is withdrawn for irrigation. Currently the watershed is used for logging, agriculture (both crops and animal grazing), and mining exploration. Residential development is occurring along the lakeshore. There used to be a lumber mill at the north end of the lake and in the past the lake was used as a holding pond for logs. As a result, there are many old sunken logs in the lake. There are about 200 houses on the lakeshore; all are on septic systems and 84 of the houses are occupied year-round. The lake has been treated with chemicals to control weeds; in 1988 Sonar was used to treat 11 acres, and in 1989 Cutrine was used to treat 12 acres. A lake association is now being organized.

Curlew Lake -- Ferry County

The worst water quality problems, in the opinion of the volunteer, are weeds, algal blooms, lake level, rough fish, and odor (described as a rotten egg smell along shallows in the spring). The volunteer is concerned about possible water quality effects from surface runoff, on-site septic systems, stream flow, internal loading, ground water, and fish net pens. The WSU Cooperative Extension Service and the Ferry County Conservation District are in the process of studying the west watershed, and a grant from Ecology was allocated for a study of the east watershed.

Summary of Other Available Information

Algal blooms have been reported in Curlew Lake for many years, and appear to be increasing in severity. In 1968, heavy algal growth was reported for the first time (Lee, 1969). The Washington Water Research Center (WWRC) reported in 1988 that there have been floating mats of algae in the lake, and that faulty septic systems and grazing livestock are likely sources of nutrient loading to Curlew Lake (WWRC, 1988).

Increased residential development along the lakeshore may also be contributing to water quality problems in the lake; 95 nearshore homes were reported in 1974 (Dion *et al.*, 1976) whereas the volunteer reports that there are now around 200 houses in the lakeshore.

In 1974, dissolved oxygen was completely depleted near the bottom of the lake, and large amounts of epiphytic algae were observed (Dion *et al.*, 1976). Trophic state indices calculated from Secchi disk transparency, total phosphorus and chlorophyll *a* data collected in 1981 show that Curlew Lake was mesotrophic.

A news article from the Republic News-Miner (October 5, 1989) written by the Curlew Lake Association stated that the algae bloom at Curlew Lake was unusually heavy in 1989. A bloom of the blue-green algae *Anabaena*, floating mats of algae, a heavy scum, and the strong smell of rotten plants were reported. Also reported was that the hydrologist from the Ferry County Conservation District suspects that nutrients are released from aquatic plants killed with herbicides, since herbicides have been applied in Curlew Lake for the past two years.

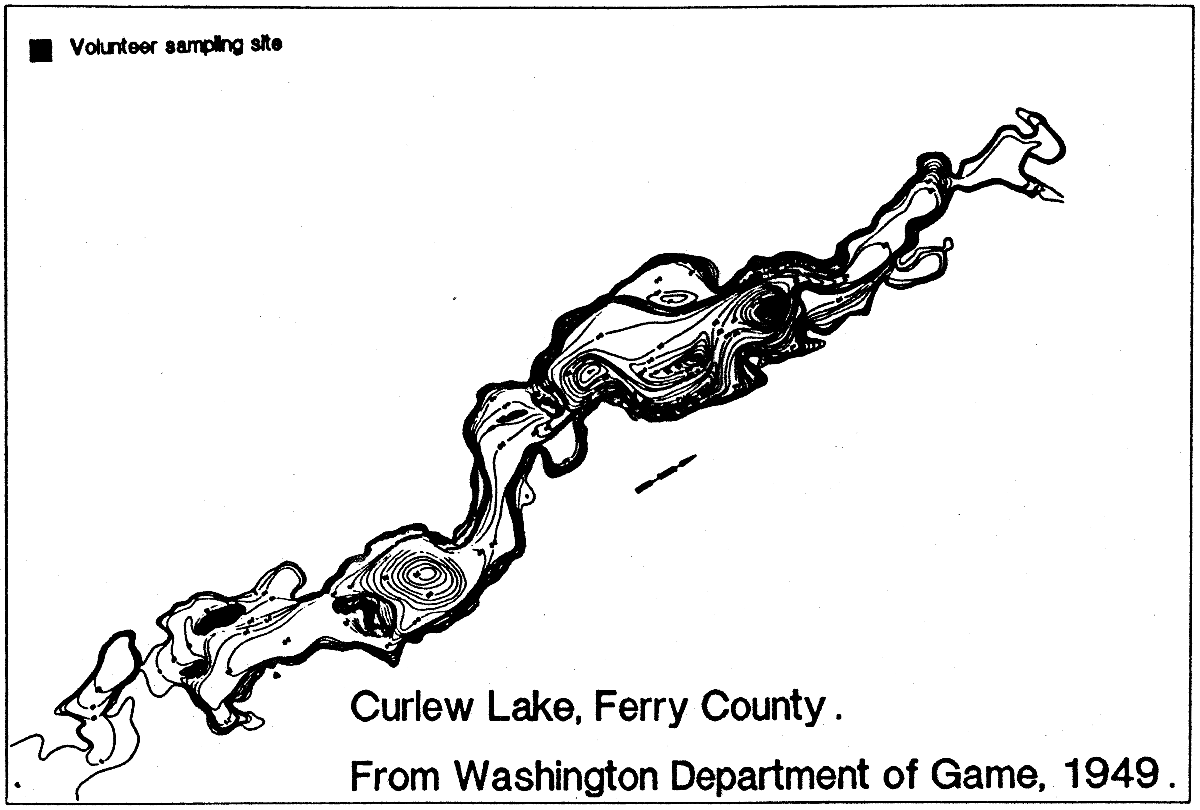
Comments

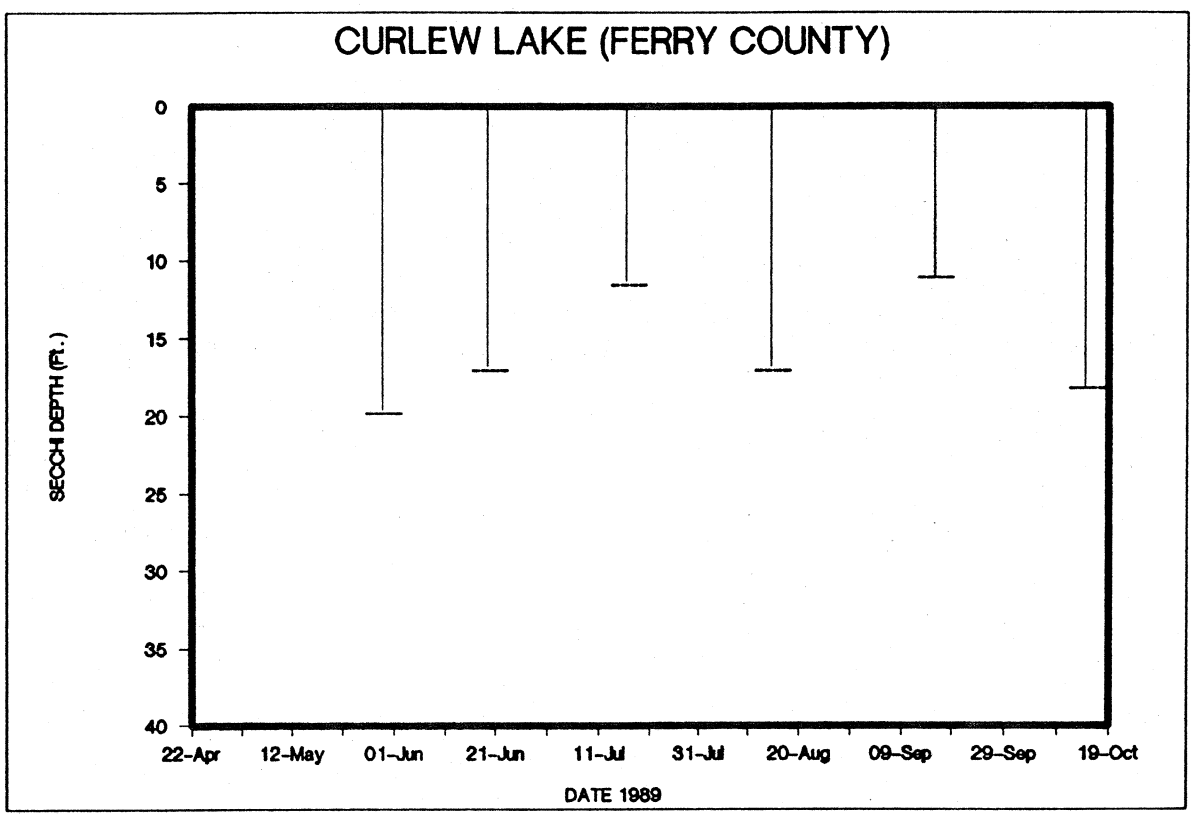
Secchi disk readings apparently do not characterize the severity of the algal blooms at Curlew Lake, because the algal growth seems to concentrate along the shorelines and not in the open water. Based on past data collected in 1974 and 1981, the trophic state of Curlew Lake is mesotrophic with high total phosphorus concentrations. Although a continued record of water clarity as measured by the Secchi disk can be used to demonstrate changes in the open water, future estimates of trophic state should be based on chemical as well as water clarity data.

It is also interesting that the greatest water clarity in Curlew Lake was measured during May. In contrast, other high elevation lakes in Eastern Washington monitored for the program such as Black, Thomas, Loon and Deer Lakes, all had their lowest water clarity readings collected during May when spring algal blooms occurred.

Curlew Lake -- Ferry County

Loon and Deer Lakes have comparable physical characteristics (altitude, lake volume, lake area, and mean and maximum depths) as Curlew Lake. Both Loon and Deer Lakes are oligotrophic and consequently have fewer water quality problems than Curlew Lake. The differences in water quality between these lakes is most likely the result from different land uses within each watershed.


Volunteer sampling site
Curlew Lake, Ferry County.
From Washington Department of Game, 1949.


CURLEW LAKE (FERRY COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Davis Lake -- Pend Oreille County

Davis Lake is located about 5.7 miles south from Usk, and 2.7 miles southwest from Dalkena. Deer Creek is the perennial inlet. Davis Lake is stabilized by a small dam at the outlet and drains via Davis Creek to the Pend Oreille River. It is weedy and shallow at the south end of the lake. Highway 211 runs along the east shore of the lake.

| | |
|---|---|
| Size (acres) | 152 |
| Maximum Depth (feet) | 147 |
| Mean Depth (feet) | 83 |
| Lake Volume (acre-feet) | 12,622 |
| Drainage Area (miles$^2$) | 17.80 |
| Altitude (feet) | 2150 |
| Shoreline Length (miles) | 2.67 |

| | |
|---|---|
| Estimated Trophic State: | oligo-mesotrophic |
| Mean Trophic State Index: | 38 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/23 | -- | -- | -- | -- | 11.00 | |
| 05/07 | 1200 | Tea | Cloudy | 15.5 | 12.83 | |
| 06/14 | 1715 | Tan | P Cloudy | 20.5 | 14.67 | |
| 07/04 | 1700 | Tan | -- | 20.5 | 12.83 | |
| 08/13 | 1645 | Tan | P Cloudy | 22.0 | 17.42 | Major thunder storm yesterday afternoon. |
| 10/01 | 1530 | Lt Tan | P Cloudy | 15.0 | 14.67 | |

The water clarity was generally good all summer, although sporadic readings may have missed any algal blooms. Water clarity was lowest during April, and was greatest during August. The water color was usually noted as "tan."

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Davis Lake is used for fishing, swimming, rowing, and hiking. There is a speed limit of five MPH for motor boats. Logging and shoreline alteration has occurred in the watershed during the past. There are about 40 houses on the lakeshore; 15 are occupied year-round. One house is being built on the southwest side. Individual homeowners rake weeds from their lakeshores. Fish are stocked in the lake. No water quality problems were reported by the volunteer. There is a wetland at the south end of the lake. Residences are located primarily along the north end of the lake.

Davis Lake -- Pend Oreille County

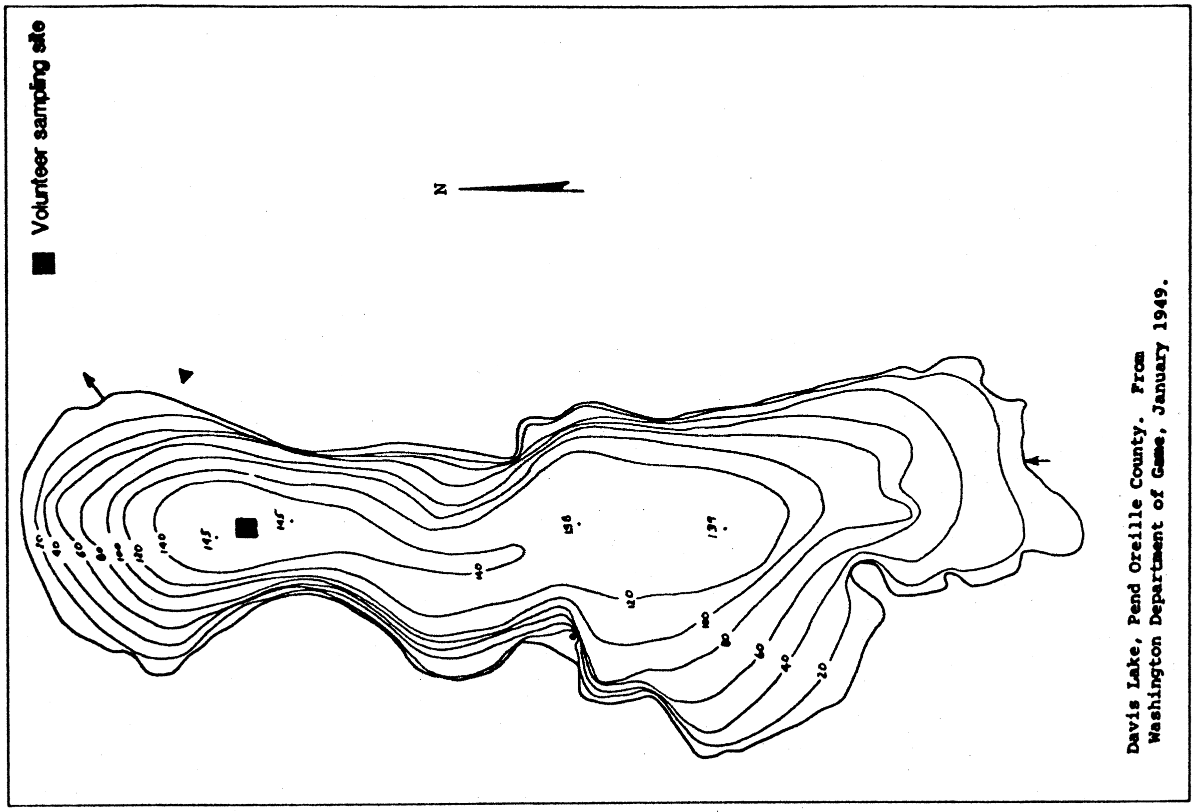
Summary of Other Available Information

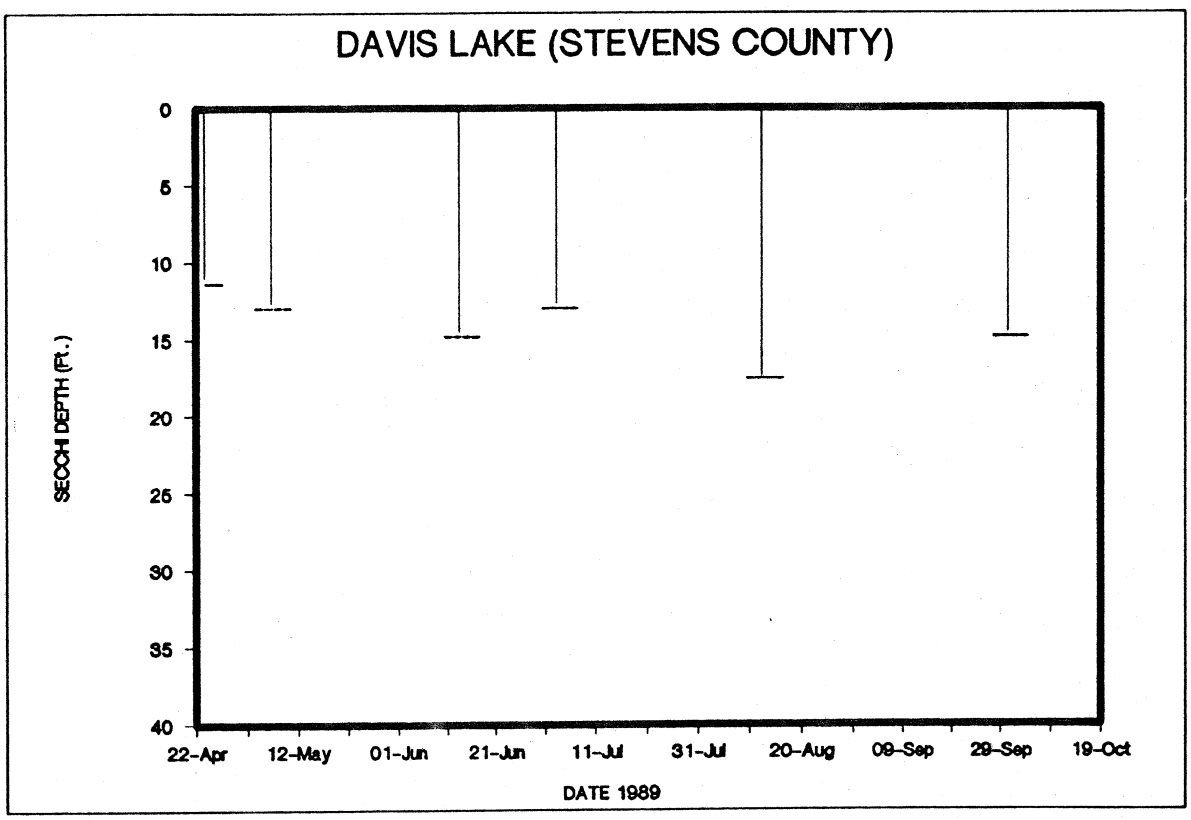
Data collected in 1974 from Davis Lake (Dion *et al.*, 1976) indicate that total phosphorus concentrations were in the range associated with mesotrophic lakes.

Comments

Like other high elevation lakes located in Eastern Washington monitored for the program, water clarity in Davis Lake was lowest during the spring. Spring algal growth most likely affected water clarity in these lakes.

Although the mean trophic state index could indicate that Davis Lake is oligotrophic, an oligo-mesotrophic estimate is reported because of the total phosphorus concentrations detected in 1974.


Volunteer sampling site
N
Davis Lake, Pend Oreille County. From
Washington Department of Game, January 1949.


DAVIS LAKE (STEVENS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Deep Lake -- Stevens County

Deep Lake is located nine miles south from Northport, and 25 miles northeast from Colville. The lake is 1.4 miles long and the shoreline is steep. Both the inlet and the outlet is the north fork of Deep Creek, which drains ultimately to the Columbia River (FDR Lake).

| | |
|---|---|
| Size (acres) | 210 |
| Maximum Depth (feet) | 49 |
| Mean Depth (feet) | 34 |
| Lake Volume (acre-feet) | 7203 |
| Drainage Area (miles$^2$) | 48.1 |
| Altitude (feet) | 2025 |
| Shoreline Length (miles) | 3.50 |

| | |
|---|---|
| Estimated Trophic State: | oligo-mesotrophic |
| Mean Trophic State Index: | 36 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/02 | 1700 | Green | P Sunny | 9.0 | 6.42 | |
| 05/16 | 1815 | Bl-Gr | P Sunny | 14.00 | 13.29 | |
| 06/02 | 1010 | Bl-Gr | Sunny | 17.0 | 17.64 | |

Like other high elevation lakes in Eastern Washington monitored for the program, the lowest water clarity occurred during early May. Because of the large gap in data from June through September, patterns in algal growth cannot be evaluated. Water color was blue-green except during early May, when the water was green.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Deep Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, hiking, and waterfowl hunting. There is one resort and two boat ramps on the lakeshore. Lake water is withdrawn for drinking and other domestic uses. Currently the watershed is used for logging, agriculture (both crop and animal grazing), and the lakeshore is being developed further for residences. In the past, both logging and mining occurred in the watershed. There are about 52 houses on the lakeshore, and 17 of these are occupied year-round. All the residences use on-site wastewater disposal systems. Fish are stocked in the lake. There is a wetland at the south end of the lake near the outlet. Weeds are especially thick in the shallow areas at the north and south ends of the lake. The worst water quality problems, in the opinion of the volunteer, are 1) weeds, 2) fish kill, 3) odor (volunteer attributes to weeds and sediments being removed), and 4) lake level. These problems are worst during July and August. The volunteer suspects that the water quality may be affected by cattle grazing close to the lake; failing and older septic systems located too close to the lake; and residential development.

Results of Intensive Sampling/Summary of Other Available Information

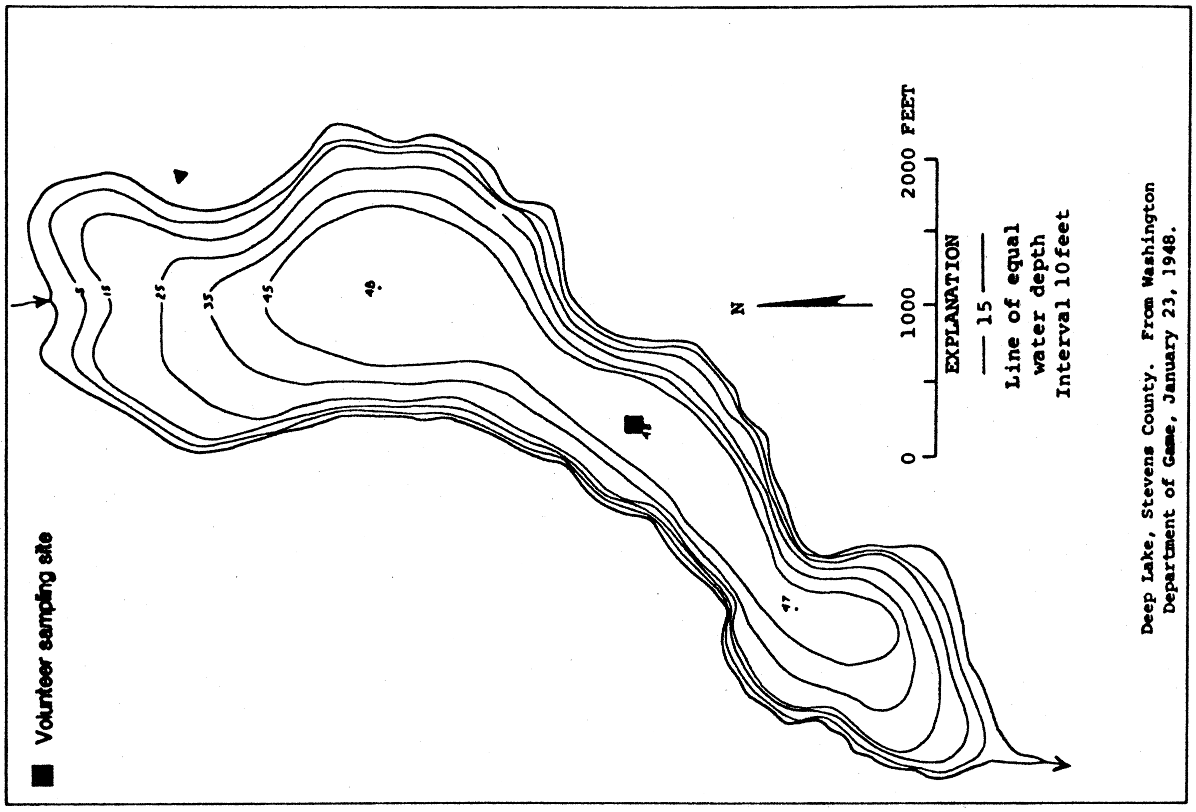
Deep Lake has characteristics of both oligotrophic lakes and mesotrophic lakes. As a result, we are calling the lake oligo-mesotrophic. An oligotrophic characteristic of the lake is the relatively deep Secchi disk transparency. Mesotrophic characteristics of the lake are the moderate concentrations of total phosphorus and chlorophyll *a*, the low dissolved oxygen concentrations near the bottom of the lake and the presence of the blue-green algae (*Anabaena* was identified from an algae sample collected during September). Surface concentrations of total phosphorus are similar to concentrations found in 1974 (Dion *et al.*, 1976).

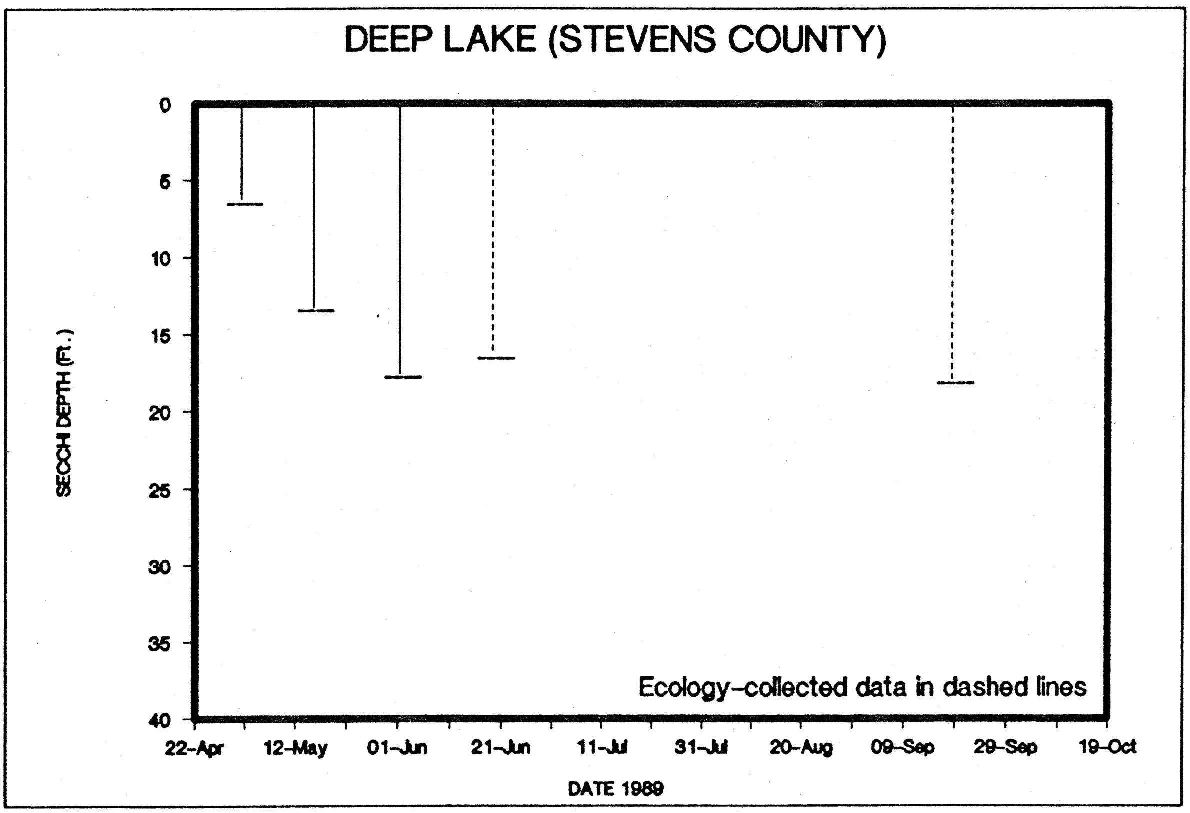
Compared to other intensively monitored lakes, Deep Lake was unusual in that specific conductance increased considerably from the surface to the bottom of the water column. Because of this unusual observation, cation and anion samples were collected during the fall sampling. Analysis of the samples showed that sulfate and bicarbonate (anions) increased in the water column from the epilimnion to the hypolimnion, whereas chloride did not. Because there were mining areas within the watershed, it is likely that the source of the anions is the surrounding geology.

Deep Lake also had high ammonia concentrations in the hypolimnion compared to other lakes sampled by Ecology in 1989. Low dissolved oxygen concentrations create an environment that favors ammonia formation over other nitrogen species. Dissolved oxygen concentrations in Deep Lake were less than 1 mg/L (most fish require at least 4.5 mg/L dissolved oxygen) from eight meters to the bottom during June, and from seven meters to the bottom during September. Bottom water samples collected during September smelled of hydrogen sulfide; hydrogen sulfide (rotten-egg smell) occurs when organic matter decomposes in water in the absence of oxygen. Depleted dissolved oxygen concentrations in the hypolimnion were also reported in 1974 (Dion *et al.*, 1976).

Comments

Secchi disk transparency seems to slightly underestimate the trophic state of Deep Lake. If collected over a period of several years, though, Secchi readings may be used to evaluate patterns of algal growth in the lake. However, more frequent Secchi readings (at least one per month) are needed to evaluate algal growth.


Volunteer sampling site
EXPLANATION
15
Line of equal water depth
Interval 10 feet
0
1000
2000 FEET
N
5
15
25
35
45
48
47
Deep Lake, Stevens County. From Washington Department of Game, January 23, 1948.


DEEP LAKE (STEVENS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed lines
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Deer Lake -- Stevens County

Deer Lake is located about 32 miles north from Spokane and 3.5 miles northeast from the town of Loon Lake. It is a natural lake in the Colville River watershed. Deer Lake drains intermittently southwesterly via a ditch. There is a large bog area (about 100 acres) at the northeast end of the lake.

| | |
|---|---|
| Size (acres) | 1110 |
| Maximum Depth (feet) | 75 |
| Mean Depth (feet) | 52 |
| Lake Volume (acre-feet) | 57,000 |
| Drainage Area (miles$^2$) | 18 |
| Altitude (feet) | 2474 |
| Shoreline Length (miles) | 8.62 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic* |
| Mean Trophic State Index: | 34 |

* See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/04 | 1410 | Green | Sunny | 15.0 | 13.29 | |
| 05/20 | 1405 | Green | P Sunny | 14.0 | 13.29 | |
| 06/06 | 1445 | Green | Sunny | 22.0 | 14.67 | Lake covered with pollen and moss. |
| 06/23 | 1345 | Green | Sunny | 22.0 | 17.19 | Small algae bloom. |
| 07/11 | 1430 | Green | Sunny | 24.0 | 24.75 | Small amount of algae in water. |
| 07/26 | 1450 | Green | Cloudy | 23.0 | 19.71 | Small amount of algae. |
| 08/11 | 1445 | Green | -- | 24.0 | 22.46 | Very bad algae bloom. |
| 08/29 | 1600 | Green | Sunny | 20.0 | 16.50 | Lots of algae, but not as large and yellow as last year. Lots of rain last week. |
| 09/17 | 1150 | Green | P Cloudy | 18.0 | 21.08 | Lots of algae starting to float on top and form clumps and turn brown. |
| 09/27 | 1445 | Green | Sunny | 15.0 | 22.91 | A lot of algae. |
| 10/15 | 1425 | Green | Sunny | 12.0 | 22.00 | Still a small amount of algae. |

Algae growth occurred throughout the sampling season, but appeared to affect water clarity primarily during May, June, and late August. Despite reports of heavy algae growth, the water clarity indicates that Deer Lake is oligotrophic.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Deer Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, hiking, and waterfowl hunting. There are two resorts and three boat ramps on the lakeshore. There is a speed limit for motor boats. Lake water is withdrawn for drinking and other domestic uses. Currently the watershed is used for logging and animal grazing, and lakeshore is being developed further for residences. There are about 700 houses on the lakeshore. All houses use septic systems, and about 100 of the houses are occupied year-round. Individual homeowners rake weeds from their lakeshore areas. Fish are stocked in the lake, and there is a wetland on the north part of the lake. The worst water quality problems, in the opinion of the volunteer, are algal blooms, weeds, sediments suspended in the water (in the spring), and odor (hydrogen sulfide; "rotten egg" smell in the fall and winter). The algae is worst during August. The volunteer is concerned about possible water effects from septic systems, logging, and residential runoff from lawns. The volunteer also noted that ten years ago one could see the bottom of the lake (40 - 50 feet down) and now this is not possible. Algae blooms now occur all over the lake; a bad algae bloom was reported by the volunteer on August 11, 1990. In September, algae clumps were seen floating on the surface and turning brown. Submerged weeds were found all along the lakeshore. Sewering the Deer Lake lakeshore has been proposed. The lake has been studied by Eastern Washington University (EWU).

Summary of Other Available Information

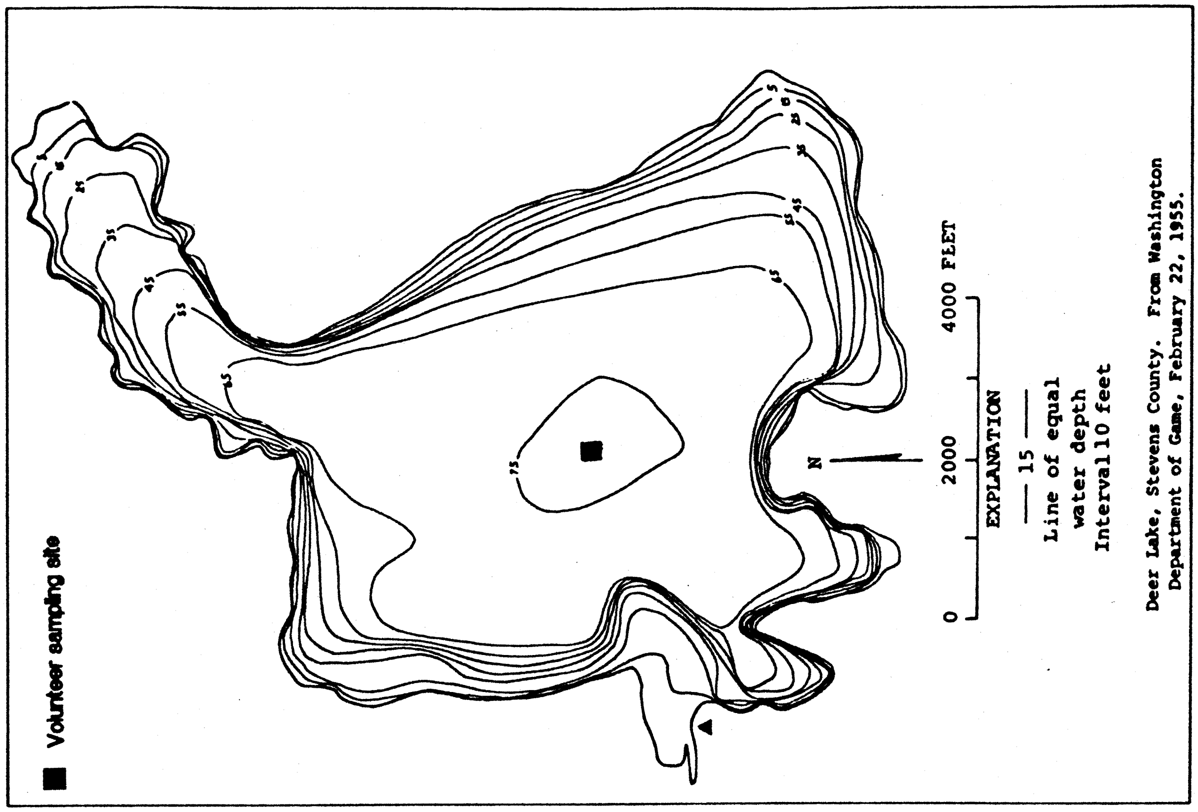
Data collected in 1972 (Dion *et al.*, 1976) and 1981 (Sumioka and Dion, 1985) indicate that Secchi disk transparency and concentrations of most nutrients in Deer Lake were characteristic of oligotrophic lakes. However, total phosphorus concentrations in 1981 were somewhat higher than would be expected given the Secchi disk transparency and the concentration of chlorophyll *a*. Deer Lake was surveyed by Ecology in 1978 and it was concluded that the lake was mesotrophic (Singleton *et al.*, 1980). However, the Secchi disk transparency and chlorophyll *a* data collected for this 1978 survey would be considered oligotrophic according to the trophic state index (Carlson, 1977) used to evaluate data for the 1989 lake surveys.

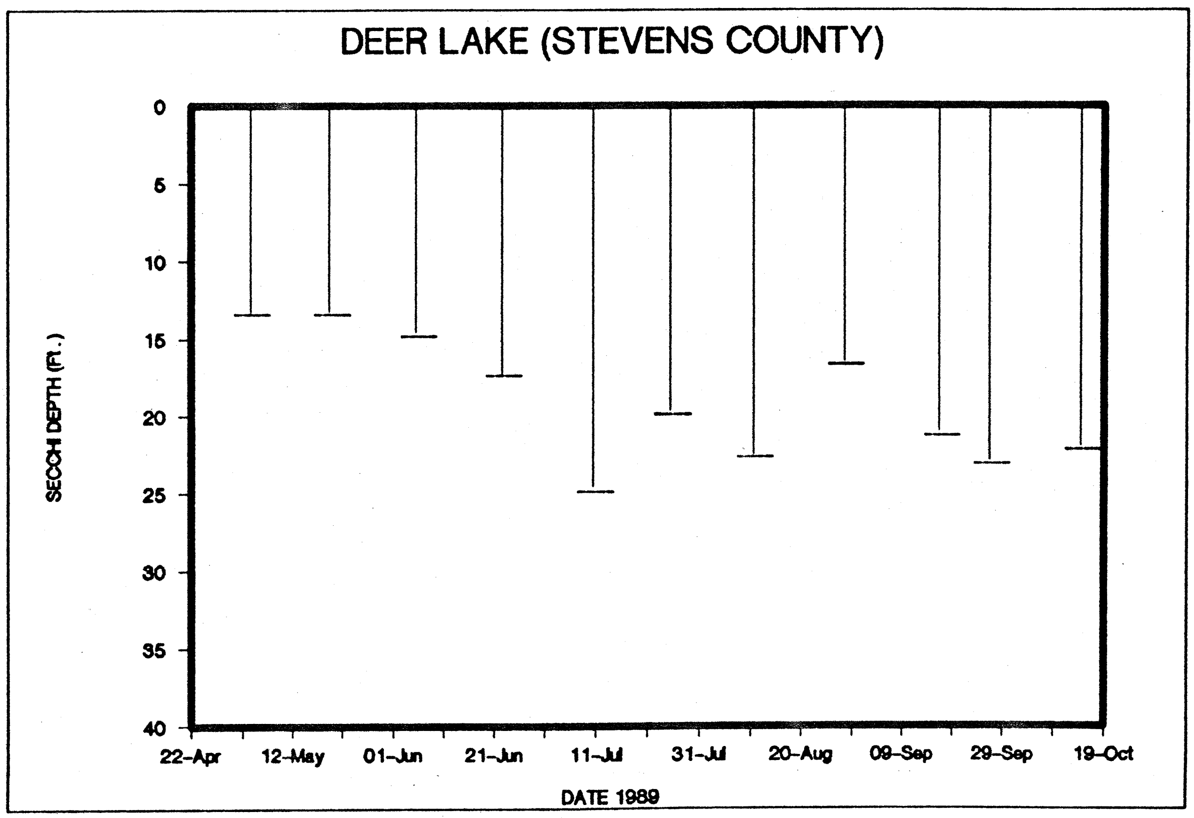
The USGS reported in 1972 that Deer Lake had 358 nearshore homes (Dion *et al.*, 1976); compared with the 700 nearshore homes reported by the volunteer, it is apparent that development has increased significantly along the shoreline.

Comments

Data analyses for surveys conducted on Deer Lake have used different methods for estimating the trophic state. As a result, the lake has been reported as both oligotrophic and mesotrophic. Although 1989 Secchi disk transparency data indicate the lake may be oligotrophic, the relatively high concentrations of total phosphorus reported in 1978 and 1981 may warrant that future estimates of trophic state be confirmed using chlorophyll *a* and total phosphorus data.

Compared with other Stevens County Lakes, Deer Lake has high water clarity, although the water clarity at nearby Loon Lake is slightly better. Compared with other lakes monitored for the program, the water quality at Deer Lake is very good. However, because the volunteer reported that the clarity has decreased with time and that algae clumps are seen in the water, monitoring should be continued so that subsequent changes may be documented. Because sewering the lakeshore has been proposed, long-term monitoring data may be used to compare pre-sewering data with post-sewering data to show if there is a water quality improvement after the area is sewered.


Volunteer sampling site
N
0
2000
4000 FEET
EXPLANATION
15
Line of equal water depth
Interval 10 feet
Deer Lake, Stevens County. From Washington Department of Game, February 22, 1955.


DEER LAKE (STEVENS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

## Duck Lake -- Grays Harbor County

Duck Lake is located on a peninsula directly southeast of Ocean Shores, Washington. Once a wetland, the lake has been extensively dredged and filled for residential and recreational development. Duck Lake is marshy with numerous small islands, and is part of a canal system that runs through the City of Ocean Shores. It drains to Grays Harbor.

| | |
|---|---|
| Size (acres) | 278 |
| Maximum Depth (feet) | 30 |
| Mean Depth (feet) | 11 |
| Lake Volume (acre-feet) | 3000 |
| Drainage Area (miles$^2$) | 1.44 |
| Altitude (feet) | 10 |
| Shoreline Length (miles) | 11.3 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 65 |

### Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 06/10 | 1430 | Green | Sunny | 20.0 | 3.21 | |
| 06/23 | 1400 | Green | Sunny | 22.0 | 1.83 | A fine brown weed is beginning to grow near the edges of the lake. |
| 07/07 | 1330 | Green | P Sunny | 21.5 | 2.52 | |
| 07/24 | 1230 | Green | Sunny | 23.5 | 2.75 | |
| 09/02 | | Green | Sunny | 21.0 | 2.06 | |
| 09/17 | 1330 | Green | Sunny | 21.5 | 2.29 | Weeds thick and starting to die at the surface of the water. |

The water clarity was consistently low (less than four feet) and the water color was green throughout the sampling period. The lowest readings (both 0.5 m, or 1.64 feet) were collected by Ecology staff during intensive monitoring. No pattern in algal growth was evident.

### Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Duck Lake is used for fishing, swimming, boating, jet skiing, and picnicking. There are two boat ramps on the lakeshore. There is a speed limit for motor boats. Lake water is withdrawn for irrigation. Lakeshore development for residences is the main activity within the watershed. There are about 120 houses on the lakeshore (compared with 14 reported in 1974; Bortleson *et al.*, 1974), and 95-98% of these are occupied year-round. The lakeshore area is not sewered. The lake was treated with Diquat and copper sulfate from 1987 - 1989 to control weeds and algae, and individual homeowners rake weeds from their lakeshore areas. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are weeds and algae, which occur in the summer from May through September. The volunteer is concerned about possible water quality effects from septic systems and the large waterfowl population at the lake. The lake has much natural wildlife: beaver, herons, ducks, geese, and otters. Duck Lake and another lake, Lake Minard, are directly connected to a large canal system. Aquatic plants are a problem throughout the lake especially from May through September. The volunteer reported that about 90% of the homes have a natural buffer strip between their homes and the lakeshore. About 98% of the lakeshore is covered with emergent plants.

Results of Intensive Monitoring/Summary of Other Available Information

Intensive survey data from 1989 confirm that Duck Lake is eutrophic, based on shallow Secchi disk readings and high epilimnetic concentrations of total phosphorus and chlorophyll *a*. Compared to the other intensively-monitored lakes, Duck Lake had the lowest Secchi disk readings some of the highest nutrient concentrations (Brower and Kendra, 1990). Dense algal blooms occurred at the surface during both sampling dates, which is probably why the turbidity was higher at the surface than at the bottom of the lake. Water near the bottom of the lake was anoxic during both sampling periods. As a result, ammonia concentrations near the bottom are higher because plants and other organic matter decomposed in the absence of oxygen. Also, when there is little or no oxygen present, elements in the sediments will be chemically reduced and released into the water column. This happens in Duck Lake and is apparent by the high specific conductance and concentrations of total phosphorus in the hypolimnion.

Compared to other lakes monitored by Ecology in 1989, Duck Lake had high concentrations of total nitrogen and total phosphorus. Because concentrations of phosphorus are usually much lower than concentrations of nitrogen, the concentration of available phosphorus usually limits the amount of algae growth in a lake. However, the phosphorus concentrations in Duck Lake are so high that nitrogen or other factors may actually be limiting algal growth. As a result, if additional nitrogen enters the water (such as from animal wastes or failing septic systems), the lake may be able to support even more algal growth.

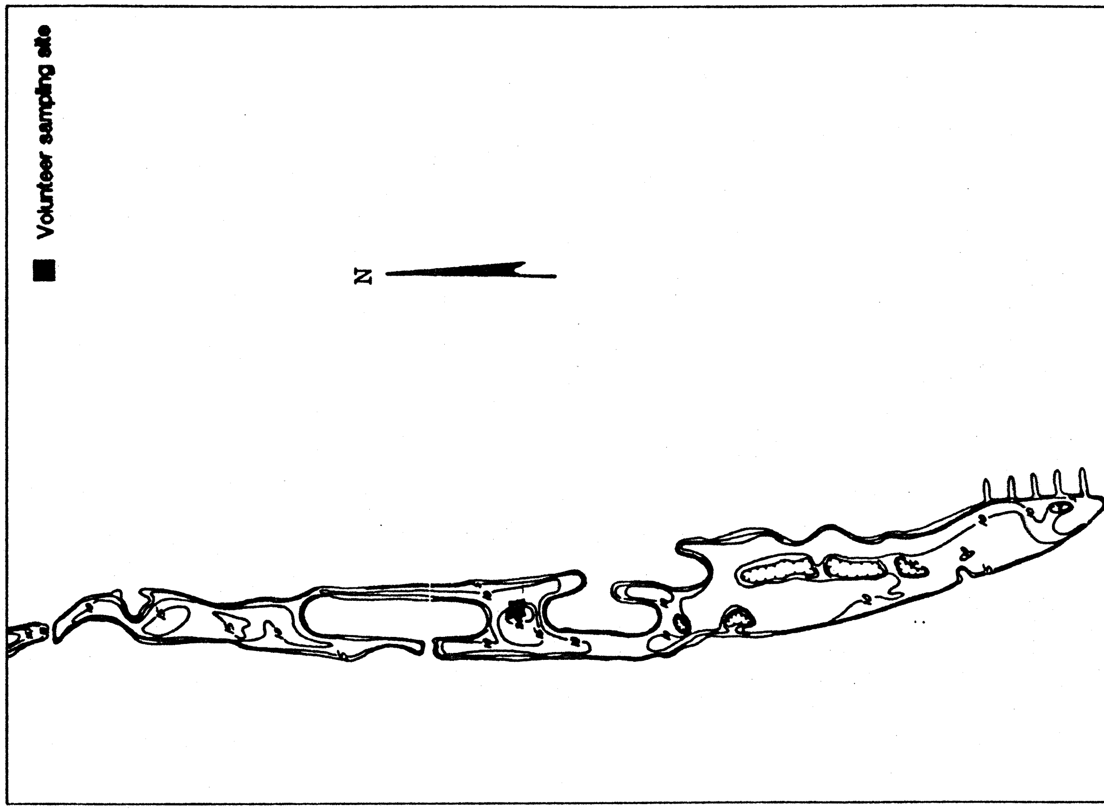
In the early 1960s a series of lakes were dredged, resulting in filling and draining of wetland areas and creating land suitable for development (Kramer, Chin and Mayo, 1989). Presently, property owners are concerned about the algae and aquatic plants that grow in the canals and the lakes. In 1986 the extent of weed growth was investigated and was found to be primarily limited to shoreline areas, due to steep slopes of the dredged canals and lakes; the use of herbicides was recommended to control plants growing in shallow boating and swimming areas (Kramer, Chin and Mayo, Inc., 1989). Hypolimnion samples were not collected during September because the lake was mixing during this period, and concentrations of nutrients would be expected to be the same from top to bottom.

Before the City of Ocean Shores was sewered, high levels of bacteria were found in one of the canals that is associated with the lake. After construction of the sewers, fecal coliform bacteria levels dropped (Kramer, Chin and Mayo, Inc., 1989). Recent (1989) data from the Grays Harbor Health Department indicate that fecal coliform bacteria range from 4-50 colonies/100 mL in the canals, ditches, and a few of the lake sites. Fecal coliform bacteria data collected by Ecology in 1989 did not indicate a bacteria problem in Duck Lake (Brower and Kendra, 1990). However, fecal coliform bacteria samples were collected in mid-channel over the deepest site of the lake, and not from a nearshore area.

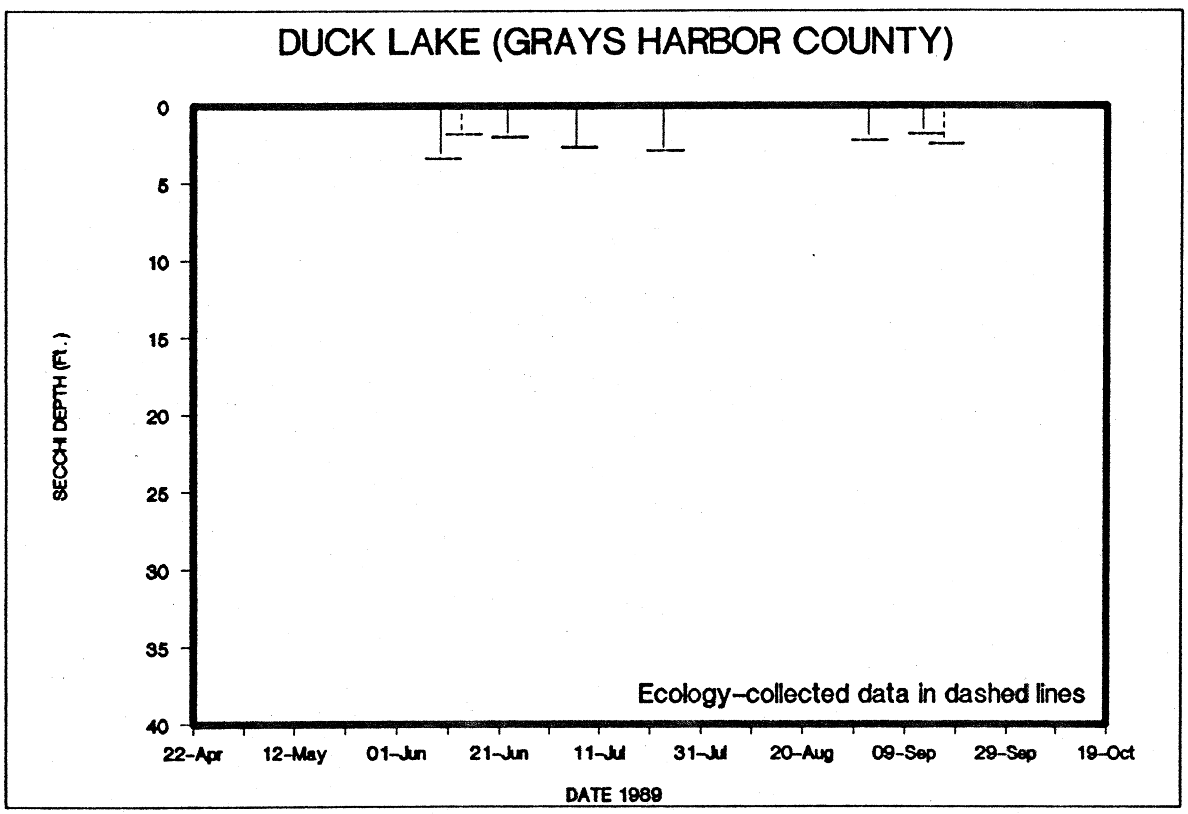
Duck Lake -- Grays Harbor County

Comments

Duck Lake had the lowest water clarity of all the lakes monitored by volunteers during 1989, and it is the only volunteer-monitored lake with a trophic state index value over 60. Duck Lake is probably becoming hypereutrophic, meaning that the lake will continue to have severe algae blooms and large areas grown over with aquatic plants. It is not likely that chemical treatment of the weeds and algae will prevent the lake from being eutrophic, but it may alleviate some of the aesthetic problems. However, because the concentrations of nitrogen and phosphorus are high enough in the lake to support large populations of plants and algae, chemical treatment of the water is a short-term solution.




Duck Lake, Grays Harbor County. From U.S. Geological Survey, March 6, 1974.



Lake Eloika -- Spokane County

Lake Eloika is located four miles west from Elk. It is three miles long and lies in a northeast/southwest direction. Lake Eloika is fed by Fan Lake and the west branch of the Little Spokane River, and drains via the west branch of the Little Spokane River to the Spokane River. Originally a natural lake, it is an enlargement of the west branch of the Little Spokane River, and extends northerly about 1000 feet into Pend Oreille County at high water periods.

| | |
|---|---|
| Size (acres) | 662 |
| Maximum Depth (feet) | 15 |
| Mean Depth (feet) | 9 |
| Lake Volume (acre-feet) | 6018 |
| Drainage Area (miles$^2$) | 111 |
| Altitude (feet) | 1905 |
| Shoreline Length (miles) | 5.91 |

| | |
|---|---|
| Estimated Trophic State: | meso-eutrophic |
| Mean Trophic State Index: | 50 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/12 | 1210 | Green | Sunny | 17.0 | 9.62 | Used disk to verify lake depth. It agrees with position on map. |
| 05/31 | 1051 | Green | Sunny | 18.0 | 12.14 | |
| 06/15 | 1206 | Green | P Sunny | 23.0 | ** | Second reading did not hit bottom - wind may have swung boat around a few feet. |
| 07/03 | 1147 | Green | Sunny | 23.0 | 9.85 | July 4th weekend, but no significant increase in boating. |
| 07/17 | 1315 | Green | P Cloudy | 24.5 | 6.42 | |
| 08/03 | 1235 | Green | P Sunny | 23.5 | 6.42 | Surface choppy; wind about 10 mph to 20 mph. Changing cloud cover. |
| 08/18 | 1045 | Green | Sunny | 22.0 | 5.50 | Algae bloom thick toward shore. |
| 09/05 | 1015 | Green | Sunny | 20.0 | 6.42 | Surface algae mostly gone; water clouded with algae particles. |
| 09/16 | 1535 | Green | P Cloudy | 19.0 | 5.73 | Particles in water seem to be larger than usual. |
| 10/03 | 1405 | Green | Sunny | 16.0 | 4.12 | Lake level came up a week or so ago. Severe algae bloom near shore. |
| 10/19 | 1315 | Green | Sunny | 11.0 | 3.90 | Severe algae near shore. Some wind stirring yesterday and today. |

** Secchi hit bottom

The water clarity was very clear in early June. The water clarity decreased from late June through October as algal growth increased.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Eloika Lake is used for fishing, picnicking, camping, waterfowl hunting, a small amount of boating, and jet skiing. There are two resorts and one boat ramp on the lakeshore. Lake water is withdrawn for a small amount of irrigation. Currently the watershed is used for logging and animal grazing, and the lakeshore is being developed further for residences. In the past, the watershed was logged and the lake was dredged. There are 47 houses on the lakeshore; of these, 25 - 30 are occupied year-round and all use onsite wastewater disposal systems. The lake has not been treated with chemicals, but Fan Lake, which drains into Lake Eloika, has been treated in the past. Individual homeowners rake weeds from their lakeshore areas. Fish are not stocked regularly.

The worst water quality problems, in the opinion of the volunteer, are 1) sediments suspended in the water, 2) weeds, 3) algal blooms, and 4) odor after algal blooms. Problems are worst during July, August, and September. The volunteer reported that a 1987 study conducted by EWU found that phosphorus is the limiting nutrient in the lake, and that upstream lakes and watersheds contribute more than 75% of the total phosphorus to the lake.

Much of the shoreline is wetlands, especially at the north and south ends of the lake, and during spring high water. Except for the two resort areas and a few private beaches, the lake is ringed with a combination of reeds, cattails, and grasses. Patches of large-leafed plants grow in the water and protrude above the surface. The Eloika Lake News reported that Purple Loosestrife was identified in the wetland area and it has since been sprayed and removed.

Summary of Other Available Information

In 1974, the USGS reported that the entire shoreline was covered with emersed aquatic plants (sedge, cattail, and water shield), and 11 - 25% of the lake surface was covered by emersed plants (Dion *et al.*, 1976). This description of the shoreline is similar to conditions reported by the volunteer in 1989.

In July 1974, the algae density was moderately high, the lake bottom was completely covered with submerged aquatic plants (*Ceratophyllum*, *Elodea*, and *Potamogeton*), and dissolved oxygen concentrations were very high (17.2 mg/L) in water 10 feet deep. The high dissolved oxygen concentrations at ten feet probably resulted from photosynthesis by the dense submerged plant community. Data collected in 1981 (Sumioka and Dion, 1985) show that dissolved oxygen concentrations decreased, but were not depleted, near the bottom of the lake. Trophic state indices calculated from Secchi disk transparency, total phosphorus and chlorophyll *a* data collected in 1981 indicate that Eloika Lake was mesotrophic.

Residential development of the lakeshore has not increased significantly since 1974; the USGS reported that in 1974 there were 41 homes along the shore of Eloika Lake (Bortleson *et al.*, 1976).

Conclusions and recommendations from a water quality assessment and restoration feasibility study conducted by EWU states there is a large amount of sediment in Eloika Lake from natural erosion. The thick sediment and the shallow water depth are optimal for macrophyte rooting and growth. Control of the macrophyte communities was recommended for reducing the internal

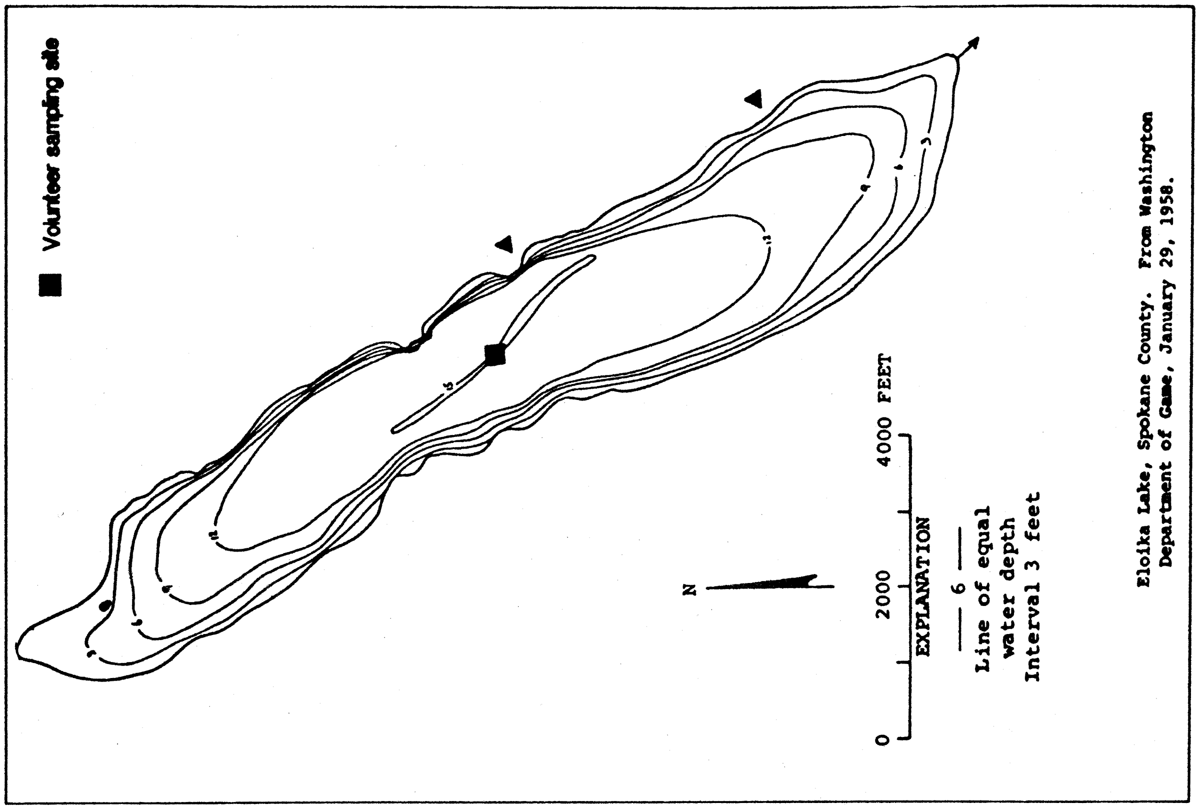
Lake Eloika -- Spokane County

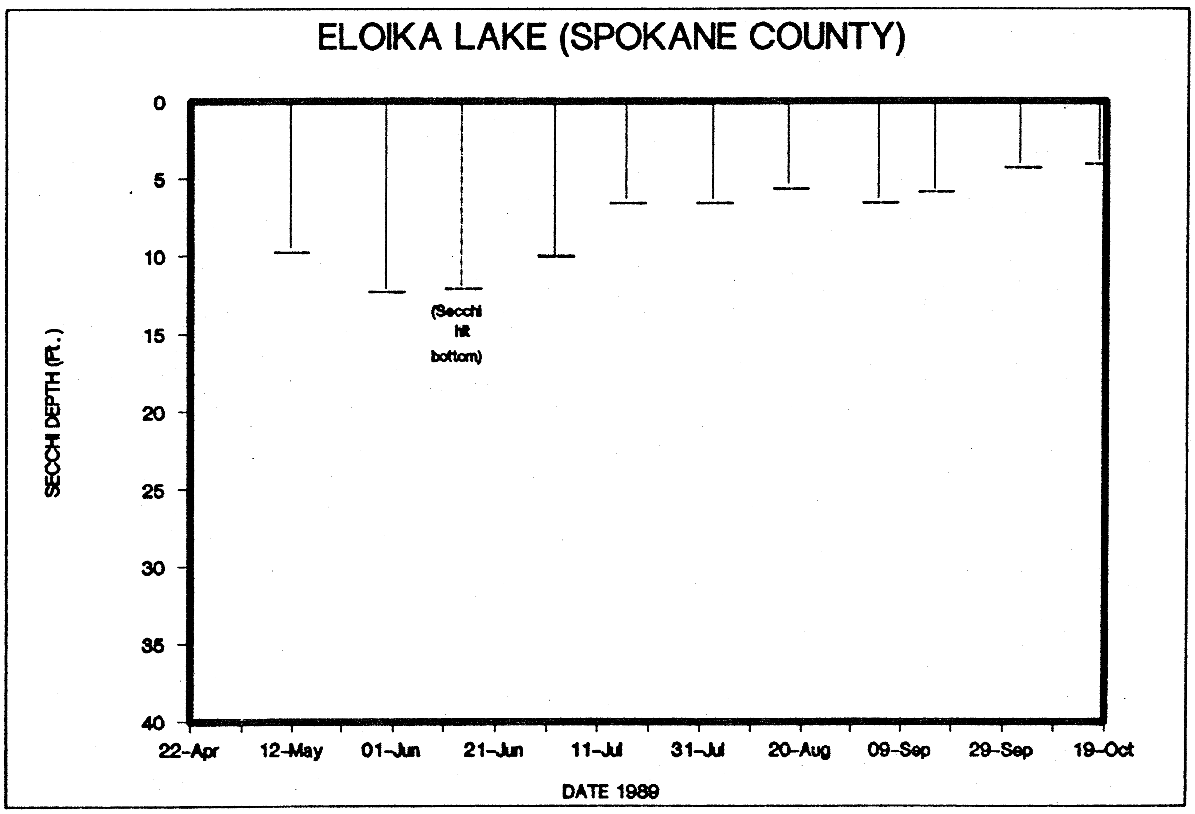
This year, Centennial Clean Water Funds have been awarded to fund a study of the nutrient loading from the upstream watersheds, and to investigate designs for a water control structure at the lake (Soules, 1989). The work will be done by EWU. Presently there is a proposal to install a water control device at the lake outlet for prolonging the water level at the natural spring high level throughout most of the year. Water level drawdown during the winter is also proposed in order to freeze some of the aquatic plant roots. The proposed actions are intended to thin, but not eliminate, aquatic plants in the lake; some plants are needed to preserve fish habitat.

Comments

Like other high elevation lakes in Eastern Washington monitored for the program, the lowest water clarity was measured in May. Spring algal blooms following thaw most likely affected the water clarity during May.

It is difficult to compare Eloika Lake with other lakes in the program because it is a "run of the river" lake, and relative to its size, Eloika lake is very shallow. The most comparable lake to Eloika Lake is Long Lake in Kitsap County, which also has logging and animal grazing within its watershed and has a shallow maximum and mean depth. Eloika Lake has slightly better water clarity than Long Lake; the average trophic state index value for Long Lake is 55.


Volunteer sampling site
N
0
2000
4000 FEET
EXPLANATION
6
Line of equal
water depth
Interval 3 feet
Eloika Lake, Spokane County. From Washington
Department of Game, January 29, 1958.


ELOIKA LAKE (SPOKANE COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
(Secchi
hit
bottom)
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Flowing Lake -- Snohomish County

Flowing Lake is located six miles north from Monroe, and 800 feet west from Storm Lake. It is fed by Storm Lake and drains to Panther Lake and ultimately to the Pilchuk River. It was called Rowing Lake on early maps. The inflow is intermittent.

| | |
|---|---|
| Size (acres) | 134 |
| Maximum Depth (feet) | 69 |
| Mean Depth (feet) | 28 |
| Lake Volume (acre-feet) | 3790 |
| Drainage Area (miles$^2$) | 0.79 |
| Altitude (feet) | 526 |
| Shoreline Length (miles) | 2.22 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 43* |

* See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/18 | 1230 | Brown | P Sunny | 15.0 | 11.69 | Readings taken at 65, 55, and 15 feet. All readings the same. |
| 06/01 | 1230 | Brown | Sunny | 20.0 | 12.37 | Water level raised about 1 foot in last 2 weeks. Boating more prevalent. |
| 06/15 | 1230 | Brown | Cloudy | 20.0 | 11.46 | Water receded by 4.5 feet since 6/1/89. Heavy boat use, swimming at Co. Park. |
| 06/29 | 1300 | Brown | Cloudy | 23.0 | 9.62 | Water receded 2.75 feet since 6/15/89. Heavy recreational use at park on hot days. |
| 07/13 | 1300 | Brown | P Cloudy | 24.0 | 9.85 | Water receded 8" since 6/29/89. Heavy boat use, swimming and recreation. |
| 07/27 | 1300 | -- | Cloudy | 24.5 | 10.54 | Water receded by 1'4" since 7/13/89. Heavy boating, swimming and recreation. |
| 08/10 | 1300 | Brown | P Sunny | 24.0 | 11.00 | Water receded by 12" since 7/27/89. Heavy boat use, swimming and recreation. |
| 08/24 | 1300 | Brown | P Cloudy | 24.0 | 11.00 | Heavy rain last 3 days, cooler weather. Water did not recede. Less recreation. |
| 09/14 | 1300 | Brown | Sunny | 24.5 | 11.46 | Water receded 6" since 8/24. Less boating and recreation. Unusually warm September temperatures. |
| 09/28 | 1300 | Brown | Sunny | 19.0 | 11.46 | Water did not recede. Less activity except on warm weekends on lake. |
| 10/12 | 1300 | Brown | Cloudy | 16.5 | 12.37 | Water level unchanged since 9/28/89. No activity on lake. |
| 10/19 | 1300 | Brown | Sunny | 16.0 | 12.37 | Bright green powdery matter floating on shore edge like oil paint in swirls. |

The water clarity remained fairly consistent throughout the algae growing season. The clarity decreased somewhat from late June through mid-August, when algal growth typically increases and recreational use (power boats) was most prevalent.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Flowing Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a county park and campground on the lakeshore. Unless water skiing, the speed limit for boats is eight mph. Water is withdrawn for irrigation only. In the past the watershed was logged and the lake was used as a log holding pond. Presently there are a number of logs on the lake bottom as a result of past logging practices. Currently the watershed is used for tree farming and lakeshore development for residences. There are 92 houses near the lakeshore; of these, 60 are occupied year-round and all are on septic systems. Homeowners rake weeds from their lakeshore areas. Fish are stocked in the lake, which attracts large populations of cormorants in the spring. On the map completed by the volunteer, two manmade lagoons near the lake are indicated. The volunteer indicated that presently there are no water quality problems at the lake, but she is concerned about potential water quality effects from motor boats in the lake.

Summary of Other Available Information

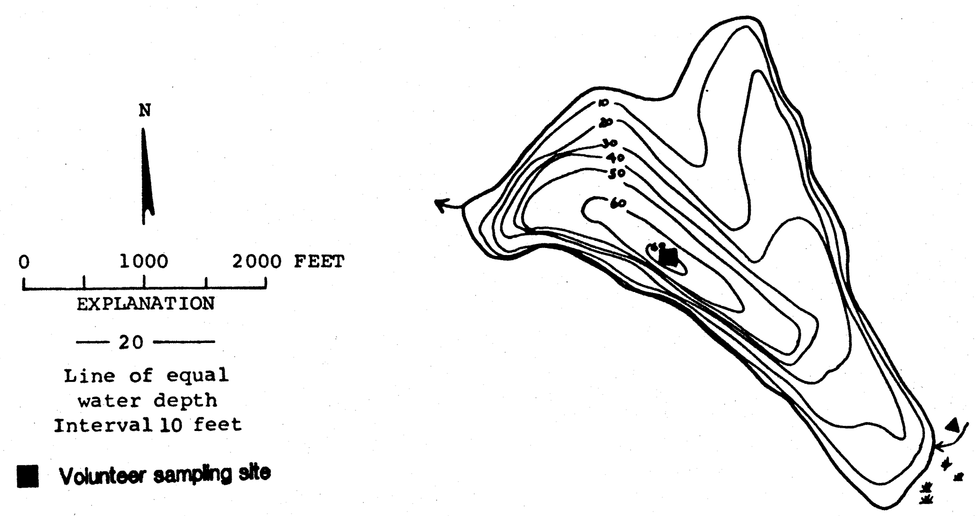
The lake has been dredged at the northeast corner (Bortleson *et al.*, 1976). Residential development of the lakeshore has increased since 1973, when the USGS reported that there were 61 nearshore homes in 1973 (Bortleson *et al.*, 1976).

On April 20, 1989, about 10 - 15 gallons of diesel oil were washed into the lake and required cleanup (R. Newman, pers. comm.).

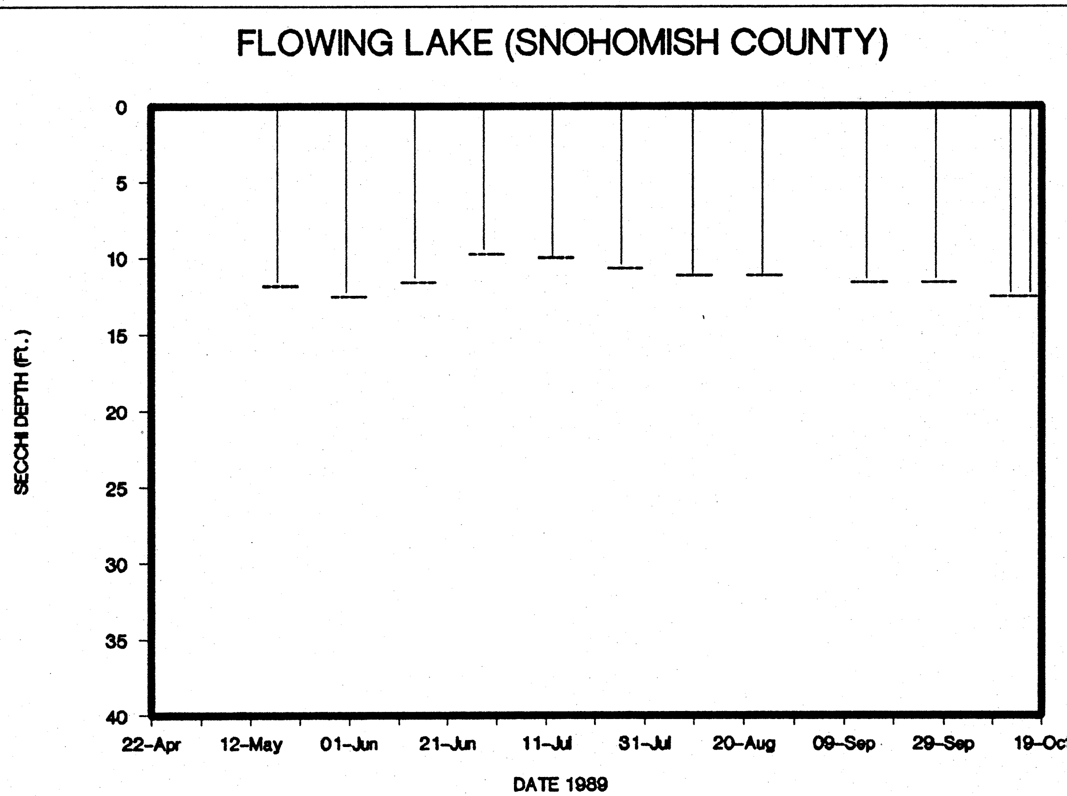
Comments

Compared with other Snohomish County lakes monitored for the program (Blackmans Lake and Lake Goodwin), Flowing Lake had the lowest average water clarity. However, the water clarity of Flowing Lake is not considered to be poor. Compared with Lake St. Clair in Thurston County, which has a similar surface area, and mean and maximum depths as Flowing Lake, Flowing Lake has the better water clarity.

Data collected in 1973 show total phosphorus concentrations that are characteristic of oligotrophic lakes, and Secchi disk transparency that is characteristic of mesotrophic lakes. Because it is possible that Secchi depth data overestimates the trophic status of Flowing Lake, it may be necessary to confirm the trophic state of the lake using chemical data.




Flowing Lake, Snohomish County. From Washington Department of Game, March 20, 1948.



Lake Goodwin -- Snohomish County

Lake Goodwin is located 7.5 miles from Marysville. It drains to Shoecraft Lake and ultimately to Tulalip Bay via Tulalip Creek. The lake is mostly spring-fed and receives winter and spring runoff. The lake is used heavily for recreation.

| | |
|---|---|
| Size (acres) | 560 |
| Maximum Depth (feet) | 50 |
| Mean Depth (feet) | 23 |
| Lake Volume (acre-feet) | 13,000 |
| Drainage Area (miles$^2$) | 5.17 |
| Altitude (feet) | 324 |
| Shoreline Length (miles) | 5.45 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 38 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/11 | 1150 | Bl-Gr | P Sunny | 17.5 | 22.69* | Small ripples on lake. Hardly any boating activity. |
| 05/29 | 1408 | Bl-Gr | Cloudy | 16.0 | 18.56 | Very little boating activity. Heavy rainfall in last few days. |
| 06/27 | 1005 | Bl-Gr | P Cloudy | 20.0 | 15.81 | No boat traffic. Water is very still and clear, bottom clearly visible near shore. |
| 07/13 | 1110 | Bl-Gr | P Cloudy | 21.5 | 13.75 | Lake calm - no boat traffic. Mostly cloudy. |
| 07/26 | 1112 | Bl-Gr | Sunny | 22.5 | 15.12 | Light boat traffic. Ripples - slight breeze. |
| 08/23 | 1347 | Bl-Gr | P Sunny | 20.5 | 14.67 | Slight breeze - ripples on lake - scattered clouds-no boat traffic. |
| 09/13 | 1350 | Bl-Gr | Sunny | 20.0 | 15.12 | Clear weather - light boat traffic; small ripples. |
| 09/28 | 1345 | Bl-Gr | Sunny | 19.0 | 16.04 | Sunny - slight haze. Brisk breeze with small waves. No boats in sight. |

* Limit for quality assurance test was exceeded for this data point.

The water clarity was highest during the spring and gradually decreased through late June. Water clarity remained fairly stable from late June through September.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Lake Goodwin used for fishing, swimming, boating, jet skiing, picnicking, and camping. There is a state park and two resorts on the lakeshore. The speed limit for boats is 35 mph. Currently the lakeshore is being developed for residences. There are about 300 houses on the lakeshore; all are on septic systems and about 250 of the houses are occupied year-round. In the opinion of the volunteer, algal blooms and sediments suspended in the water present mild water quality problems during August. The volunteer is concerned about possible water quality effects from septic systems. Fish are stocked in the lake. Except for the state park and the resorts, the lake front is all residential. There are approximately 375 lots on the lake, and there are a few lots still undeveloped. The two resorts, plus one resort no longer in business, take up about 1800 feet of shoreline. The state park has approximately 750 feet of shoreline. There are three or four community beach areas that take up 300 or 400 feet of shoreline. Information concerning numbers and sizes of lots was derived by the volunteer from plot maps available at Snohomish County courthouse.

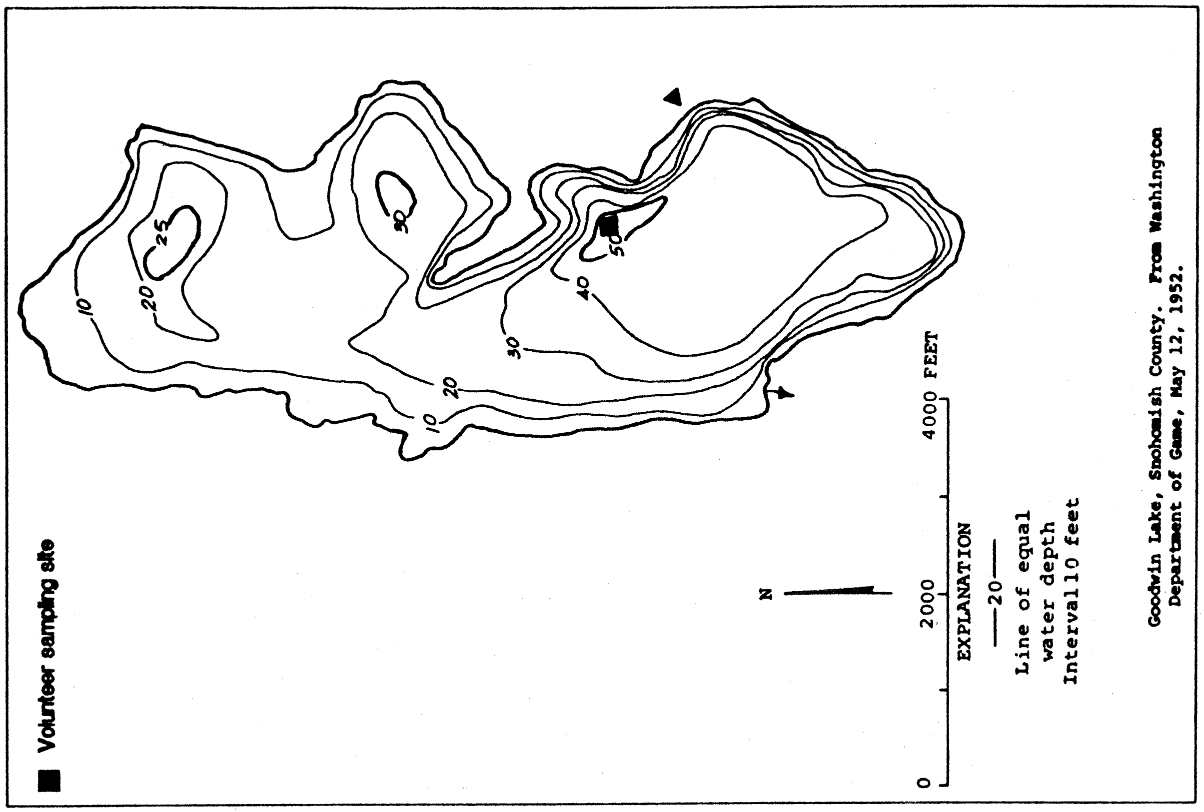
Summary of Other Available Information

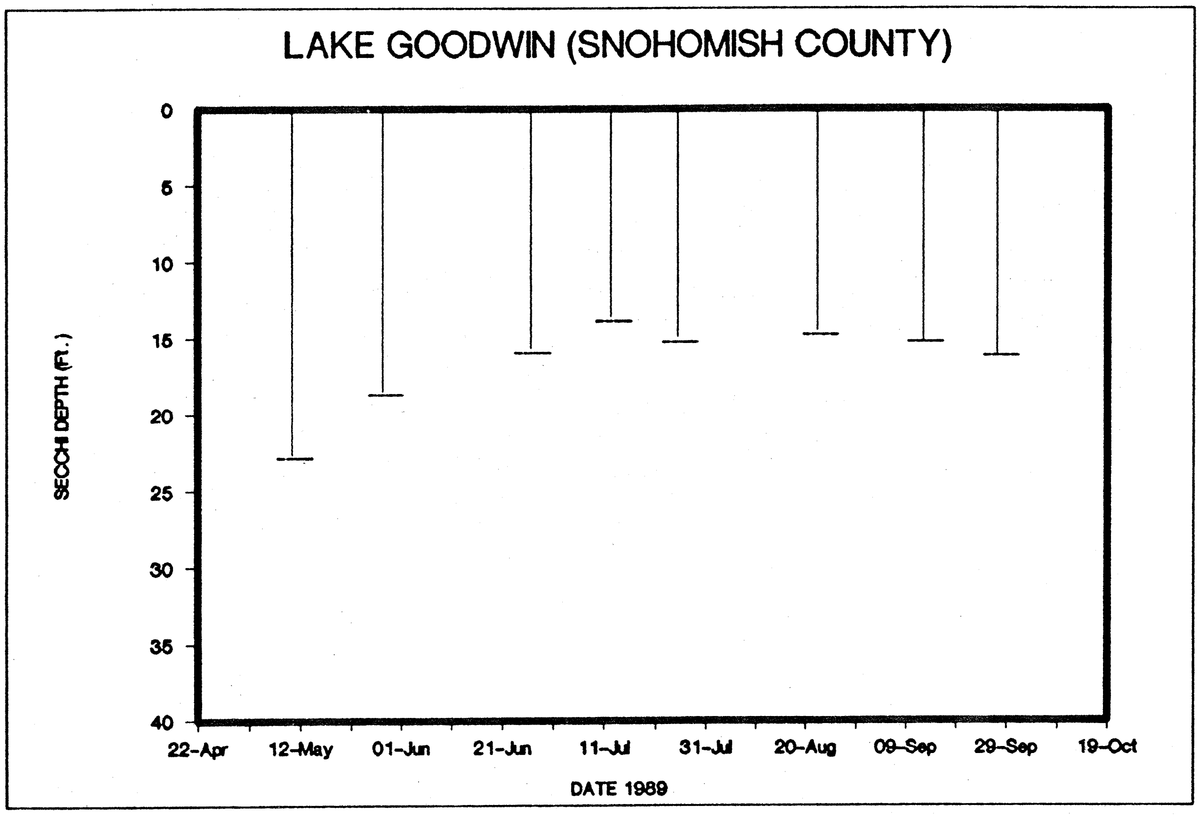
Lake Goodwin is one of the Seven Lakes investigated for a study funded by Ecology and conducted by Entranco Engineers in 1983. The study identified failing septic systems along the lakeshore as likely sources for about 13% of the total annual loading of total phosphorus into Lake Goodwin, as well as several sites of shoreline algal growth and bacterial contamination (Edwards *et al.*, 1987). All trophic state parameters (Secchi disk transparency and epilimnetic concentrations of total phosphorus and chlorophyll *a*) indicated the lake was oligotrophic.

Although nutrient concentrations were low in 1983, data from 1968 (Lee, 1969) and 1972 (Bortleson *et al.*, 1976) indicate that dissolved oxygen concentrations were depleted near the lake bottom during the summer. Dissolved oxygen concentrations are depleted as bacteria decompose organic matter (such as plants and algae) in the hypolimnion, and often precedes onset of eutrophication.

Comments

Lake Goodwin exhibits the same general pattern in water clarity as Flowing Lake, a nearby Snohomish County Lake. However, the water clarity was greater at Goodwin Lake than at Flowing Lake, particularly during the spring.


Volunteer sampling site
10
20
25
30
40
50
EXPLANATION
20
Line of equal water depth
Interval 10 feet
0
2000
4000 FEET
N
Goodwin Lake, Snohomish County. From Washington Department of Game, May 12, 1952.


LAKE GOODWIN (SNOHOMISH COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Goss Lake -- Island County

Goss Lake is located on Whidbey Island, three miles west of Langley. It drains westerly to Holmes Harbor. Three intermittent streams contribute minor inflow early in the year. There is no outlet. No gasoline-powered boats are allowed on the lake.

| | |
|---|---|
| Size (acres) | 47 |
| Maximum Depth (feet) | 60 |
| Mean Depth (feet) | 32 |
| Lake Volume (acre-feet) | 1500 |
| Drainage Area (miles$^2$) | 1.41 |
| Altitude (feet) | 130 |
| Shoreline Length (miles) | 1.91 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 35 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/15 | 1200 | Green | Sunny | 18.0 | 11.00 | |
| 05/29 | 1220 | Green | P Cloudy | 15.0 | 19.25 | Interesting difference from last Secchi reading. |
| 06/10 | 1414 | Green | Sunny | 19.0 | 19.25 | |
| 06/26 | 1340 | Green | P Cloudy | 24.0 | 14.21 | Lake depth somewhat changed because anchoring gear replaced; new gear more accurate. |
| 07/10 | 1200 | Blue | P Cloudy | 19.0 | 15.12 | |
| 07/23 | 1300 | Blue | Sunny | 21.0 | 11.15 | |
| 08/06 | 1215 | Blue | Sunny | 22.0 | 11.00 | |
| 08/26 | 1215 | Blue | Sunny | 20.0 | 25.97 | |
| 09/15 | 1230 | Blue | Sunny | 18.0 | 27.04 | |
| 10/03 | | Blue | -- | 16.5 | 27.96 | |

The fluctuations in water clarity were very dramatic, showing distinct periods when algal growth affected water clarity. The water clarity was high throughout the sampling period despite algal growth during mid-May and late June - early July.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Goss Lake is used for fishing, swimming, canoeing/rowing, sailing, and hiking. There is a boat ramp and a beach on the lakeshore. Water is withdrawn for domestic uses only, although it is not used for drinking. The lakeshore is being developed for residences. There are 46 houses on the lake; of these, 18-20 are occupied year-round and all are on septic systems. Fish are stocked in the lake.

Goss Lake -- Island County

In the opinion of the volunteer, the only lake water problem is the water level fluctuating with rain and drought conditions. According to the volunteer, the "Lake (is) remarkably clean and unspoiled; hope to keep it that way." The volunteer is concerned about possible water quality effects from residential development on the lakeshore, and septic systems.

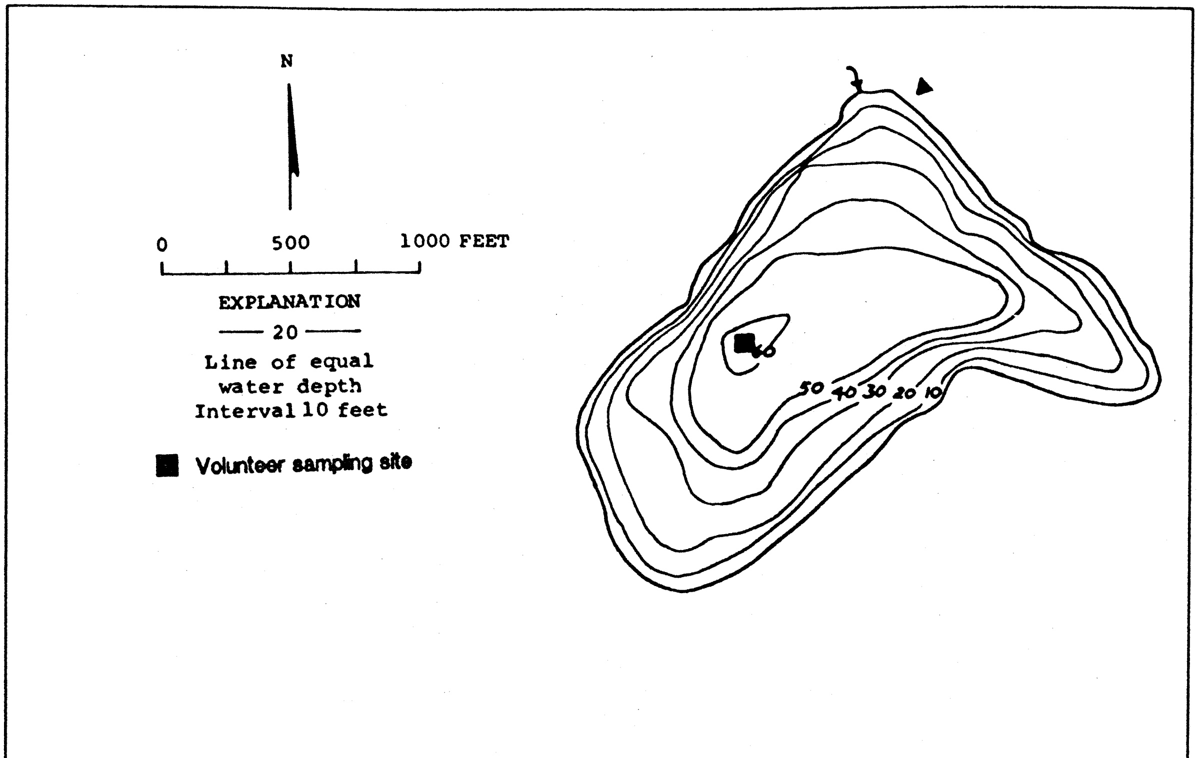
Results of Intensive Sampling/Summary of Other Available Information

Intensive survey data from 1989 confirm that Goss Lake is oligotrophic, based on the high Secchi disk transparency and the low epilimnetic concentrations of total phosphorus and chlorophyll *a* (Brower and Kendra, 1990). However, dissolved oxygen concentrations were depleted near the bottom of the lake by June, which is not characteristic of an oligotrophic lake. Increases in dissolved oxygen concentrations at five meters (during June) and six meters (during September) probably resulted from algae photosynthesis at these depths. Very little aquatic plant growth was noted, including sparse patches of cattails (*Typha* spp.) on the east and west ends of the lake and smartweed (*Polygonum* spp.) on the north end. The water was "tea" colored, probably from humic materials released from the decomposition of woody debris in the water. Nutrient concentrations in 1989 were similar to concentrations detected in 1973 (Bortleson *et al.*, 1976). Dissolved oxygen concentrations near the bottom of the lake were not depleted in 1973.

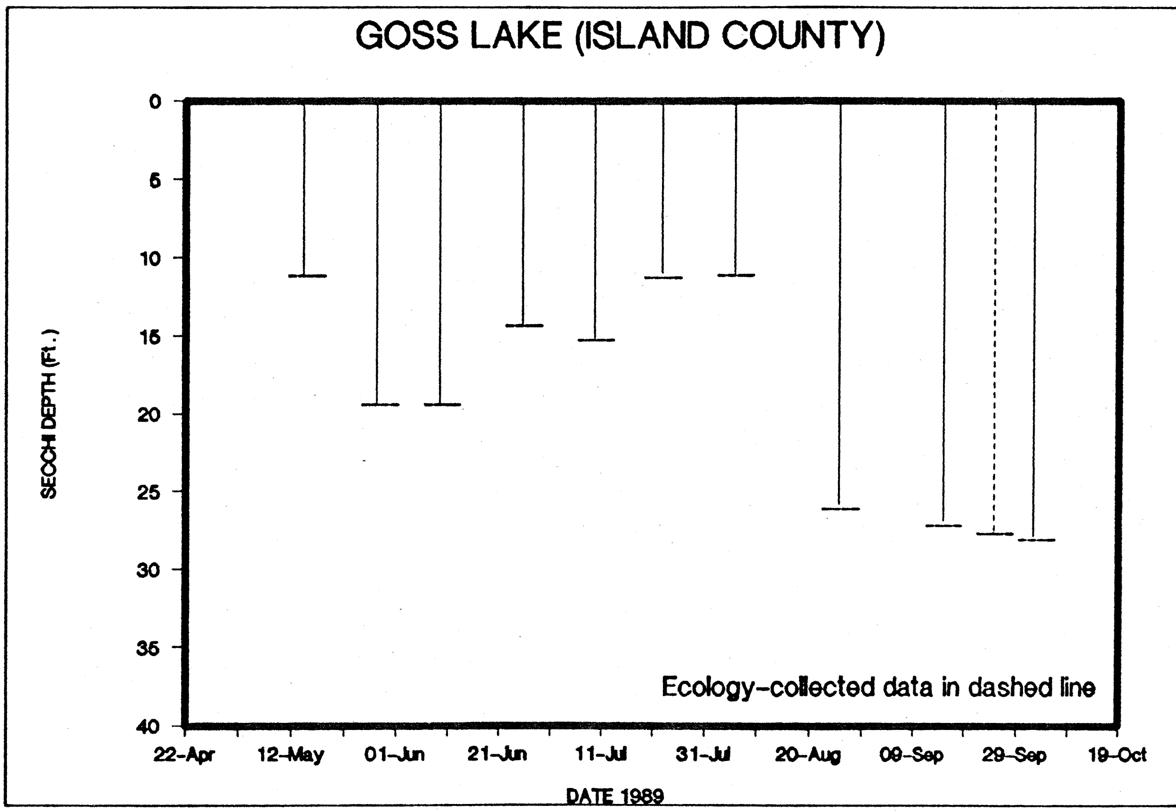
There has been a moderate increase in residential development along the shore of Goss Lake since 1973, when the USGS reported that there were 36 nearshore homes (Bortleson *et al.*, 1976).

Comments

Compared to other nearby lakes sampled in the program (such as Lone Lake and Cranberry Lake), the water quality of Goss Lake is very good. Lone Lake, which is less than a mile away, is shallower and has a larger watershed that is more developed than the Goss Lake watershed. Fewer watershed activities, more pervious surface in the watershed, and a greater amount of natural vegetation around the shore of Goss Lake are likely to contribute to its relatively higher water quality.




Goss Lake, Island County. From Washington Department of Game, January 23, 1949.



Island Lake -- Mason County

Island Lake is located two miles southwest from Keyport. It has a one acre island, and drains via Barker Creek to Dyes Inlet. There is only ground water inflow. A dense pattern of residential development surrounds the lake.

| | |
|---|---|
| Size (acres) | 108 |
| Maximum Depth (feet) | 31 |
| Mean Depth (feet) | 21 |
| Lake Volume (acre-feet) | 2246 |
| Drainage Area (miles$^2$) | 0.26 |
| Altitude (feet) | 230 |
| Shoreline Length (miles) | 1.74 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 37 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/09 | 1145 | Blue | Cloudy | 17.0 | 15.58 | Wind calm - water smooth. |
| 05/23 | 1030 | Blue | Cloudy | 15.5 | 14.67 | Water calm. |
| 06/06 | 1415 | Blue | Sunny | 19.0 | 11.46 | Light bloom. On 6/1 heavy stratification of blue-white color at shore. First time this has been seen. |
| 06/20 | 1130 | Blue | Sunny | 18.5 | 16.73 | Light wind, chop on water. No visible algae in water. |
| 07/06 | 1330 | Blue | Sunny | 20.5 | 17.19* | Calm. |
| 07/18 | 1300 | Blue | Sunny | 21.0 | 18.33 | |
| 08/01 | 1320 | Blue | P Sunny | 20.0 | 13.52* | |
| 08/15 | 1020 | Blue | P Cloudy | 21.0 | 14.21 | |
| 09/14 | 1200 | Blue | Sunny | 20.5 | 18.33 | |
| 09/27 | 1445 | Blue | Cloudy | 18.0 | 14.67 | |
| 10/08 | 1200 | Blue | Sunny | 17.0 | 16.50 | |

*Limit for quality assurance test was exceeded for this data point.

A brief algal bloom occurred in early June as shown by the water clarity and remarks from the volunteer. Varying water clarity from August through October suggest algal growth occurred but not in bloom quantities.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Island Lake is used for fishing, swimming, boating, and jet skiing. Motor boating is "subject to Mason County regulations". Water is withdrawn for irrigation only. There are no current watershed activities, although the watershed has been logged in the past. There are 84 houses on lakeshore; all are on septic systems and about 80 of the houses are occupied year-round. Fish are stocked in lake.

Island Lake -- Mason County

The lake level varies up to five feet during the year. There are wetlands. Lily pads ("about 2-inches in diameter, no flower," possibly *Brasenia*) are found along about 55 - 60% of the shoreline. Submerged weeds ("oblong leaves, some reach water surface," possibly *Potamogeton* spp.) are found in about 0-15 feet of water on the west side of the lake.

In the opinion of the volunteer, algal blooms during August and September present the worst water quality problems in Island Lake. In 1989 there was a severe algal bloom around April 1, and a brief bloom around June 1. The volunteer is concerned about possible water quality effects from septic systems.

Summary of Other Available Information

The number of nearshore homes has not changed appreciably since 1974; the USGS reported there were 85 nearshore homes in 1974 (Bortelson *et al.*, 1976) and 88 nearshore homes in 1981 (Sumioka and Dion, 1985).

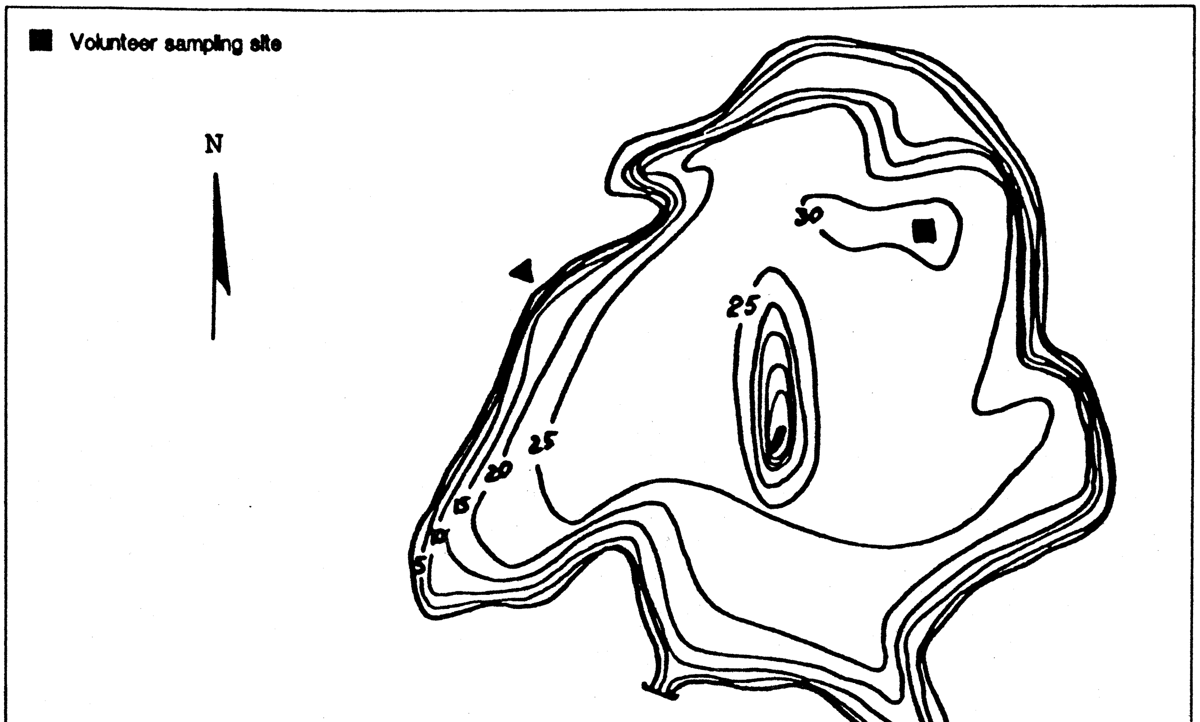
Trophic state indices calculated from Secchi disk and chlorophyll *a* data collected in 1981 (Sumioka and Dion, 1985) indicate that Island Lake was oligotrophic. However, total phosphorus concentrations were high and more characteristic of concentrations found in eutrophic lakes. Total phosphorus concentrations measured in 1974 (Bortleson *et al.*, 1976) were characteristic of concentrations found in oligotrophic lakes. Current total phosphorus data will be needed to determine whether total phosphorus concentrations have actually increased in Island Lake since 1974.

Island Lake was surveyed in 1970 along with other Mason County lakes. Blue-green algal growth was documented during the fall of 1970. Conclusions from the survey included that nutrients were being recycled from the sediments and contributed to the extensive diatom blooms that occurred from January to March, 1971, and that it was likely that there were some outside sources of nutrients into the lake (Funk *et al.*, 1972).

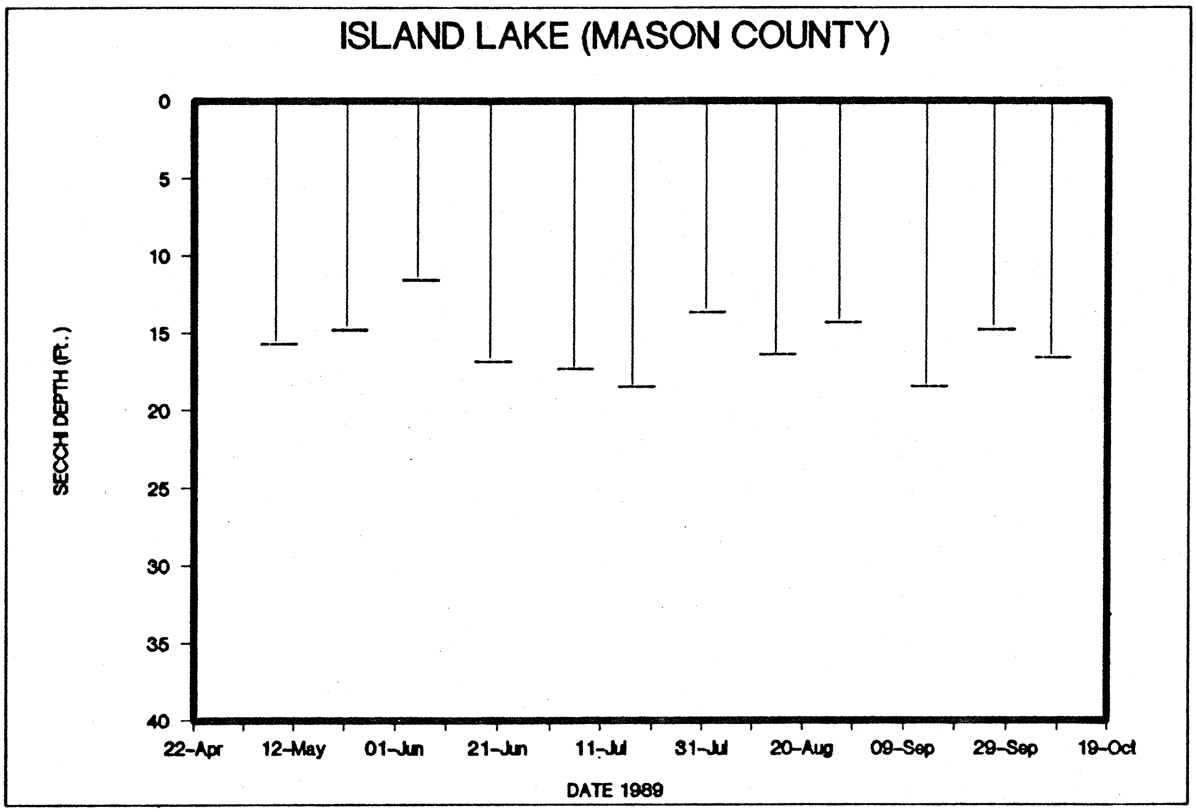
Comments

In August 1974 the USGS reported that the lake supported a sparse growth of aquatic macrophytes (Bortleson *et al.*, 1976). Because the volunteer reported floating-leaved and submerged aquatic plant species in the lake, it is possible that the macrophyte density has increased in the lake since 1974.

In general, most lakes in the program with a mean depth of at least 20 feet are oligotrophic. Island Lake is no exception. Compared with other Mason County lakes monitored for the program, the water clarity of Island Lake is somewhat better than water clarity at Tiger and Phillips Lakes. The physical characteristics (maximum and mean depths, and drainage area size) of Wooten Lake are similar to those of Island Lake; although the water clarity is somewhat better at Wooten Lake than at Island Lake, algal and plant growth are gradually increasing in both lakes.




Island Lake, Mason County. From Washington Department of Game, February 15, 1952.



Lake Kahlotus -- Franklin County

Lake Kahlotus is located about 40 miles northeast of Pasco, at Kahlotus. It is fed primarily by runoff and agricultural return water, and drains westerly a short distance before disappearing underground in Washtucna Coulee. The acreage varies with seasons. Acreage reported is from 1955 aerial photographs.

| | |
|---|---|
| Size (acres) | 380 |
| Maximum Depth (feet) | 24 |
| Mean Depth (feet) | 14 |
| Lake Volume (acre-feet) | 5140 |
| Drainage Area (miles$^2$) | 167 |
| Altitude (feet) | 880 |
| Shoreline Length (miles) | 5.34 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 54 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 06/21 | 1308 | Green | Sunny | 21.0 | 6.42 | Site moved due to plants. Several dead fish on shore - bluegill, some bass. |
| 07/11 | 1255 | Green | Sunny | 25.0 | 1.60 | Heavy algae and plant growth. Water level dropping rapidly; may have caused fish deaths. |
| 09/07 | 1125 | Green | Sunny | 19.5 | 7.33 | Slower aquatic plant growth (cooler night temps) - algae bloom is still heavy. |

The sampling location was established where there was the least amount of plant growth. In July the very low Secchi depth coincided with very heavy algal and plant growth.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Lake Kahlotus is used for fishing and waterfowl hunting. Presently there are no restrictions on motor boat use. The water is not withdrawn for any uses. Currently both crop agriculture and animal grazing occur within the watershed (The USGS reported that in 1974 100% of the watershed was used for agriculture; Dion *et al.*, 1976). There is only one house on the lakeshore and it is occupied year-round. Fish are stocked in the lake, and the volunteer reported, "In 1980, the Tri-Cities Bass Club planted largemouth bass, bluegill, and crappie. Later perch were introduced by an individual."

Lake Kahlotus -- Franklin County

The worst water quality problems, in the opinion of the volunteer, are 1) weeds, 2) algal blooms, 3) lake level, 4) odor ("offensive - heavy decomposition of matter; plants and fish"); and 5) fish kill. The problems are worst during the summer, from mid-May through mid-September. The volunteer is concerned about the possible effects of motor boat use on lake quality and has observed chopped-up plant floating on the surface. Submerged plant growth, most *Potamogeton pectinatus* with some *Myriophyllum* sp., is heavy throughout the lake and is particularly heavy all along the shoreline. The present size of the lake is considerably smaller than shown on the map; the volunteer reports that the lake hasn't covered 380 acres since the early 60s. The lowered lake level has exposed an island on the southwest side of the lake and created wetlands at the west and east ends of the lake.

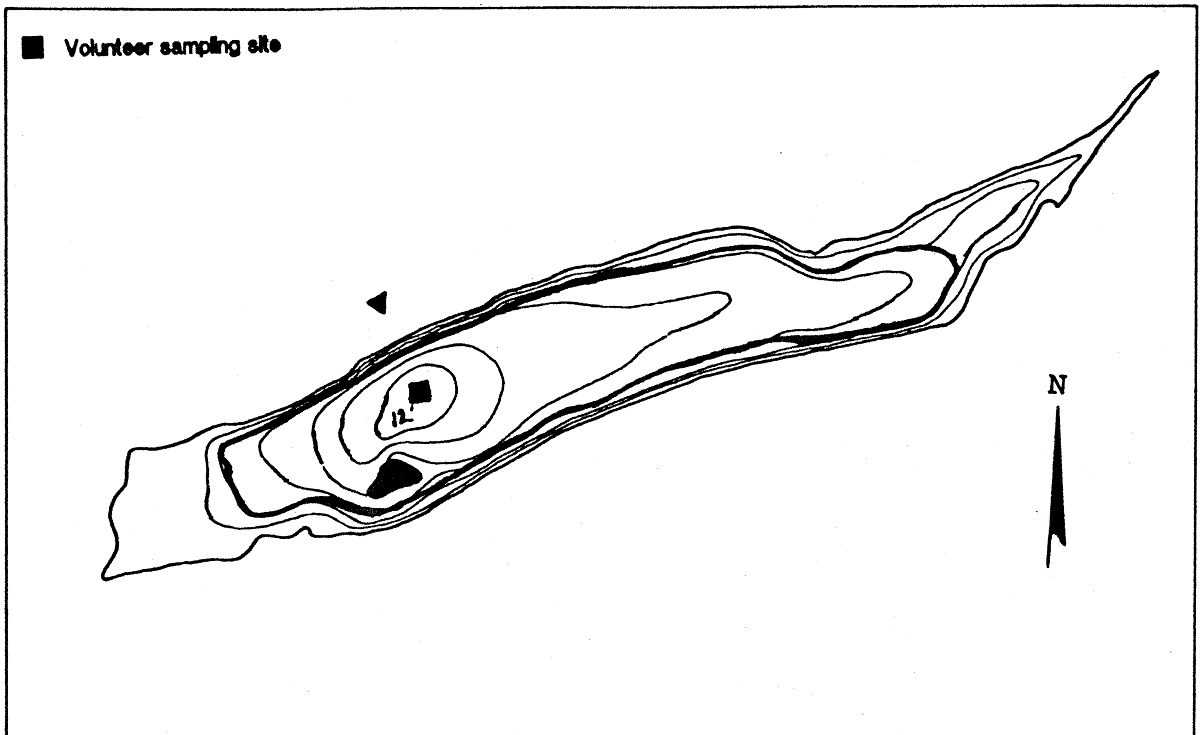
Results of Intensive Monitoring/Summary of Other Available Information

Sediment and largemouth bass samples were collected from Lake Kahlotus by Ecology as part of a statewide toxics survey. Relatively low concentrations of phenol (190 - 280 $\mu$g/Kg) and 4-methylphenol (59 $\mu$g/Kg) were detected in the sediment samples. These are naturally occurring substances that are generally considered to have low toxicity to aquatic organisms. Because concentrations of heavy metals and DDT by-products were also low, the fish and sediment from Lake Kahlotus appeared to be uncontaminated (Johnson and Norton, 1990).

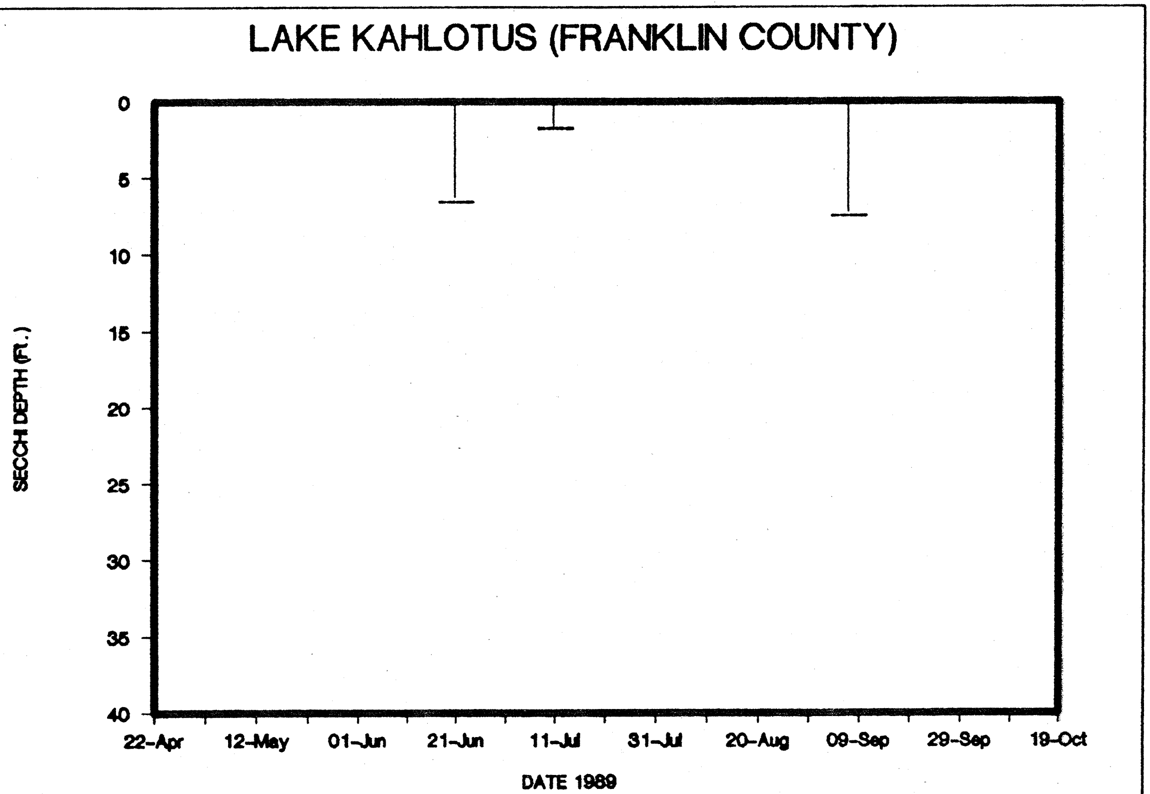
In 1974 the USGS surveyed Lake Kahlotus and reported extremely high concentrations of total phosphorus and orthophosphorus in the water, and the lake bottom was described to be covered completely with submersed aquatic plants and filamentous green algae (Dion *et al.*, 1976).

Comments

Compared with other lakes monitored for the program, the water clarity of Kahlotus Lake is very poor. Only three other lakes had lower average water clarity. One of these lakes, Lacamas Lake in Clark County, has similar size, drainage area size, and land uses as Kahlotus Lake.




Kahlotus Lake, Franklin County. From Washington Department of Game, July 13, 1954.



## Lake Killarney -- King County

Lake Killarney is located 3.5 miles from Auburn. It is fed primarily by runoff and ground water and drains via Hylebos Creek to Commencement Bay. The volunteer sampled the south arm of the lake; the size of the south arm is 24 acres.

| | |
|---|---|
| Size (acres) | 46 |
| Maximum Depth (feet) | 15 |
| Mean Depth (feet) | 9 |
| Lake Volume (acre-feet) | 230 |
| Drainage Area (miles$^2$) | 0.24 |
| Altitude (feet) | 385 |
| Shoreline Length (miles) | 1.25 |

| | |
|---|---|
| Estimated Trophic State: | meso-eutrophic |
| Mean Trophic State Index: | 49* |

* See Comments section

### Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/26 | 1300 | Brown | Cloudy | 17.5 | 7.33 | High water level around April 7, 1989. |
| 06/02 | 1400 | Brown | Sunny | 23.0 | 7.33 | Water level dropped 8" from 4/7/89. Only fishermen using lake; no outboard motor use. |
| 06/13 | 1200 | Brown | P Sunny | 22.5 | 8.02 | Calm water. Lake still receiving light use; a couple of small O/B last weekend. |
| 06/22 | 1330 | Brown | Sunny | 22.0 | 6.42 | Slight wind, temp last two weeks below normal. Light lake use on weekends. |
| 07/04 | 1200 | Brown | P Sunny | 22.0 | 4.81 | Raining almost every day, below average temp. Water level dropped 12" since 4/7. |
| 07/15 | 1300 | Brown | Raining | 22.0 | 3.90 | Water level dropped 14.5" since April. Light use on lake. |
| 07/28 | 1300 | Brown | Sunny | 24.0 | 5.04 | Lake level dropped 16.5" since spring. |
| 08/04 | 1400 | Brown | Sunny | 22.5 | 5.73 | Water level dropped 17.5" since spring high level. |
| 08/13 | 1230 | Brown | P Sunny | 23.0 | 7.79 | Water level has dropped 19 1/2". |
| 08/22 | 1400 | Brown | P Sunny | 22.5 | 9.17 | Heavy rain yesterday. Lake level dropped 20.5" since spring. |
| 09/08 | 1400 | Brown | Sunny | 21.0 | 8.25 | Lake level dropped 2 feet since spring high. |
| 09/18 | 1430 | Brown | Sunny | 20.0 | 9.17 | Lake level dropped 25.75". |
| 10/13 | 1400 | Brown | P Cloudy | 15.0 | ** | Lake level dropped 28" from spring high (April). |

** Secchi hit bottom

The lake height measured from the volunteer's dock was graphed with the Secchi data to show the relationship between the lake height and the water clarity. The lake level increases (most likely from runoff following rain events), correspond to water clarity decreases. This is particularly evident from July through August. The water color was brown on every sampling day.

Lake Killarney -- King County

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Lake Killarney is used for fishing, swimming, canoeing/rowing, and sailing/wind surfing. The speed limit for boats is approximately five mph, and the lake is closed after dark.

Lakeshore development for residences is the only activity occurring in the watershed. There are 53 houses on the lakeshore; all are occupied year-round and are on septic systems. The lake has been chemically treated this year and in the past to control lily pads. Fish are stocked and the lake has wetland areas. In the opinion of the volunteer, the worst water quality problems are 1) sediments suspended in the water, 2) lake level, and 3) weeds (during the summer). The volunteer is concerned about possible water quality problems from sediments in spring runoff and older septic systems. There is a lake improvement group, and most residents voluntarily pay $75 per year to have the lilypads and weeds controlled with chemicals. Most of the aquatic plants grow in 0-10 feet of water; lily pads are localized in cove areas. Emergent plants grow in the north basin only, on the north side.

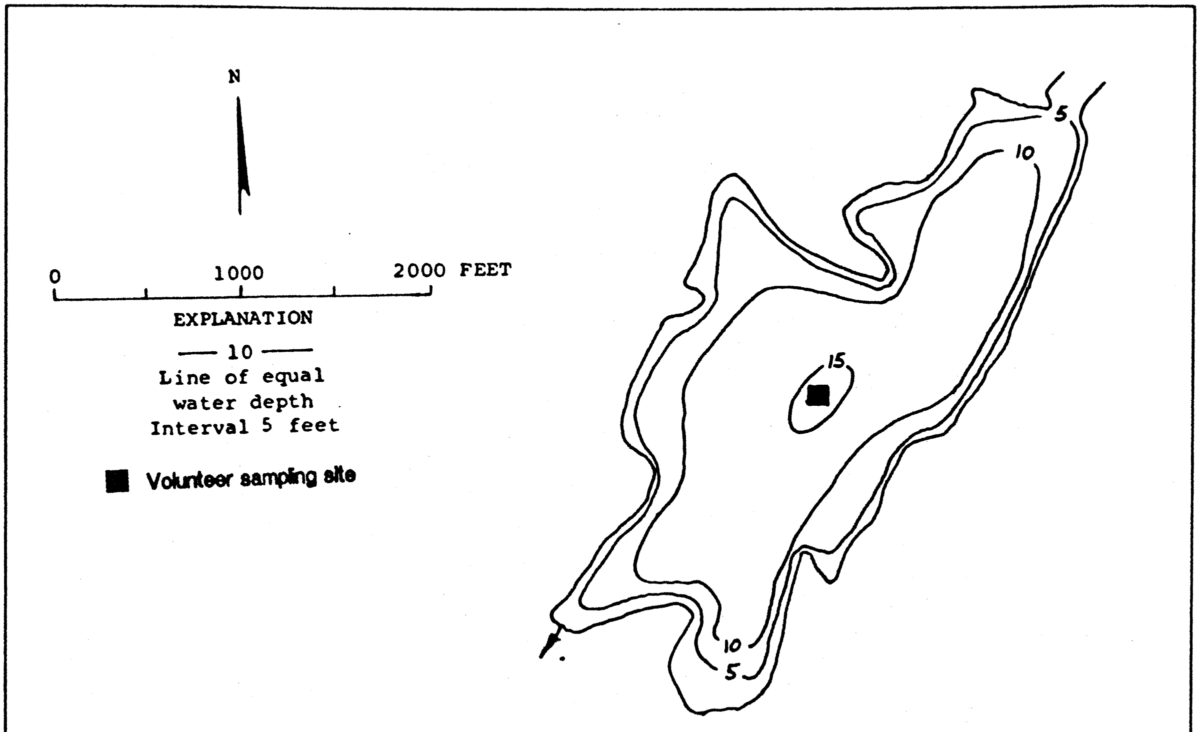
Summary of Other Available Information

Total phosphorus data from 1973 (Bortleson *et al.*, 1976) were characteristic of concentrations found in mesotrophic lakes. However, because the volunteer reports that sediments enter the lake, and because phosphorus is released into a water column when aquatic plants decompose after they are chemically treated, phosphorus concentrations may have increased since 1973.

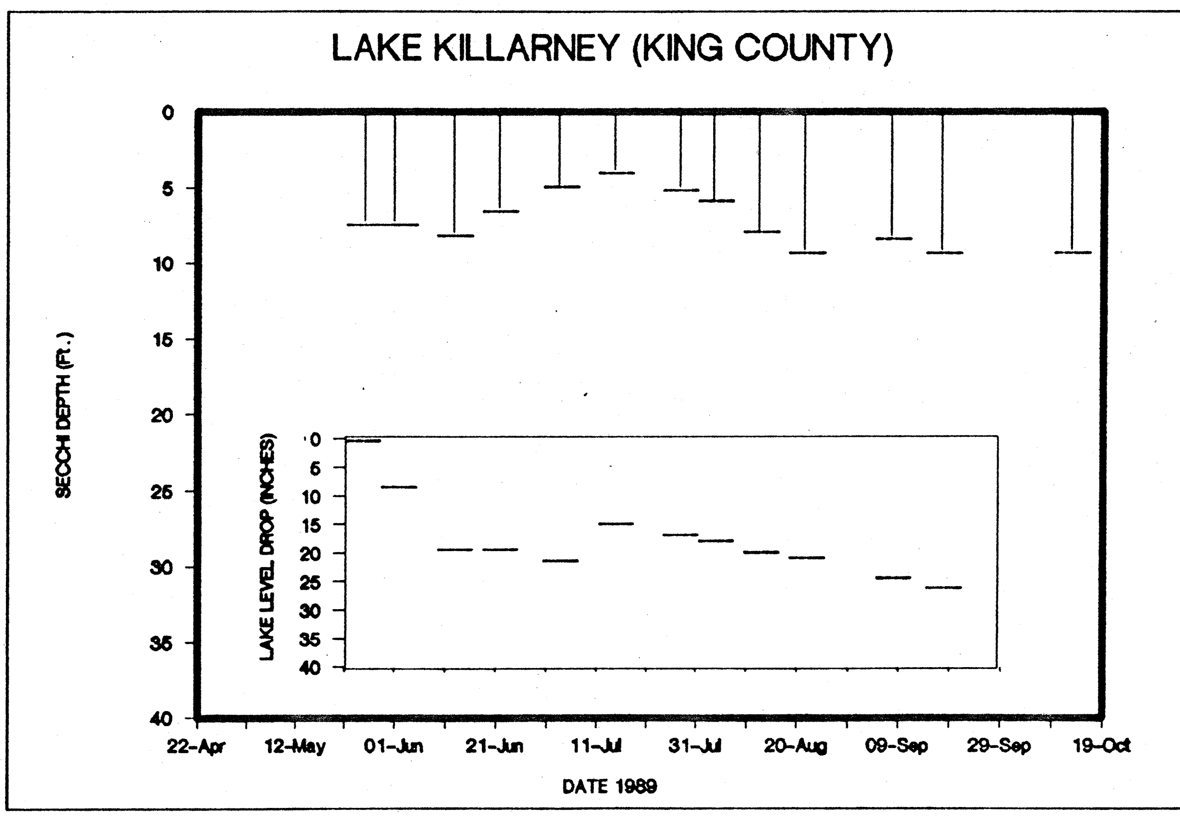
Eurasian water milfoil was successfully eradicated from Lake Killarney with Sonar, an aquatic herbicide (K. Hamel, pers. comm.).

Comments

Lake Killarney is borderline between mesotrophy and eutrophy, so the trophic state has been estimated as meso-eutrophic. The relationship shown between lake level and water clarity indicates that the water clarity in Lake Killarney may be affected by suspended sediments and not by algal growth. As a result, it is difficult to compare the water quality of Lake Killarney with other lakes monitored from the program, and the trophic state estimated from Secchi data is probably overestimated and should be confirmed using total phosphorus and/or chlorophyll *a* data.




Killarney (South Arm) Lake, King County.
From Washington Department of Game, February 1, 1949.



Kitsap Lake -- Kitsap County

Kitsap Lake is located in an urban area, three miles west from Bremerton. It is fed by an unnamed tributary that flows into the southern end of the lake, and drains via Kitsap Creek to Dyes Inlet. The lake is stabilized by a dam.

| | |
|---|---|
| Size (acres) | 250 |
| Maximum Depth (feet) | 29 |
| Mean Depth (feet) | 18 |
| Lake Volume (acre-feet) | 4500 |
| Drainage Area (miles$^2$) | 2.73 |
| Altitude (feet) | 156 |
| Shoreline Length (miles) | 2.69 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 35* |

* See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/03 | 1100 | Brown | Sunny | 18.0 | 18.79 | Water calm, slight ripple. Lake water height 8" below winter high water. |
| 05/18 | 1300 | Blue | P Cloudy | 18.0 | 19.71 | Strong wind blowing from the south. Wave action - choppy. |
| 05/31 | 1030 | Blue | Sunny | 18.0 | 18.56 | Slight breeze blowing. Lake height: 3" below average winter high water. |
| 06/15 | 1100 | Blue | Sunny | 21.0 | 17.64 | Fairly windy with riffle on water. Lake height 4" below average winter water. |
| 06/29 | 1105 | Blue | Cloudy | 21.0 | 18.79 | Lake height 3" below average winter high water. |
| 07/12 | 1107 | Blue | Sunny | 22.5 | 19.25 | Windy, strong riffle on water. Lake height 3" below average winter high water. |
| 07/28 | 1100 | Blue | P Cloudy | 23.0 | 20.16 | Light wind. Lake height 3" below average winter high water. |
| 08/15 | 1050 | Blue | P Sunny | 22.5 | 20.16 | Light wind - Lake height 4" below average winter high water. |
| 08/29 | 1015 | Blue | Sunny | 22.0 | 16.96 | Algae - small green particles. Some large patches floating on surface by shore. |
| 09/13 | 1030 | Blue | -- | 21.5 | 17.19 | Water was dead calm. |
| 09/29 | 1250 | Blue | Sunny | 20.5 | 20.16 | Light wind blowing, slight riffle on lake. |
| 10/09 | 1300 | Blue | Sunny | 19.0 | 20.16 | Light wind, but water calm. Considerable green algae floating in water. |

The water clarity did not fluctuate much over the summer, although a brief algal bloom occurred during late August - early September.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Kitsap Lake is used for fishing, swimming, boating, and jet skiing. There are two boat ramps and a park on the lakeshore. The speed limit for motor boats is 45 mph, and no wakes are permitted within 200 feet of the shore. Lake water is used only for irrigation. Currently the watershed is used for logging and industrial development, and the lakeshore is being developed for residences. In the past the watershed was logged, used for agriculture and mining, and the shoreline was altered. There are 113 houses on the lakeshore; all of these are occupied year-round. The lakeshore is partially sewered. Fish are stocked in the lake. There is a wetland at the south end near the inlet. The worst water quality problems, in the opinion of the volunteer, are 1) garbage, debris and leaves; 2) sediments suspended in the water; 3) weeds; and 4) algal growth. Problems are worst during July and August. The volunteer is concerned about possible water quality effects form power boats, and runoff.

Submerged plant growth covers the lake bottom in up to 15 feet of water. Although the volunteer reports that plant growth was less in 1989 than in the previous two or three years, the overall growth of plants in the lake, when compared to past data, has apparently increased.

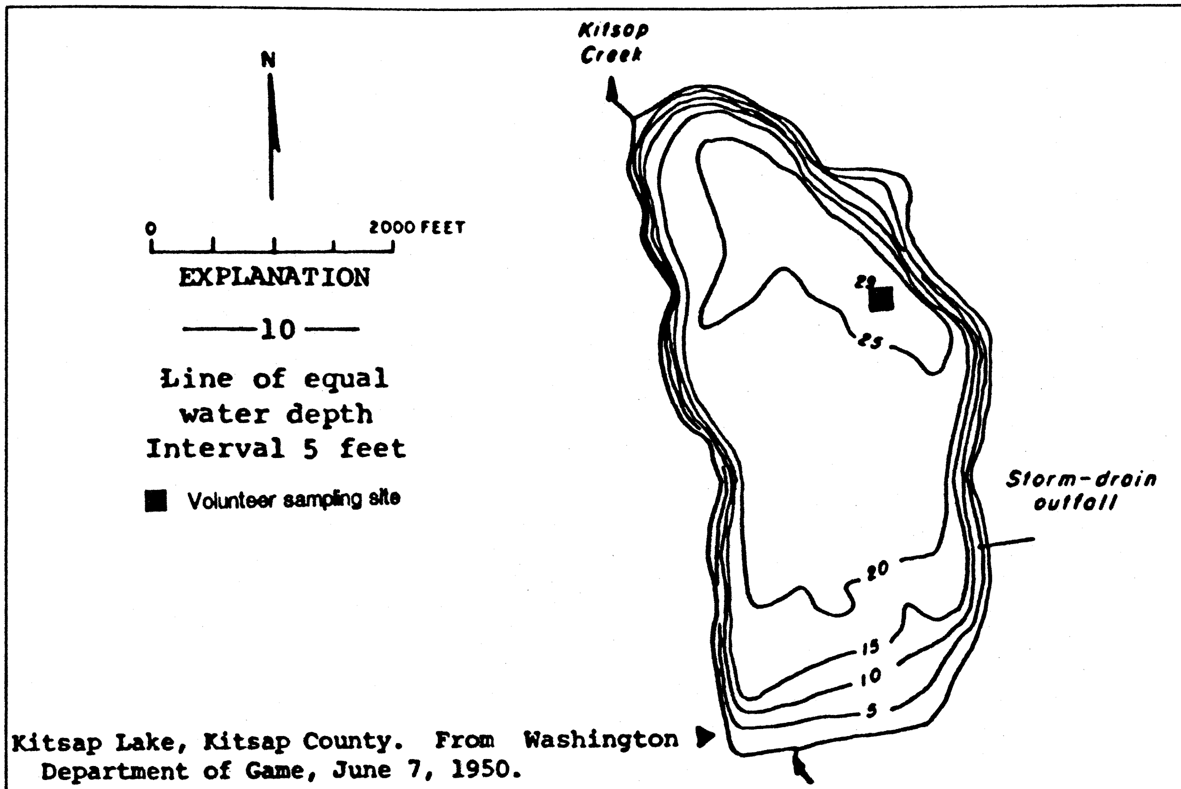
Summary of Other Available Information

There has been a moderate increase in residential development along the lakeshore; the USGS surveyed Kitsap Lake in 1971 and reported that there were 90 nearshore homes (Bortleson *et al.*, 1976).

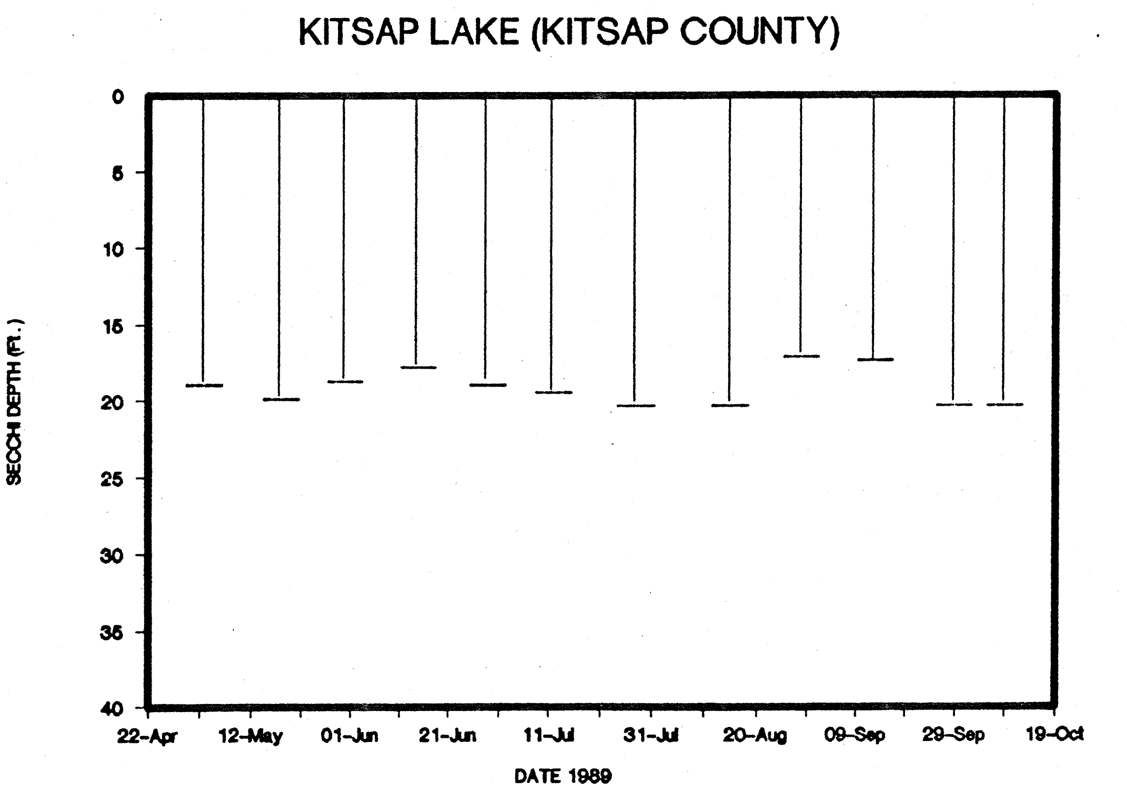
Comments

Compared to other lakes in the program, the water quality of Kitsap Lake is very good. With the exception of Kitsap Lake, all other lakes in the program with a mean depth of less than 20 feet are mesotrophic or eutrophic. Sewering the lakeshore and stormwater controls for new development have probably preserved the high water clarity of the lake.

Data collected in 1971 (Bortleson *et al.*, 1976) and 1981 (Sumioka and Dion, 1985) indicate total phosphorus concentrations that are characteristic of mesotrophic lakes. Because Secchi depth data may be underestimating the trophic status of Kitsap Lake, future estimates of trophic status should be confirmed using chemical as well as transparency data.




Kitsap Lake, Kitsap County. From Washington Department of Game, June 7, 1950.



Lacamas Lake -- Clark County

Lacamas Lake is located one mile north from Camas. It is formed by two dams in Lacamas Creek at Round Lake. Including Round Lake, it is three miles long. It is fed by Lacamas Creek and drains to the Washougal River.

| | |
|---|---|
| Size (acres) | 315 |
| Maximum Depth (feet) | 65 |
| Mean Depth (feet) | 24 |
| Lake Volume (acre-feet) | 7489 |
| Drainage Area (miles$^2$) | 64.3 |
| Altitude (feet) | 179 |
| Shoreline Length (miles) | 5.34 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 57 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/12 | 1530 | Green | P Sunny | 18.0 | 10.54 | North end - creek entrance: Secchi 11.0 feet, 16 degrees, green color. |
| 06/20 | 1600 | Bl-Gr | Sunny | 20.0 | 6.42 | Sudsy bubbles along edge when motor boats are active. |
| 07/12 | 1645 | Green | Sunny | -- | 5.50 | Algae growing good - lake use by motor boats heavy. |
| 08/05 | 1500 | Green | P Sunny | 21.0 | 2.98 | Algae growth is continuing to increase. |
| 08/28 | 1445 | Gr-Br | P Sunny | 21.0 | 2.52 | Heavy algae scum present at all times in both slow and faster-moving lake areas. |
| 09/13 | 1530 | Green | Sunny | 21.5 | 2.75 | Lake continues to be covered with heavy algae growth. |

The water clarity gradually decreased from May through September as algae growth increased over the summer. There are not enough readings to determine when the actual onset of the bloom occurred or when the lake recovered from the bloom. Sudsy bubbles noted by the volunteer on June 20 may be from organic matter whipped up by winds and motor boats.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Lacamas Lake is used for fishing, swimming, boating, jet skiing, picnicking, and hiking. There is a picnic area and three boat ramps on the lakeshore. Currently the watershed is used for agriculture (crops, orchards, and animal grazing/feeding operations), and the lakeshore is being developed further for residences. There are 13 houses on the lakeshore. A large complex of 219 residences is now under construction in the watershed west of the lake. More area on the east side of the lake is being proposed for further development. The lakeshore is fully sewered. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are weeds, algal blooms, sediments suspended in the water, garbage, debris, leaves, and odor (smells similar to sewer). Visually, the problems are reported to be worst from June to October. The volunteer noted that algae growth has been very heavy the last two years, and weed growth advances yearly. The volunteer reported that a feasibility study conducted in 1985 concluded that 97%

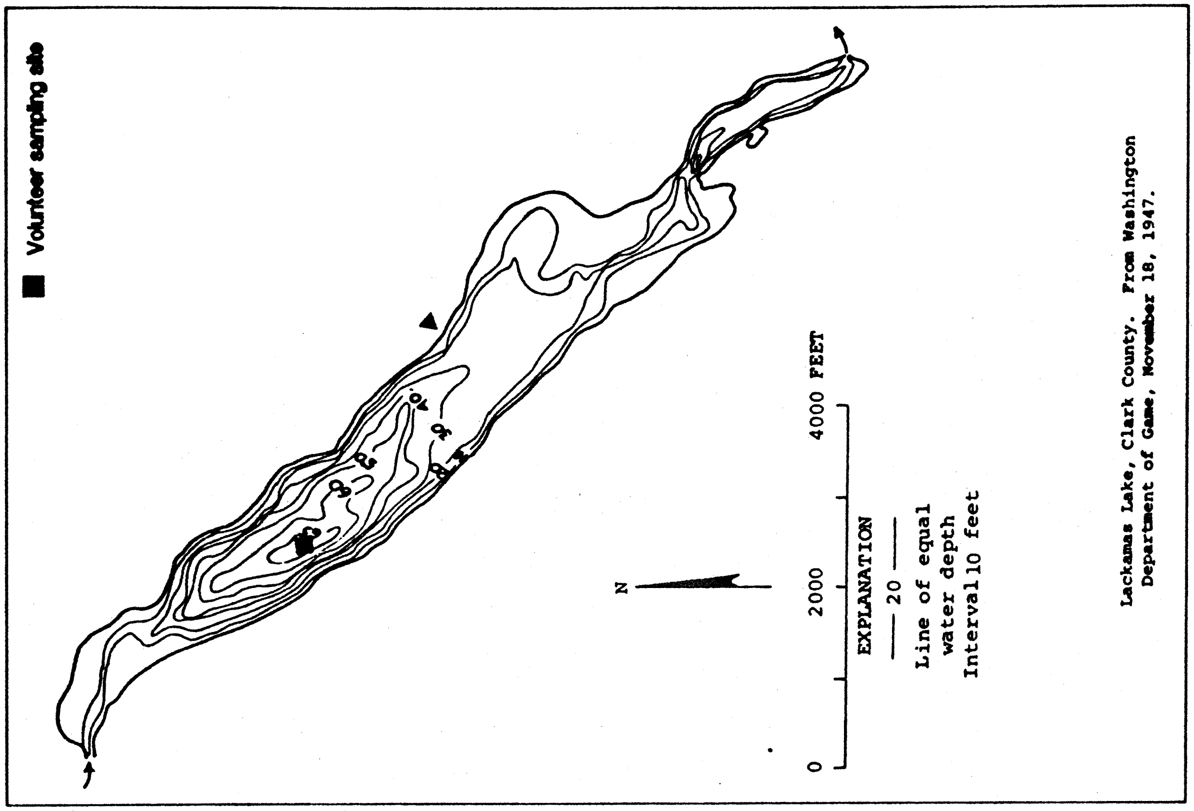
of the enrichment of the lake water was due to agricultural practices in the watershed, and to decrease algal growth in the lake, phosphorus loading to the lake needs to be reduced by 84%. As a result, best management practices to control runoff from animal wastes are being implemented. The shoreline is completely covered with submerged weeds in up to ten feet of water. There are wetland areas on each end of lake; lily pads cover much of the area near the southern wetland.

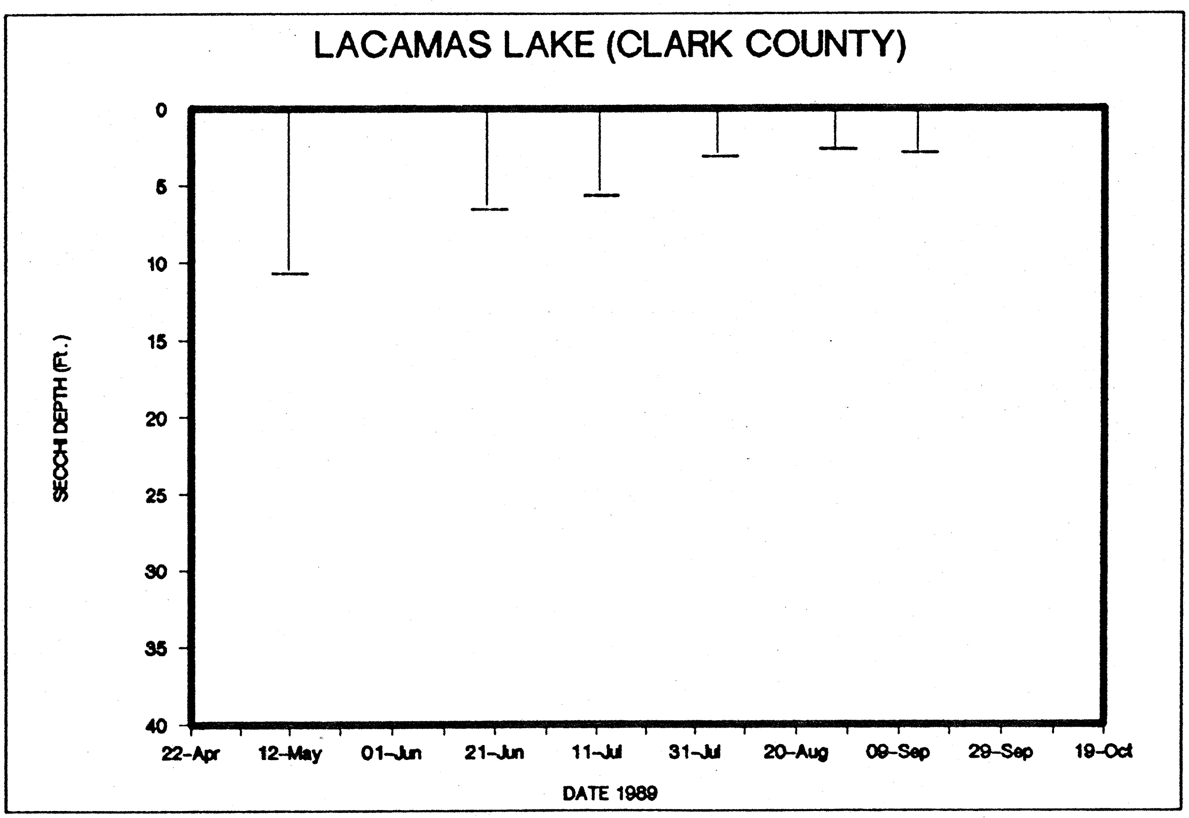
Summary of Other Available Information

In 1974 most of the submerged aquatic plants were *Elodea*, *Ceratophyllum*, and *Potamogeton* (Bortleson *et al.*, 1976). Data collected by the USGS in 1974 (Bortleson *et al.*, 1976) and 1981 (Sumioka and Dion, 1985) show that total phosphorus concentrations were well within the range associated with eutrophic lakes, and were considerably higher in 1981 than in 1974. The Intergovernmental Resource Center (IRC) will be monitoring Lacamas Lake in 1991 to evaluate the nutrient budget of the lake.

Comments

Compared with other lakes monitored for the program, the water clarity of Lacamas Lake is not good. Only two other lakes in the program, Barnes Lake and Duck Lake, had lower average water clarity during 1989. Kahlotus Lake in Franklin County has a similar size, drainage area size, and extent of agricultural land use of the watershed as Lacamas Lake; although Kahlotus Lake is shallower and consequently supports more rooted aquatic plants, the water clarity at Kahlotus Lake is slightly better than at Lacamas Lake.


Volunteer sampling site
EXPLANATION
20
Line of equal water depth
Interval 10 feet
0
2000
4000 FEET
N
Lackamas Lake, Clark County. From Washington Department of Game, November 18, 1947.


LACAMAS LAKE (CLARK COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Liberty Lake -- Spokane County

Liberty Lake is located 15 miles east from Spokane. It is fed by Liberty Creek, and drains northwesterly to an irrigation canal and the Spokane River.

| | |
|---|---|
| Size (acres) | 710 |
| Maximum Depth (feet) | 30 |
| Mean Depth (feet) | 23 |
| Lake Volume (acre-feet) | 16,000 |
| Drainage Area (miles$^2$) | 13.30 |
| Altitude (feet) | 2,053 |
| Shoreline Length (miles) | 4.77 |

| | |
|---|---|
| Estimated Trophic State: | meso-eutrophic |
| Mean Trophic State Index: | 46 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/22 | 1100 | Blue | P Cloudy | 15.5 | 12.19 | (See accompanying profile data collected for phase 1 monitoring.) |
| 06/07 | 1030 | Blue | Sunny | 19.0 | 13.38 | (See accompanying data.) |
| 06/20 | 1300 | Blue | Cloudy | 18.5 | 9.17 | (See accompanying data.) |
| 07/10 | 1130 | Blue | P Sunny | 22.2 | 9.17 | |
| 07/24 | 1130 | Blue | P Sunny | -- | 9.17 | |
| 08/07 | 0930 | Bl-Gr | Sunny | 22.8 | 8.25 | |
| 08/21 | 1100 | Bl-Gr | Cloudy | 21.0 | 5.96 | Raining. |
| 09/05 | 1100 | Bl-Gr | P Cloudy | 19.0 | 5.96 | |
| 09/18 | 1100 | Bl-Gr | P Cloudy | 18.0 | 5.96* | |
| 10/02 | 1100 | Bl-Gr | Sunny | 17.0 | 5.96 | |
| 10/16 | 1100 | Bl-Gr | Sunny | 13.5 | 7.52* | |

*Limit for quality assurance test was exceeded for this data point.

The water clarity was highest during May and early June, and decreased from late June through October. It appears that algal growth is constant yet stable throughout the summer.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Liberty Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a picnic area, camping facility, two boat ramps, a county park, and a beach on the lakeshore. Lake water contributes to aquifer recharge. Currently the watershed is used for logging, animal grazing, lakeshore development for residences, and a county park ORV area. In the past, the lake was dredged. There are 917 houses in the watershed; all of the houses are occupied year-round. The lakeshore is fully sewered. The lake has been chemically treated in the past for controlling algae and for eliminating rough fish. Alum was used in 1974 and 1980 to precipitate phosphorus from the water. Rotenone hasn't been used since 1974. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are 1) lake level, 2) weeds, and 3) algae ("not to bloom proportions but noticeable"). Problems are worst during August and September. In the opinion of the volunteer, uncontrolled stormwater, uncontrolled lake level and lake sediments are possible sources of water quality problems.

There are wetland areas near both of the outlets. Submerged plants (*Potamogeton*, *Elodea*, and *Ceratophyllum*) cover the entire shoreline up to a depth of six meters. Lily pads (*Nuphar*) and cattails (*Typha* spp.) grow near the marsh at the south outlet. The lakeshore is completely residential except for the county park, a church camp and small areas southeast of Dreamwood Bay where steep slopes limit development. Three inlets were identified by the volunteer that receive stormwater.

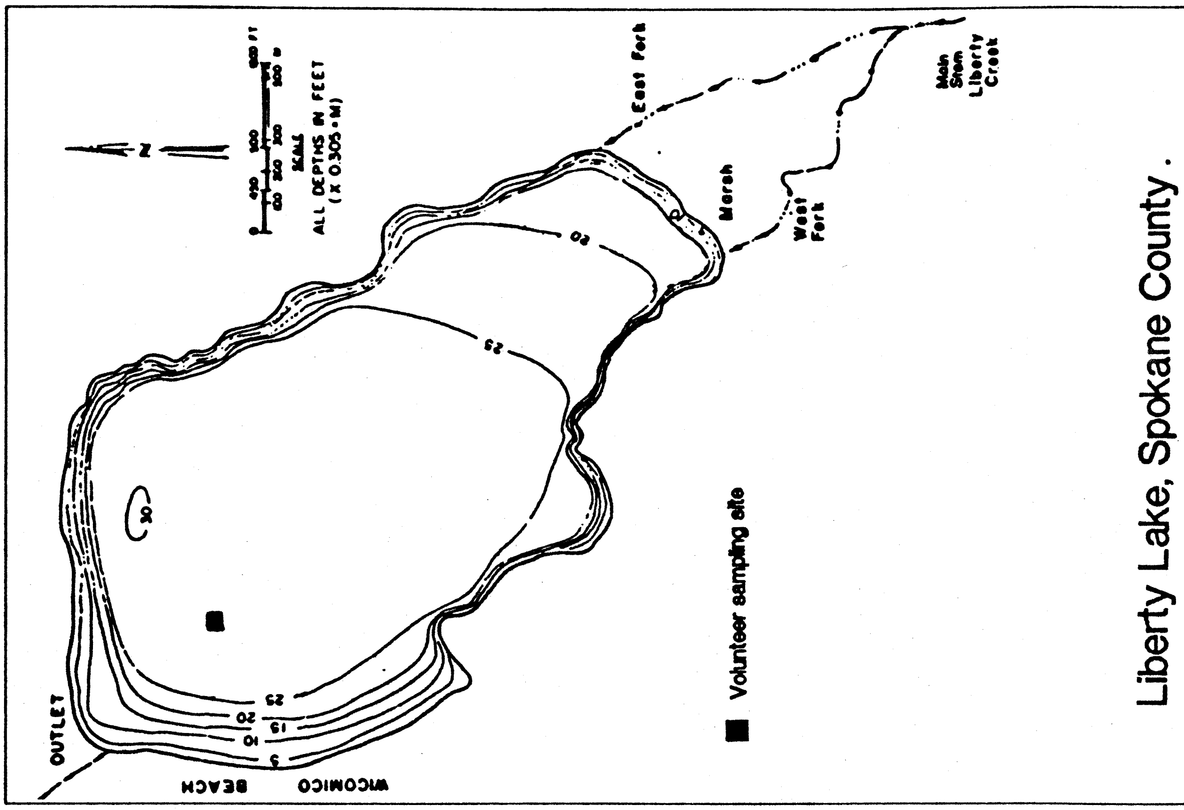
Summary of Other Available Information

The Liberty Lake Sewer District is very active in lake protection; lake restoration measures have been completed and profile data (temperature, dissolved oxygen, pH, conductivity, alkalinity, and acidity) are being collected from two lake stations. Lake restoration included a restoration analysis, prerestoration water quality monitoring, construction of marsh flooding controls in 1979, dredging 21 hectares of lake bottom in 1980-1981, and whole-lake alum treatments in October 1980 and May 1981. The project was concluded with two years of lake monitoring. A watershed management study complemented the in-lake work in 1982-85, and further marsh channel repairs in 1985 eliminated the major point where marsh waters entered the lake. New construction projects within the watershed now require a Stormwater Management Plan, which needs to be approved by the Sewer District. The annual phosphorus load has decreased due to decreased inflow from the Liberty Creek Marsh and a decreased amount of phosphorus released from the lake sediments (Michael Kennedy Engineers, 1986).

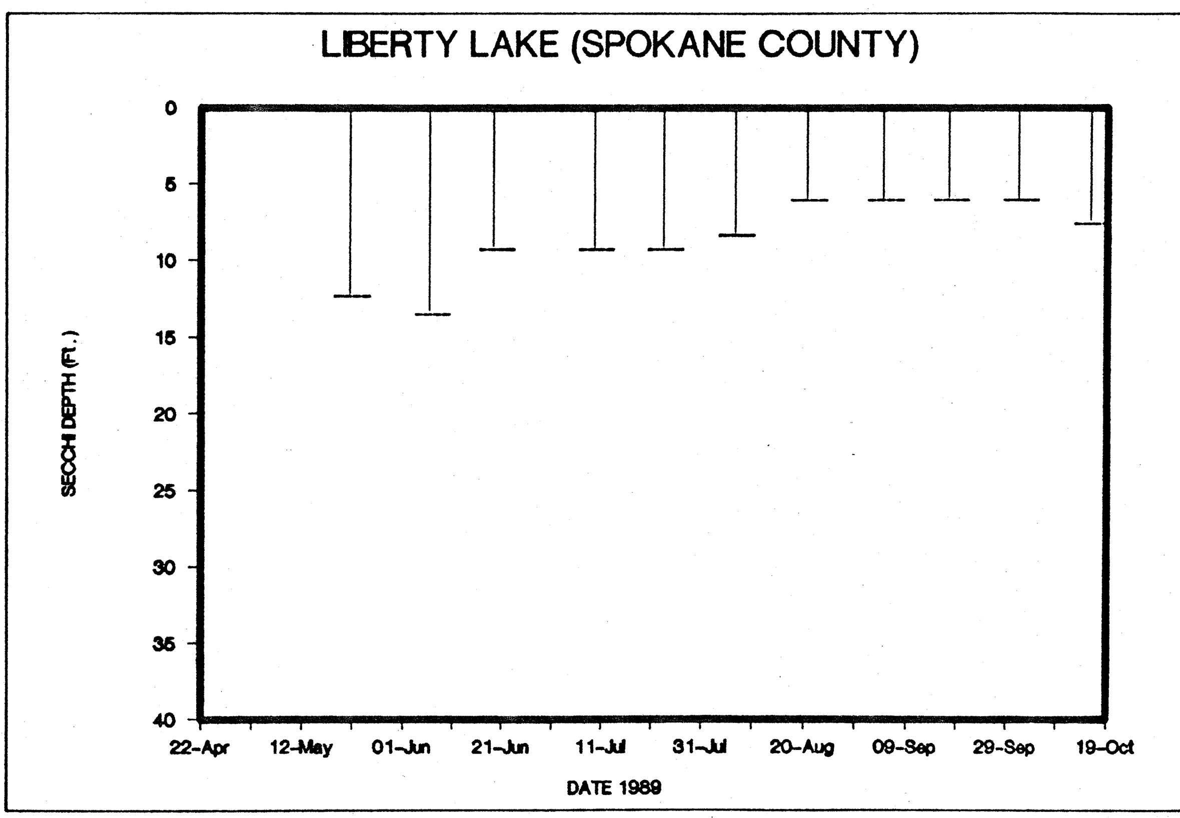
The restoration efforts have resulted in quite a success story for Liberty Lake. Prior to restoration, the lake was eutrophic with mats of blue-green algae, fish kills, and swimming beach closures. From 1983 - 1985 the trophic state (Carlson, 1977), of Liberty Lake decreased from 62.14 to 54.40 indicating an improvement in the water quality following restoration. Data from 1989 suggest further improvement in the water quality of Liberty Lake.

Comments

The water clarity of Liberty Lake in 1989 is comparable to the clarity measured from nearby Newman Lake. Compared with other lakes in the program, most lakes with a mean depth greater than 20 feet are oligotrophic. The exceptions, Liberty Lake included, are those lakes that definitely show signs of cultural eutrophication. It is encouraging that the restoration measures have improved the water quality of Liberty Lake; without restoration Liberty Lake would likely have had a considerably higher trophic state index value.



Liberty Lake, Spokane County.
Volunteer sampling site
SCALE
ALL DEPTHS IN FEET
(X 0.305 = M)
N
East Fork
Main Stem Liberty Creek
Marsh
West Fork
OUTLET
WICOMICO BEACH
5
10
15
20
25
30

LIBERTY LAKE (SPOKANE COUNTY)
SECCHI DEPTH (FT.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Long Lake -- Kitsap County

Long Lake is located 3.5 miles southeast from Port Orchard. It is two miles long. It is fed by Salmonberry Creek, and drains via Curley Creek to Yukon Harbor.

| | |
|---|---|
| Size (acres) | 339 |
| Maximum Depth (feet) | 12 |
| Mean Depth (feet) | 6 |
| Lake Volume (acre-feet) | 2180 |
| Drainage Area (miles$^2$) | 9.36 |
| Altitude (feet) | 118 |
| Shoreline Length (miles) | 5.07 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 56* |

* See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/08 | 1400 | Brown | P Sunny | 21.0 | 5.50 | Water clear to about 1 foot, then it starts to turn brown. |
| 05/22 | 0945 | Gr-Br | Cloudy | 15.0 | 4.52 | More sediments near surface than last reading. UW harvesting south end since 5/3. |
| 06/13 | 0855 | Gr-Br | Cloudy | 23.0 | 5.46 | Weed harvester broke down June 6th. Lots of algae floating to surface. |
| 06/25 | 0907 | Brown | Sunny | 24.0 | 5.41 | Lots of sediment in water from surface on down. Lots of daily water skiing. |
| 07/11 | 0945 | Brown | Sunny | 22.0 | 5.66 | Weed harvester is repaired and back to work! Water temp was cooler this time. |
| 07/25 | 0925 | Brown | Sunny | 23.0 | 5.01 | Lots of sediment in lake - from surface down as far as you can see! Lots of daily water skiing going on. |
| 08/08 | 0916 | Brown | Sunny | 23.0 | 5.00 | A lot of suspended sediment; lots of water skiing and jet boats. Still harvesting. |
| 08/29 | 1430 | Gr-Br | P Cloudy | 24.0 | 3.25 | Lots of algae; pea-size to size of a half-dollar. Also light-green scum near shore. |
| 09/12 | 1645 | Green | Sunny | 24.0 | 2.75 | Bad algae bloom/scum the last 2 weeks. Am running the harvester now; about six 1-ton loads of weeds cut each day from the south end of the lake. |
| 09/30 | 1004 | Gr-Br | Cloudy | 19.0 | 3.02 | Not as much algae floating in water now. Some scum floating on the southwest shore. |
| 10/16 | 1210 | Green | Sunny | 15.0 | 7.20 | Lots of algae, green scum on shorelines. Creek clogged; lake can't flush. |
| 11/04 | 1447 | Blue | P Cloudy | 13.0 | 7.64 | Winter storms have cleared up the water. Total of 162 tons of weeds cut and removed. |

Variations in water clarity over the summer were very subtle, although Secchi readings and volunteer reports indicate algal blooms occurred in late May -early June, and in September. The water clarity improved considerably from October through November; the November reading is not graphed because of the time scale used.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Long Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, hiking, and waterfowl hunting.

Long Lake -- Kitsap County

There is a picnic area, camping area, and a park on the lakeshore. There is a time restriction and a distance from shore limit that apply to motor boat use. Lake water is withdrawn for drinking and other domestic uses. Currently the watershed is used for agriculture (tree farms, haying, and animal grazing) and residential development is occurring near the lakeshore. In the past the shoreline has been altered and the lake has been dredged. There are 150 homes on the lakeshore; all use on-site wastewater disposal systems and 130 of the houses are occupied year-round. The lake has been chemically treated to control weeds and algae. Alum was used in 1975, 1976, and 1980. Weeds were mechanically harvested from May 1 - October 31, 1989. No fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are 1) weeds (a year-round problem), 2) algal blooms (from May through September), and 3) sediments suspended in the water (June - August). The volunteer reported the lake was once 30 feet deep, and now is 12 - 15 feet deep. The volunteer is concerned about possible water quality effects from runoff, development, lawn fertilizer, and water skiing. There are wetland areas near the inlets, the outlet and near the golf course. The entire basin is covered with submerged plants and lily pads. The submerged weeds are especially thick in the south basin near the inlet. The University of Washington started harvesting plants in the south end of the lake about the third of May.

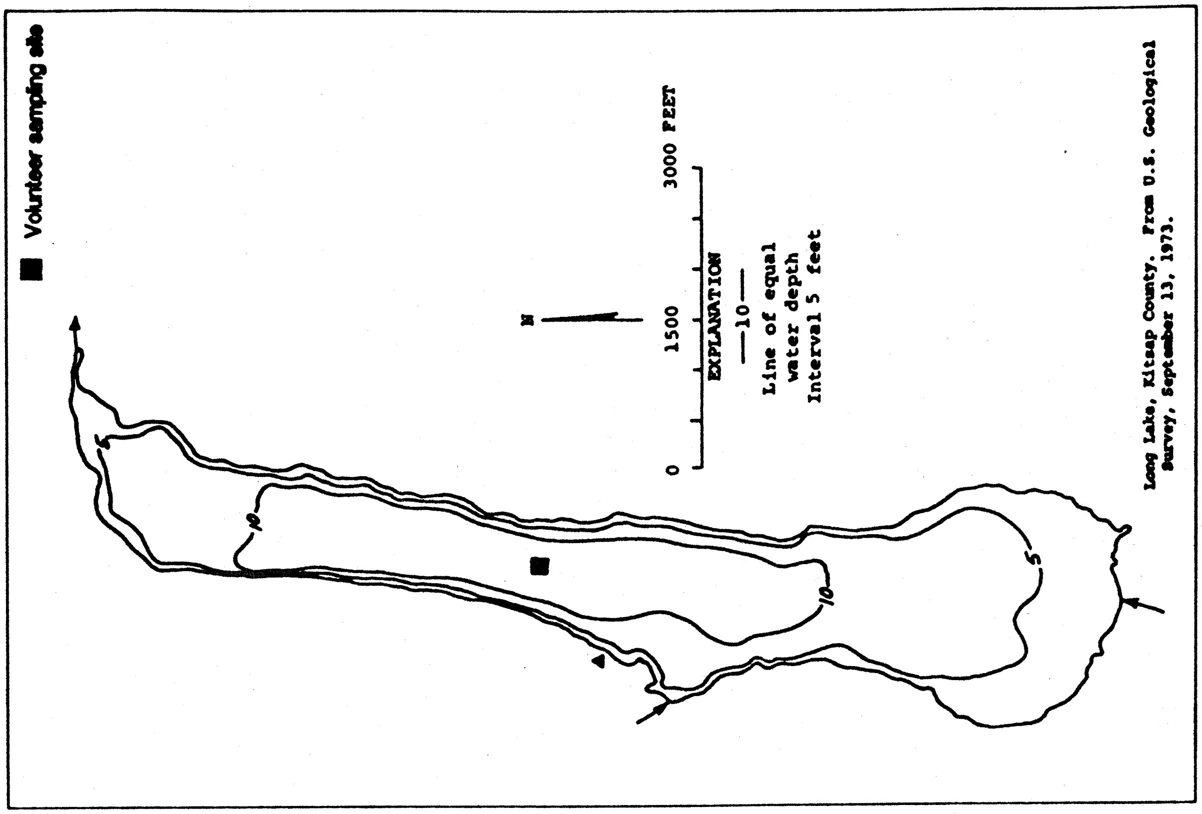
Summary of Other Available Information

Data collected in 1973 show that based on high total phosphorus concentrations and low Secchi disk transparency, Long Lake was eutrophic (Bortleson *et al.*, 1976). Residential development of the lakeshore has increased since 1973; the USGS reported that in 1973 there were 121 nearshore homes (Bortleson *et al.*, 1976).

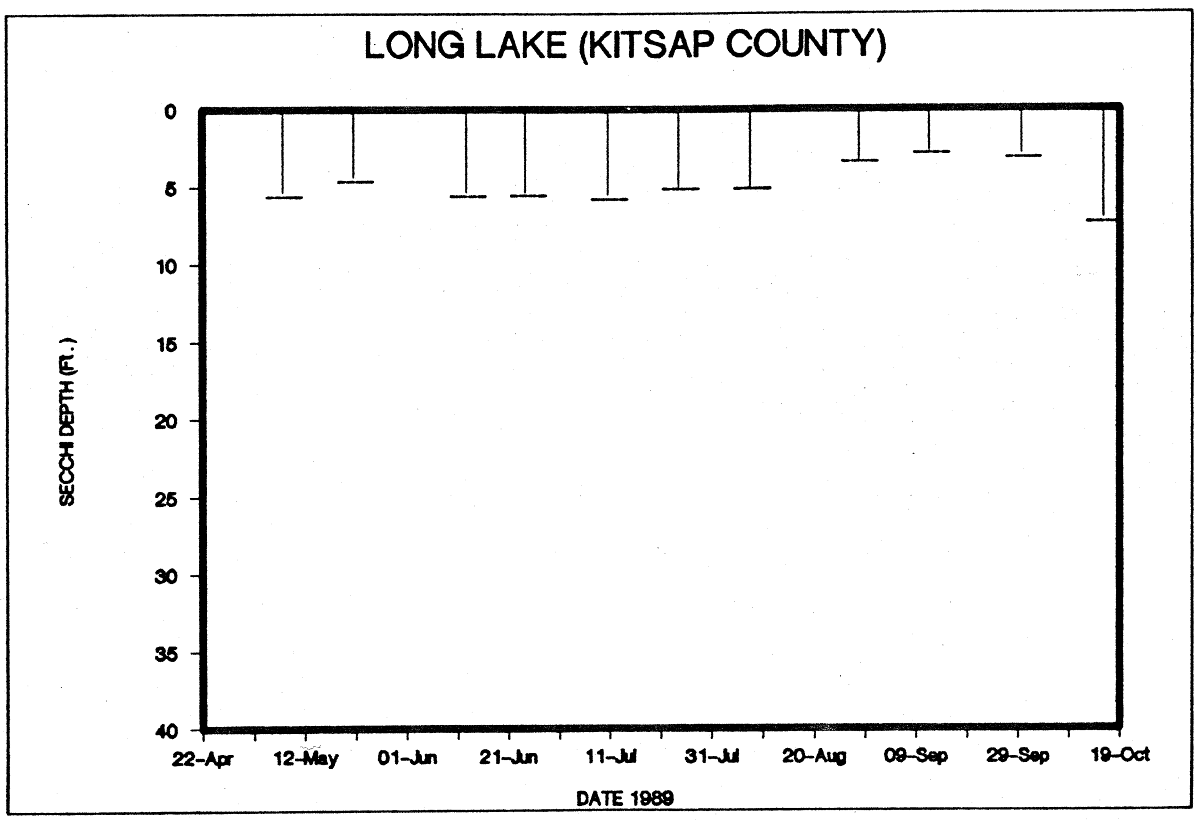
Researchers at the University of Washington have recently proposed that the dense cover of plants (*Elodea densa*) in Long Lake decrease the release of phosphorus from lake sediments by protecting sediments from wind mixing (Welch and Kelly, 1990). Rooted aquatic plants can be an important source of internal phosphorus loading because plant roots can retrieve phosphorus from lake sediments, and this phosphorus is released into the water column when the plants die and decay. However, by shielding the bottom layers of water from mixing with upper layers of water, the plant beds may trap phosphorus in bottom waters and may have contributed to prolonging the effectiveness of previous alum treatments (Welch and Kelly, 1990). The lake was also drawn down in 1979 to reduce rooted aquatic plant populations (Welch and Kelly, 1990).

Comments

Of the lakes monitored for the program, there was a relationship between mean depth and trophic state. Shallower lakes generally had higher trophic states than deeper lakes. Long Lake is one of the shallowest lakes monitored for the program and also has one of the highest trophic states of the monitored lakes. Because the volunteer's remarks included several references to suspended sediments, it is possible that water clarity in Long Lake is not affected primarily by algal growth. Future estimates of trophic state should probably be confirmed using chemical data.



Volunteer sampling site
N
0
1500
3000 FEET
EXPLANATION
—10—
Line of equal water depth
Interval 5 feet
10
10
5
Long Lake, Kitsap County. From U.S. Geological Survey, September 13, 1973.

LONG LAKE (KITSAP COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Long Lake -- Thurston County

Long Lake is located 5.5 miles east from Olympia. It is two lakes, connected by a narrow neck. It is two miles long and has two islands, Holmes Island (13 acres) and Kirby Island (2.4 acres). Long Lake is fed by Patterson Lake and drains via Himes/Woodland Creek and Lois Lake to Henderson Inlet.

| | |
|---|---|
| Size (acres) | 330 |
| Maximum Depth (feet) | 21 |
| Mean Depth (feet) | 12 |
| Lake Volume (acre-feet) | 3900 |
| Drainage Area (miles$^2$) | 8.25 |
| Altitude (feet) | 153 |
| Shoreline Length (miles) | 7.08 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 44 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/21 | 1100 | Brown | P Sunny | 18.0 | 8.94* | Changing cloud cover. Tiny white flecks floating throughout the water column. |
| 06/04 | 1145 | Green | Sunny | 24.0 | 13.29 | A lot of boat traffic in water 6/3/89. Sunny, in 80's for past three days. |
| 06/20 | 1300 | Brown | P Cloudy | 21.0 | 11.00 | Rained for two days prior to sampling. |
| 07/12 | 1330 | Brown | Sunny | 20.6 | 11.92 | Morning of 6/30 there was a yellow green algae bloom in the northwest cove. |
| 07/24 | 1300 | Green | Sunny | 21.8 | 12.83 | |
| 08/04 | 1200 | Green | Sunny | 23.0 | 13.06 | The water was a little choppy. |
| 08/18 | 1300 | Gr-Br | Sunny | 24.0 | 9.17 | Lots of boat traffic. Floating islands of aquatic plants are being chopped up by harvester, boat traffic and waves. |
| 09/02 | 1100 | Brown | P Cloudy | 21.0 | 5.50 | Plants on Secchi disk and anchor, mostly Eurasian milfoil, some coontail and *Elodea*. |
| 09/18 | 1300 | Green | Sunny | 20.0 | 4.58 | Water very still. |
| 10/02 | 1200 | Green | Sunny | 18.0 | 6.42 | Not finding Eurasian milfoil in coontail beds, except in areas closer to shore. |

*Limit for quality assurance test was exceeded for this data point.

The water clarity was lowest in September, most likely from a fall algal bloom.

Summary of Questionnaire Results and Information from the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Long Lake is used for fishing, swimming, boating, jet skiing, picnicking and camping. There is a picnic area, one resort, seven boat ramps, a park and a beach on the lakeshore. There is a speed limit of 45 mph for boats. Water skiing is restricted to areas outside buoys and between 11 a.m. and 6 p.m., or one hour before sunset. Water is withdrawn for some irrigation. Currently the watershed is used for agriculture (both crops and animal grazing), industrial development and lakeshore development for residences. In the past the watershed was logged, and the lake was dredged.

Long Lake -- Thurston County

There are about 700 houses on the lakeshore; all are occupied year-round and use onsite wastewater disposal systems. The lake has been chemically treated in the past to control both weeds and algae. According to the volunteer, alum was used in the fall of 1983 and Rodeo was used to control lilies prior to 1983. Weeds are now harvested from the lake using a mechanical harvester and individual homeowners rake weeds from their lakeshore areas. Fish are stocked in the lake. There are wetland areas. The worst water quality problems, in the opinion of the volunteer, are weeds, algal blooms, lake level, and sediments suspended in the water. The volunteer is concerned about the effects of inflow from Patterson Lake, dense growths of Eurasian water milfoil and coontail, and seagulls on nutrient loading and water quality.

The Lakes Improvement Association has drafted an aquatic weed management plan to revise the existing alum/harvesting program managed by the Thurston County Public Works Department. Aquatic plant management in Thurston County now discourages the use of herbicides. The proposed plan will allow more flexibility in the old harvesting plan to allow for hand pulling, bottom screening, harvesting, and a limited amount of herbicidal use. Alum application will be discontinued if the plan is adopted and biological food chain manipulation and nutrient trapping will be considered instead as algae controls. An application of fluoridone (Sonar) to eliminate Eurasian water milfoil from the lake is also being considered[1]. The Lakes Improvement Association sponsored a milfoil-awareness educational program to help protect other Thurston County lakes from Eurasian milfoil infestation.

The volunteer noted that all deeper water basins are infested with coontail. The major infestations of Eurasian water milfoil are on the downwind north side; but it is also found along all shorelines in depths of water of about six to ten feet. Plants identified by the volunteer are Eurasian water milfoil, coontail (*Ceratophyllum* spp.; heavy growth especially thick in early spring to late fall in the north, center, and southern deeper basins), pondweed (*Potamogeton* spp.; three varieties), *Elodea*, northern water milfoil, bladderwort, wild celery (*Vallisneria*, also known as tape grass), water silk, *Chara*, bryozoans, both white and yellow flowered water lily (*Nymphaea odorata* and *Nuphar polysepalum*, respectively), cattails (*Typha*), reed canary grass, bulrush and water iris (*Iris pseudacorus*).

<u>Summary of Other Available Information</u>

Long Lake has a history of heavy algal growth. In 1968, algal blooms and Secchi disk transparency of only four feet were reported by Lee (1969).

From Entranco Engineers (1987): Restoration activities were initiated to address blue-green algal blooms and prolific aquatic plant growth in Long Lake. In 1978, a Phase I Diagnostic/Feasibility study was conducted by Entranco Engineers on Hicks, Patterson, Long

---

[1] Sonar was applied in July 1991.

and Lois Lakes. Conclusions and recommendations from the study included whole-lake alum treatments to precipitate phosphorus from the water column, and mechanical harvesting of plants. In 1983, both Long and Patterson Lakes were treated with alum. Mechanical harvesting of plants has been occurring in Long Lake since 1983.

Eurasian water milfoil (*Myriophyllum spicatum*) is thought to age and die (senesce) over the course of a summer, contributing to the internal phosphorus loading of a lake (Welch and Kelly, 1990). It is possible that senescence of Eurasian milfoil and the decay of plants cut by the harvester, combined with fall overturn, contributed to the growth of the fall algal bloom.

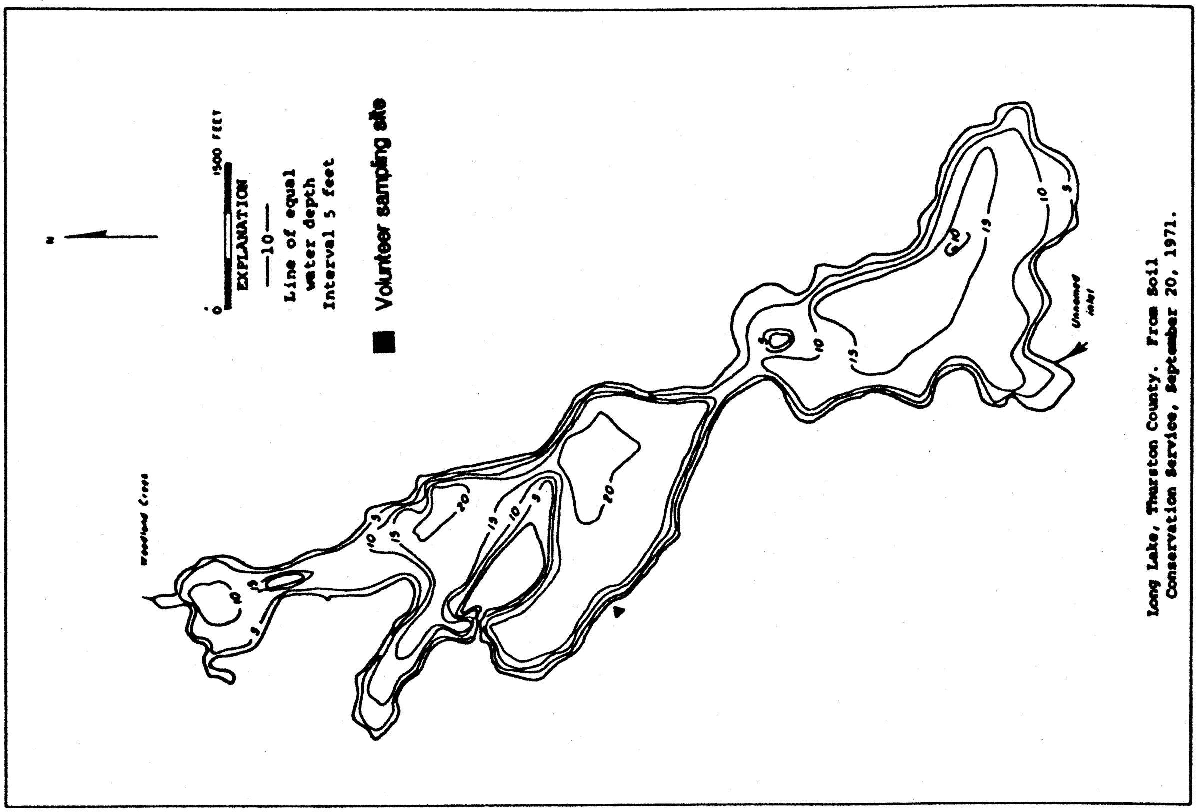
Residential development along the lakeshore has increased significantly since 1971; the USGS reported that there were 205 nearshore homes in 1971 (Bortleson *et al.*, 1976) and there were 117 nearshore homes in 1959 (Bortleson *et al.*, 1974).

The Thurston County Health Department collects water quality data from several lakes, including Long Lake.

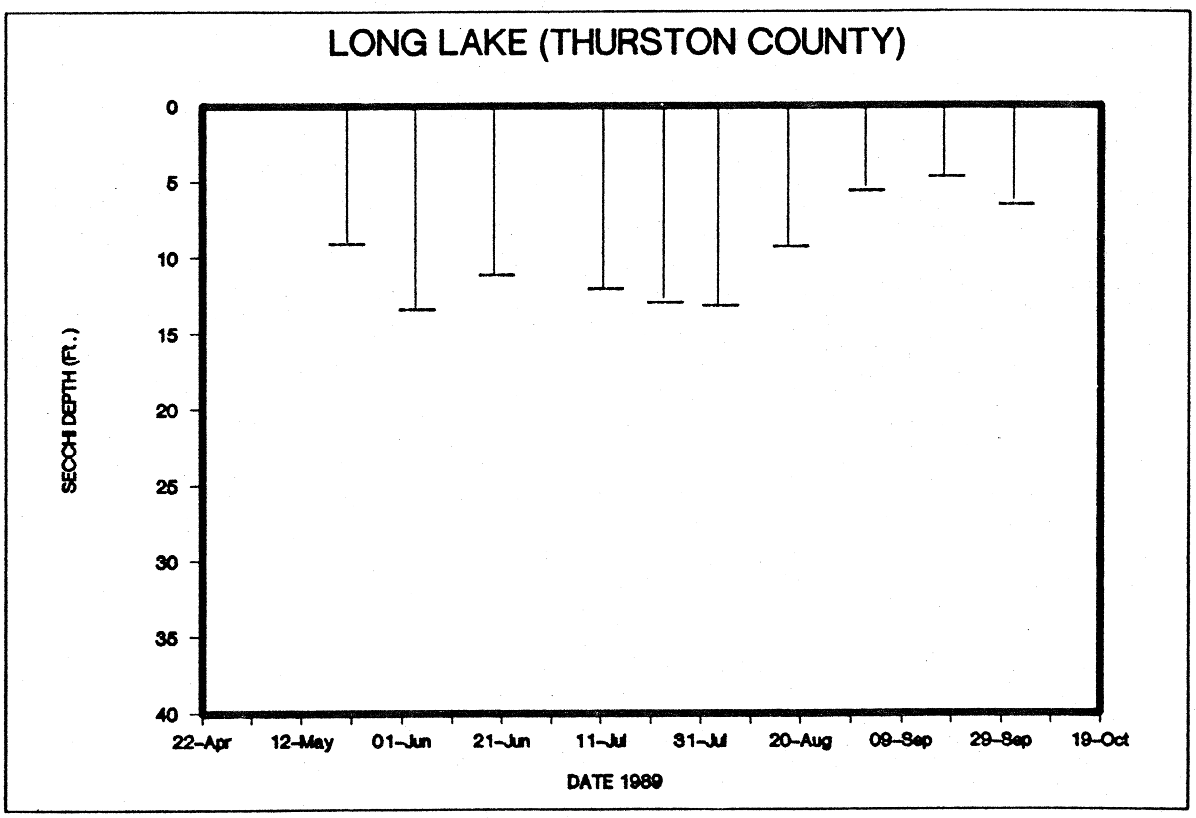
Comments

There was a relationship between mean depth and trophic state among the lakes monitored for the program; in general, lakes with a mean depth of less than 20 feet were mesotrophic or eutrophic. Long Lake was no exception.

The water clarity of Long Lake was better than the clarity of Lake Steilacoom in Pierce County. Both lakes have similar size and depth characteristics, and are two lakes joined by a narrow neck. Based on the Secchi disk readings, Lake Steilacoom is eutrophic, with a mean trophic state index value of 52. Given two lakes with similar physical characteristics and considerable nutrient loading from runoff/inflows and internal loading, it is likely that the differing trophic states of the lakes is due to different land uses within the lakes' watersheds. Lake Steilacoom is urban and receives runoff from a much larger drainage basin than Long lake, and Lake Steilacoom has a long history (about 30 years) of chemical treatment to control weeds and especially algae.




Long Lake, Thurston County. From Soil Conservation Service, September 20, 1971.



Loon Lake -- Stevens County

Loon Lake is located 28 miles north from Spokane, and south and adjacent to the city of Loon Lake. It is about 2.6 miles long. It is a natural lake with a regulating gate at the outlet. The lake level was established at 2381.25 feet in 1950 by court decree. Loon Lake is fed by five unnamed inlets and drains via Sheep Creek to the Colville River.

| | |
|---|---|
| Size (acres) | 1,100 |
| Maximum Depth (feet) | 100 |
| Mean Depth (feet) | 46 |
| Lake Volume (acre-feet) | 52,000 |
| Drainage Area (miles$^2$) | 14.10 |
| Altitude (feet) | 2,381 |
| Shoreline Length (miles) | 7.92 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 32 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/04 | 1320 | Green | Sunny | 12.0 | 17.42 | Thermocline appears between 10 - 30 feet. |
| 05/18 | 1245 | Bl-Gr | P Sunny | 14.5 | 19.25 | Wind from SW at 15 - 20 mph. Heavy rain in the past 24 hrs. Air temp. 14°C. |
| 06/04 | 1045 | Green | Sunny | 17.0 | 22.91 | No rain in last 24 hrs. Lake has a lot of pine pollen in it. |
| 06/16 | 1430 | Bl-Gr | P Sunny | 20.0 | 21.54 | Partially sunny weather - heavy rain last 24 hours. Cooling trend last 24 hours. |
| 06/29 | 1500 | Bl-Gr | P Sunny | 21.0 | 23.83 | Cool, showers last few days. Lake color very dark but Secchi reading best yet. |
| 07/17 | 1400 | Bl-Gr | P Sunny | 22.5 | 21.08 | Last 24 hours rainy and windy - seasonally cool - fluctuating barometer. |
| 08/06 | 1400 | Bl-Gr | Sunny | 22.5 | 23.83 | Hot and calm weather last 24 hours. |
| 08/20 | 1230 | Green | Sunny | 23.0 | 22.91 | Windy - had been stormy in last 24 hours and cooler. |

Like other high elevation lakes in Eastern Washington, the lowest water clarity occurred during April and May because of spring algal growth. Fluctuations in water clarity during the rest of the summer appear to be influenced by stormy periods prior to the sampling dates.

Summary of Questionnaire Results and Information from the Volunteer

The questionnaire on lake and watershed uses was not returned.

Summary Other Available Information

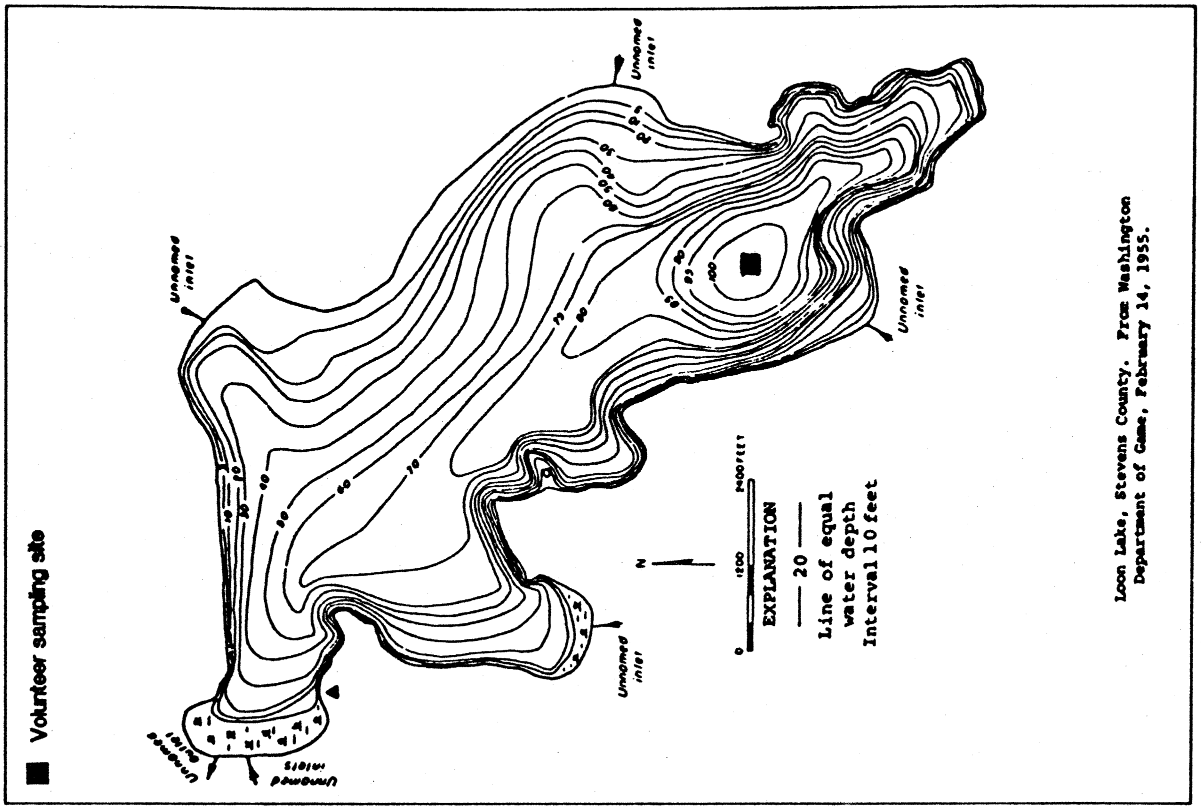
The following are from the volunteer's remarks and questionnaire responses. Loon Lake was sewered in 1986, funded in part by Ecology/EPA grants. Before the lakeshore was sewered, surveys conducted by Ecology in 1968 (Lee, 1969), 1971-1972 and 1978 indicated that Loon Lake was mesotrophic (Singleton *et al.*, 1980). Although Secchi disk transparency and chlorophyll *a* data collected in 1978 were characteristic of oligotrophic lakes using the trophic state index from Carlson (1977), in 1978 the dissolved oxygen concentrations near the bottom of Loon Lake were depleted, and blue-green algae species (*Anabaena circinalis* and *Aphanothece nidulans*) were identified (Singleton *et al.*, 1980). Dissolved oxygen concentrations were also depleted from 55 to 70 feet in October, 1968 (Lee, 1969). Depleted dissolved oxygen concentrations in the hypolimnion and blue-green algae are not characteristic of oligotrophic lakes.

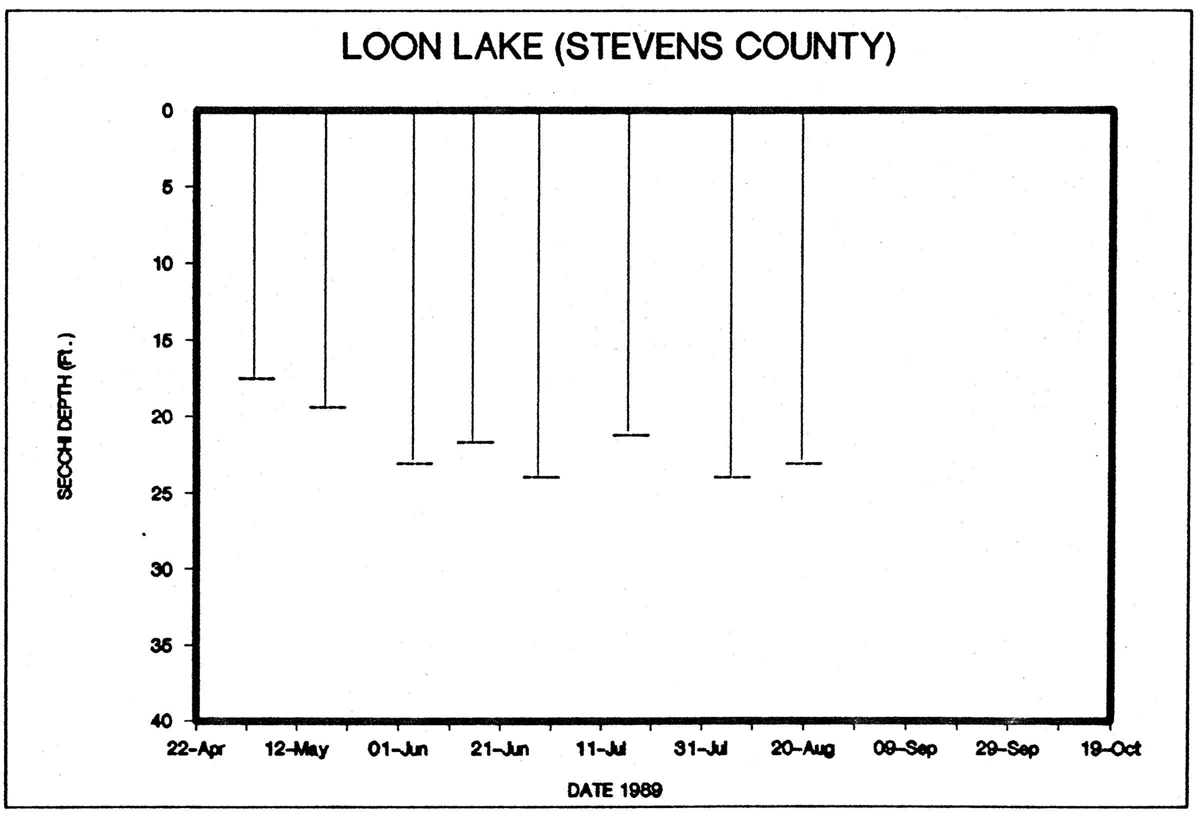
Mean Secchi disk transparency decreased significantly from 6.5 meters in 1972 to 5.3 meters in 1978 (Singleton *et al.*, 1980). The mean of Secchi disk readings in 1989 was 21.6 feet (6.6 meters), indicating that the water clarity in 1989 was much better in 1989 than in 1978. Trophic state indices calculated from Secchi disk transparency, total phosphorus and chlorophyll *a* data collected in 1981 show that Loon Lake was oligotrophic in 1981 (Sumioka and Dion, 1985).

The Loon Lake Property Owners Association hired a contractor to collect monthly profile data from April-September, 1989. We concluded that Loon Lake is oligotrophic based on evaluations of the raw data.

Comments

Compared to other lakes monitored for the program, in 1989 the water clarity at Loon Lake is very good and is somewhat better than nearby Deer Lake.


Volunteer sampling site
EXPLANATION
20
Line of equal water depth Interval 10 feet
Loon Lake, Stevens County. From Washington Department of Game, February 14, 1955.


LOON LAKE (STEVENS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Lake Louise -- Pierce County

Lake Louise is located 1.5 miles southwest from Steilacoom, in a 50 foot depression. It has no inlets or outlets, and it seeps to Puget Sound.

| | |
|---|---|
| Size (acres) | 39 |
| Maximum Depth (feet) | 35 |
| Mean Depth (feet) | 22 |
| Lake Volume (acre-feet) | 860 |
| Drainage Area ($miles^2$) | 0.34 |
| Altitude (feet) | 230 |
| Shoreline Length (miles) | 0.91 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic* |
| Mean Trophic State Index: | 34 |

*See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 06/04 | 1400 | Bl-Gr | Sunny | 25.0 | 16.20 | Quite windy the past few days. Took reading despite it was not all that calm. |
| 06/24 | 1300 | Bl-Gr | Sunny | 21.0 | 19.48 | The water was a tad choppy, due to a NE wind. |
| 07/10 | 1500 | Bl-Gr | Sunny | 23.0 | 21.38 | Not sure I am in the exact same spot each time; try to approximate. |
| 07/25 | | Bl-Gr | Sunny | 26.0 | 20.16 | Windy. |
| 08/17 | 1300 | Bl-Gr | Sunny | 25.0 | 20.16 | |
| 10/16 | 1330 | Bl-Gr | Sunny | 15.0 | 20.16 | |

The water clarity was lowest during June. Overall, the water was clear and blue-green in color throughout the sampling period.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Lake Louise is used for fishing, swimming, boating, and jet skiing. There is one public access. There is a time restriction for water skiing. Currently a large residential development is being built in the watershed. There are about 100 houses on the lakeshore; all of these are occupied year-round and the lakeshore is sewered. Lakeshore residents pay $75 per year so that the lake can be chemically treated. The lake has been treated with chemicals for the past 10-15 years to control both weeds and algae. This year the lake will be treated to control weeds and algae. Fish are stocked in the lake. No water quality problems were noted by the volunteer. Lakeshore residents are concerned about residential runoff into the lake.

Lake Louise -- Pierce County

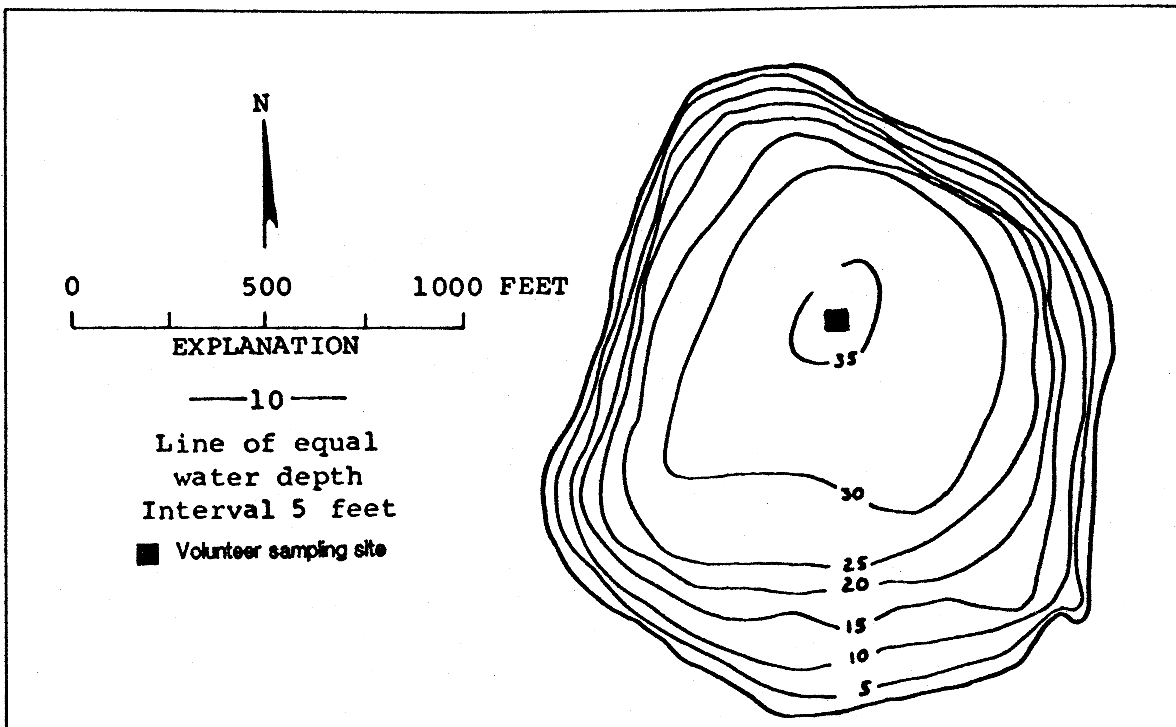
Summary of Other Available Information

Trophic state indices calculated from Secchi disk transparency and total phosphorus data collected in 1981 show that in 1981 Lake Louise was mesotrophic; the trophic state index value for total phosphorus was 47, which is approaching the range associated with eutrophic lakes (Sumioka and Dion, 1985). In contrast, Secchi disk transparency and total phosphorus data collected in 1973 indicate that in 1973 the lake was oligotrophic (Bortleson *et al.*, 1976). Residential development of the lakeshore has increased since 1973; the USGS reported that in 1973 there were 74 nearshore homes (Bortleson *et al.*, 1976).

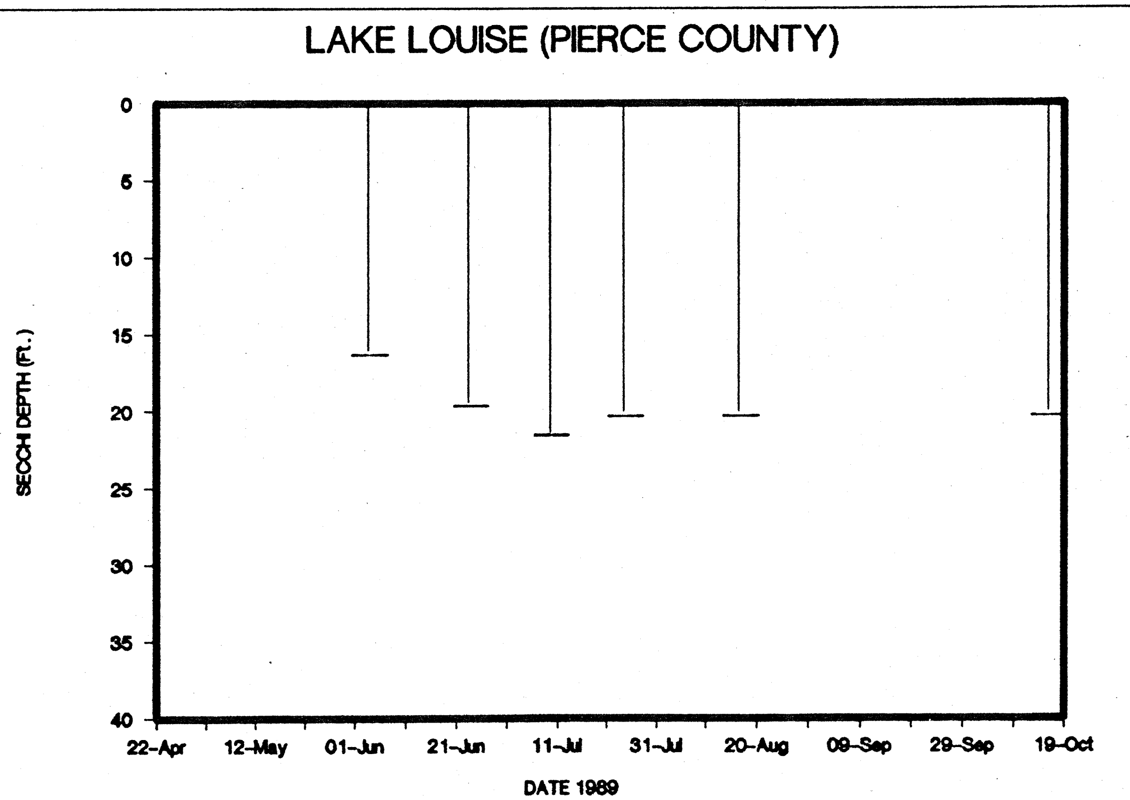
Comments

Water quality variance records with Ecology show that Rodeo, Aquathol-K and copper sulfate have been used for the past ten years to control algae in Lake Louise. Because Lake Louise is treated with chemicals to control algae, the Secchi depth readings do not give an accurate picture of the trophic state of the lake. Future estimates of the trophic state should be based on chemical data (total phosphorus and/or chlorophyll *a*). However, a continued record of Secchi disk transparency can be used to document the severity of algal blooms at Lake Louise.

Compared with other lakes monitored for the program, the water clarity of Lake Louise is very good. Lake Steilacoom in Pierce County and Clear Lake in Thurston County also have long histories of chemical treatment to control algal, but water clarity at these lakes is not very good. Even with chemical treatment, Secchi data indicate that Clear Lake is mesotrophic and Lake Steilacoom is eutrophic.




Louise Lake, Pierce County. From Washington Department of Game, June 5, 1950.



## Mason Lake -- Mason County

Mason Lake is located eight miles southwest from Belfair. It is four miles long and is fed by Shumocher Creek. Mason Lake drains via Sherwood Creek to North Bay and Case Inlet. It is the largest and deepest lake in Mason County. Macrophytes are dense around the shoreline and are concentrated near development in the northern arm of the lake.

| | |
|---|---|
| Size (acres) | 1000 |
| Maximum Depth (feet) | 90 |
| Mean Depth (feet) | 48 |
| Lake Volume (acre-feet) | 49,000 |
| Drainage Area (miles$^2$) | 20.2 |
| Altitude (feet) | 194 |
| Shoreline Length (miles) | 10.9 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 33 |

### Volunteer - Collected Data

### Station 1

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/01 | 1500 | Bl-Gr | P Cloudy | 9.0 | 20.16 | |
| 05/19 | 1020 | Bl-Gr | P Sunny | 12.0 | 20.62 | |
| 06/12 | 1230 | Bl-Gr | P Sunny | 19.0 | 22.91 | |
| 06/20 | 1600 | Brown | P Cloudy | 17.0 | 24.75 | About 5 knots wind, could not hold boat real steady. |
| 07/09 | 0830 | Bl-Gr | Sunny | 18.5 | 24.29 | Clear and calm - good accurate depth measurement. |
| 07/23 | 1330 | Bl-Gr | Sunny | 18.0 | 21.08 | Clear and calm - weather ideal for test. |
| 08/07 | 1220 | Bl-gr | Sunny | 21.0 | 18.33 | Beautiful day; calm. |
| 10/09 | 1400 | Green | Sunny | 18.0 | 24.75 | Pinhead-size white things in water, about 100 per cu-ft. Have seen this before. |

### Station 2

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/04 | 1145 | Bl-Gr | Sunny | 15.0 | 22.00 | |
| 05/27 | 1215 | -- | Sunny | 14.0 | 23.83 | |
| 06/23 | 1800 | Bl-Gr | Sunny | 19.0 | 25.66 | Boat drifted some - hard to get accurate depth measurement. |
| 07/13 | 1215 | Bl-Gr | P Cloudy | -- | 22.91 | |
| 07/24 | 2000 | Bl-Gr | P Sunny | 19.0 | 22.91 | |
| 08/10 | 1700 | Bl-Gr | Sunny | 20.5 | 23.83 | |
| 08/28 | 1750 | Green | -- | 20.0 | 20.16 | |
| 09/10 | 1200 | Green | Sunny | 19.0 | 24.75 | |
| 10/24 | 1115 | Bl-Gr | Sunny | 15.0 | 24.75 | Clear and calm. Still small particles in the water, appear smaller than n 10/9. |

Mason Lake -- Mason County

## Station 3

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/12 | 1100 | Bl-Gr | P Sunny | 15.0 | 19.25* | |
| 06/14 | 1030 | Green | P Cloudy | 19.0 | 22.91 | |
| 07/05 | 1010 | Bl-Gr | Sunny | 19.0 | 22.91 | Sunny, no wind. |
| 07/16 | 0900 | Bl-Gr | P Cloudy | 19.0 | 22.91 | Moderate chop. |
| 08/03 | 1430 | Bl-Gr | P Cloudy | 20.0 | 19.25* | Overcast, calm. |
| 08/18 | 1200 | Bl-Gr | Cloudy | 21.0 | 22.00 | |
| 09/04 | 1115 | -- | Sunny | 19.5 | 27.04 | |
| 09/14 | 1730 | -- | Sunny | 21.0 | 22.91 | Clear and warm. |
| 10/24 | 1200 | Bl-Gr | Sunny | 15.0 | 25.66 | |

## Station 4

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/06 | 1115 | Bl-Gr | P Sunny | 18.0 | 19.71* | |
| 05/31 | 1335 | Bl-Gr | P Cloudy | 16.0 | 18.79* | |
| 06/27 | 1320 | Bl-Gr | P Sunny | 19.0 | 20.63* | |
| 07/13 | 1350 | Bl-Gr | Sunny | 19.5 | 20.63 | |
| 08/01 | 1310 | Bl-Gr | P Cloudy | 19.0 | 22.92 | |
| 08/12 | 1115 | Bl-Gr | Sunny | 19.5 | 24.75 | |
| 09/02 | 1156 | Bl-Gr | P Cloudy | 18.5 | 19.25* | |
| 09/11 | 1450 | Blue | Sunny | 18.5 | 25.66 | |
| 10/24 | 1130 | Bl-Gr | Sunny | 16.0 | 25.44 | |

## Station 5

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/10 | 1015 | Bl-Gr | Sunny | 15.0 | 22.00 | Windy, 5 - 10 mph. |
| 06/30 | 1300 | -- | Cloudy | 17.0 | 18.33 | Windy. Raining, water color gray. |
| 07/14 | 1000 | Bl-Gr | Sunny | 19.0 | 22.91 | Winds calm, lake surface smooth. |
| 08/03 | 1115 | Bl-Gr | P Sunny | 19.5 | 19.25 | |
| 08/15 | 1030 | Bl-Gr | Cloudy | 18.5 | 21.08 | Calm surface. |
| 09/03 | 1040 | Bl-Gr | Sunny | 18.0 | 24.29 | |
| 09/13 | 1010 | Bl-Gr | Sunny | 19.5 | 26.58 | Calm wind and surface. |
| 10/24 | 1145 | Bl-Gr | Sunny | 15.0 | 25.21 | |

*Limit for quality assurance test were exceeded for this data point.

Volunteers monitored five lake stations in Mason Lake. Three deep water stations (stations 2, 4, and 5) and two stations in water about 60 feet deep on each end of the lake (stations 1 and 3) were monitored. At all stations, spring algal growth decreased the water clarity during May. Late summer algal growth occurred during August at stations 1, 3 and 5, and during late

August/early September at the deeper water stations (stations 2 and 4). The water clarity values were similar between Station 1, 2, 3, and 5. Values at Station 4 were somewhat lower than at the other stations.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteers' remarks and questionnaire responses. Mason Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a picnic area, a camping area, two marinas, four boat ramps, and a park on the lakeshore. Lake water is withdrawn for drinking and other domestic uses. Currently the watershed is used primarily for logging and residential development along the lakeshore is occurring. There are about 650 houses on the lakeshore; of these, about 300 are occupied year-round and all are on septic systems. Fish are not stocked in the lake. There are wetlands associated with the lake, and a few individual homeowners rake weeds from their lakeshore areas. The worst water quality problems in Mason Lake, in the opinions of the volunteers, are 1) weeds, and 2) algal blooms. The volunteers are concerned about possible water quality effects from lawn and garden fertilizers and older septic systems.

Results of Intensive Monitoring/Summary of Other Available Information

Samples for the 1989 intensive monitoring were collected at the deep site of Mason Lake (volunteer Station #4). Overall the data confirmed that Mason Lake is oligotrophic, as indicated by deep Secchi disk transparency and relatively low epilmnetic concentrations of total phosphorus and chlorophyll *a*. Although dissolved oxygen concentrations were high throughout the water column during June, dissolved oxygen concentrations were somewhat lower in the hypolimnion during September, most likely due to decomposition of organic matter at the lake bottom. Data collected in 1968 show that dissolved oxygen concentrations were less than 1 mg/L in the bottom 15 feet of the lake (Lee, 1969).

Secchi data collected in 1970 (Funk *et al.*, 1972), 1972 (Bortleson *et al.*, 1974), 1981 (Sumioka and Dion, 1985) and 1989 (Brower and Kendra, 1990) show that the lake is oligotrophic. However, the concentrations of total phosphorus varied considerably between the 1972, 1981 and 1989 surveys. The lowest concentrations of total phosphorus were detected during the 1989 survey. Concentrations of chlorophyll *a* were also lower in 1989 compared to data collected in 1972; 1972 data varied from the eutrophic range to the oligotrophic range from March to May, 1972 (Bortleson *et al.*, 1974; Brower and Kendra, 1990).

Compared to other intensively-monitored lakes in 1989, the chlorophyll *a* concentrations in Mason Lake were among the lowest observed during both June and September (Brower and Kendra, 1990). Because chlorophyll *a* measurements indicate the volume of algae growing in water; the low concentrations found show that algae growth in Mason Lake is low compared to some of the other lakes monitored in June.

Mason Lake -- Mason County

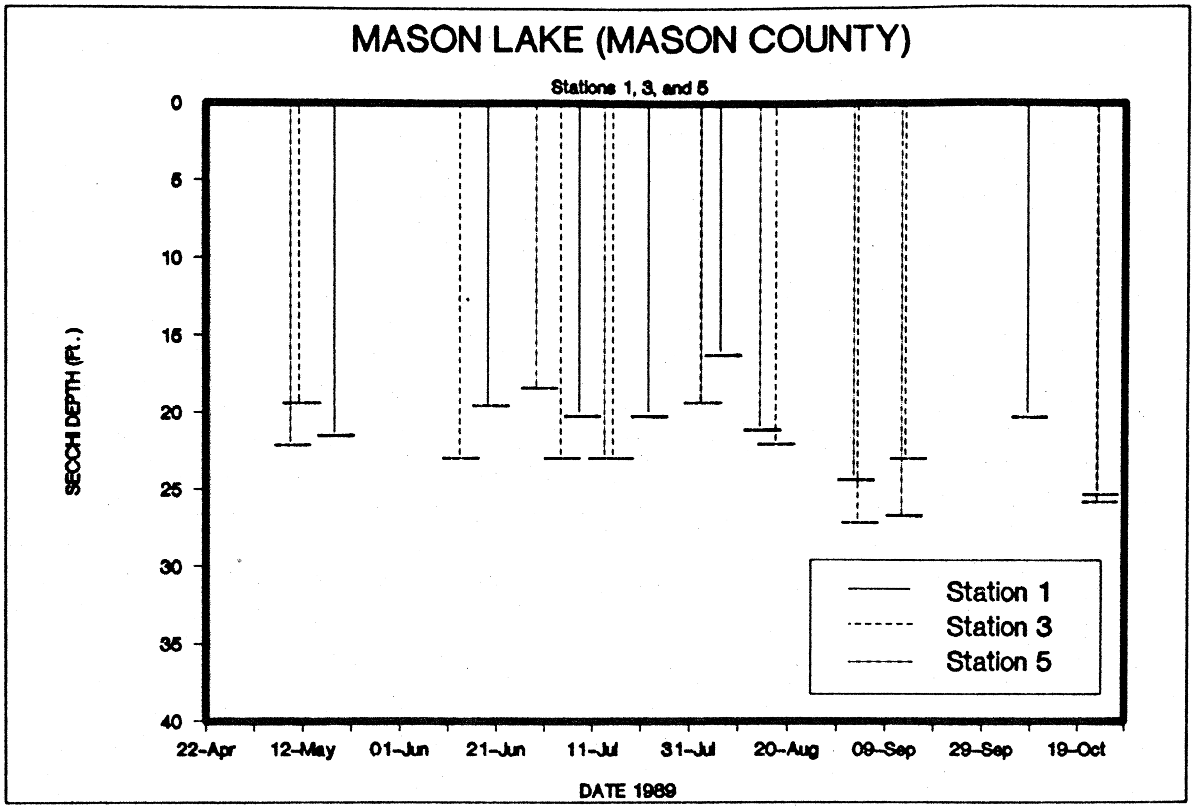
Low algal growth is also indicated by the very low turbidity and corresponding high Secchi transparency observed in Mason Lake.

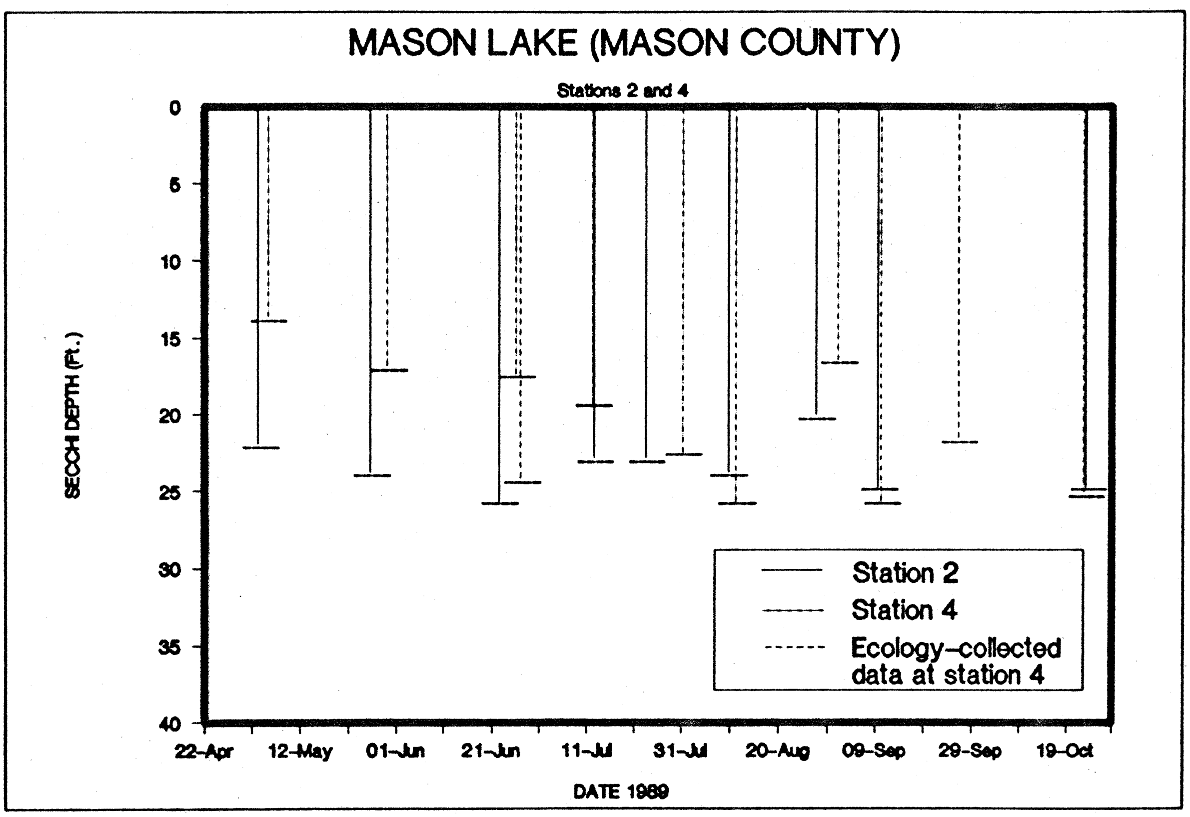
Residential development along the shore of Mason Lake has increased since 1972; the USGS reported that in 1972, there were 571 nearshore homes (Bortleson *et al.*, 1976).

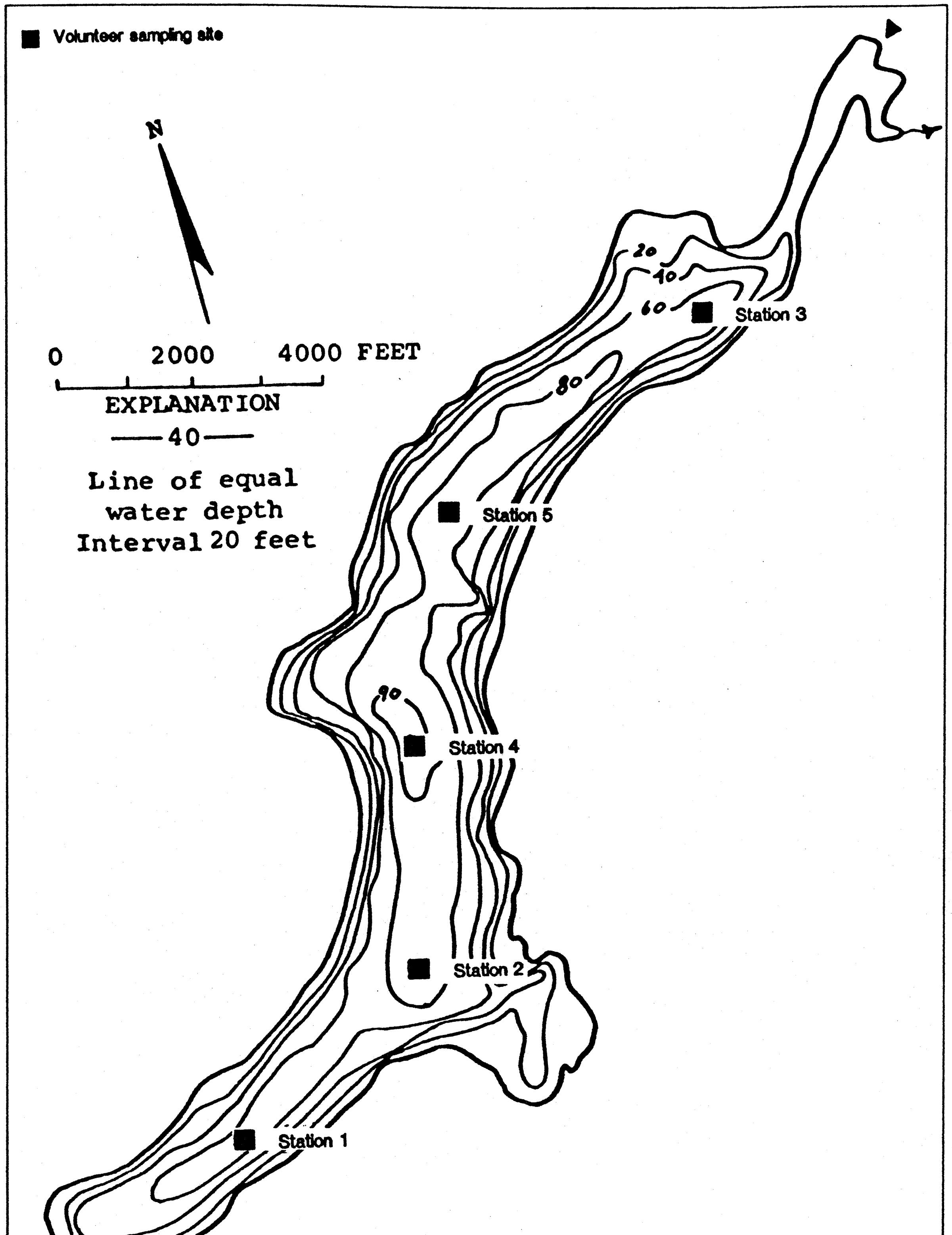
In September 1983, Allied Aquatics identified and mapped the following aquatic plants in Mason Lake: *Potamogeton amplifolius, Nymphaea odorata, Brasenia schreberi, Elodea, Vallisneria, Potamogeton pusillus*. These plants were located mostly on the north and northwest shore of the lake.

Comments

Despite the dense residential development in areas and heavy recreational use, the water quality of Mason Lake is very good. There were only two other Western Washington lakes (Crescent Lake and Summit Lake) monitored for the program that had higher average Secchi depths, and both of these lakes are deeper and less residentially developed than Mason Lake. Continued water clarity monitoring of Mason Lake may be used to determine whether the water quality of the deeper part of the lake is changing over time.


MASON LAKE (MASON COUNTY)
Stations 1, 3, and 5
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989
Station 1
Station 3
Station 5


MASON LAKE (MASON COUNTY)
Stations 2 and 4
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989
Station 2
Station 4
Ecology-collected data at station 4




Mason Lake, Mason County. From Washington Department of Game, May 4, 1954.

Newman Lake -- Spokane County

Newman Lake is located about 16 miles east from Spokane. Thompson Creek is the principal inlet at the north end of the lake. Newman Lake drains via the Spokane Valley Irrigation Canal, which controls the lake elevation. The canal drains southeasterly into the Spokane River Valley.

| | |
|---|---|
| Size (acres) | 1200 |
| Maximum Depth (feet) | 30 |
| Mean Depth (feet) | 19 |
| Lake Volume (acre-feet) | 23,000 |
| Drainage Area (miles$^2$) | 28.6 |
| Altitude (feet) | 2124 |
| Shoreline Length (miles) | 9.75 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic* |
| Mean Trophic State Index: | 44* |

*See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/14 | 1030 | -- | P Sunny | 16.0 | 7.79 | |
| 06/04 | 1830 | Green | -- | 20.0 | 7.33 | |
| 07/09 | 1505 | Gr-Br | Sunny | 23.0 | 4.58 | |
| 08/13 | 1630 | Green | P Sunny | 22.0 | 7.79 | The lake "turned over" since July; usually happens earlier. Clarity much improved. |
| 09/02 | 1045 | Bl-Gr | P Sunny | 19.0 | 19.94 | Test site treated with alum. We are all ecstatic over the post-treatment quality of our lake water! |

The water clarity decreased from May through early July, as algal growth increased over the summer. The lake was treated with alum between the last two readings, showing the dramatic increase in water clarity following the alum treatment.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteers's remarks and questionnaire responses. Newman Lake is used for fishing, swimming, boating, jet skiing, hiking, and waterfowl hunting. There is a picnic area, a privately-owned camping area, and two resorts on the lakeshore. Speed limits are established for motor boats used at night and inside buoys. Lake water is withdrawn for drinking and other domestic uses, and for irrigation. The watershed is used primarily for logging, and also for agriculture (both crops and animal grazing). In the past, the watershed was logged, mined, and the shoreline was altered some. There are 420 houses on the lakeshore;

of these, 85 are occupied year-round, and all are on septic systems. The lake was treated with alum in August 1989 to control algae growth and phosphorus recycling from the sediments.

Individual homeowners rake weeds from their lakeshore areas. Fish are stocked in the lake, and the lake has wetland areas. Water quality problems, in the opinion of the volunteer, are 1) algal blooms, 2) weeds, 3) surface water runoff, and 4) garbage, debris and leaves. Oxygen depletion in the lower strata of the lake was also noted by the volunteer as a water quality problem. Lily pads cover about 25% of lake shoreline and the entire lake bottom is covered by submerged plants and algae. The volunteer suggested that nutrients in lake sediments, and surface and subsurface runoff could contribute to water quality problems.

Washington State University completed a two-year lake restoration feasibility (Phase I) study. Lake restoration (Phase II) is now in progress. Restoration plans include alum treatment and installation of an aerator. A watershed plan has been prepared and implemented, and a septic system survey will be conducted by the Spokane County Health Department.

Summary of Other Available Information

Several surveys have shown that Newman Lake was having water quality problems. A survey conducted in 1968 reported that a moderate algal bloom was occurring during October, and as a result the Secchi disk transparency was only four feet (Lee, 1969). In June 1974, the algal density was moderately high, concentrations of total phosphorus and orthophosphorus were high, the Secchi disk transparency was only five feet, hydrogen sulfide (rotten-egg smell) was present in hypolimnion samples, and concentrations of dissolved oxygen in the water were depleted from 26 feet deep down to the bottom of the lake (Dion *et al.*, 1976).

In 1978, the Washington Water Research Center (WWRC) reported that the lake was meso-eutrophic. Algal blooms mainly of *Aphanizomenon flos-aquae* and *Anabaena flos-aquae* (both are types of blue-green algae and are associated with high phosphorus concentrations) persisted from July through December 1978. By the end of July, the hypolimnion was anoxic, probably from the decay of sinking algae. This anoxia contributed to the decline in fishing success at Newman, as well as the odor problem (WWRC, 1978).

In 1987 the WWRC reported that the soils around Newman Lake are not adequate for septic systems and that septic systems are contributing significantly to the nutrient loading of the lake. Newman Lake has been experiencing episodes of extensive blooms of undesirable algae since the late 1960s (WWRC, 1988).

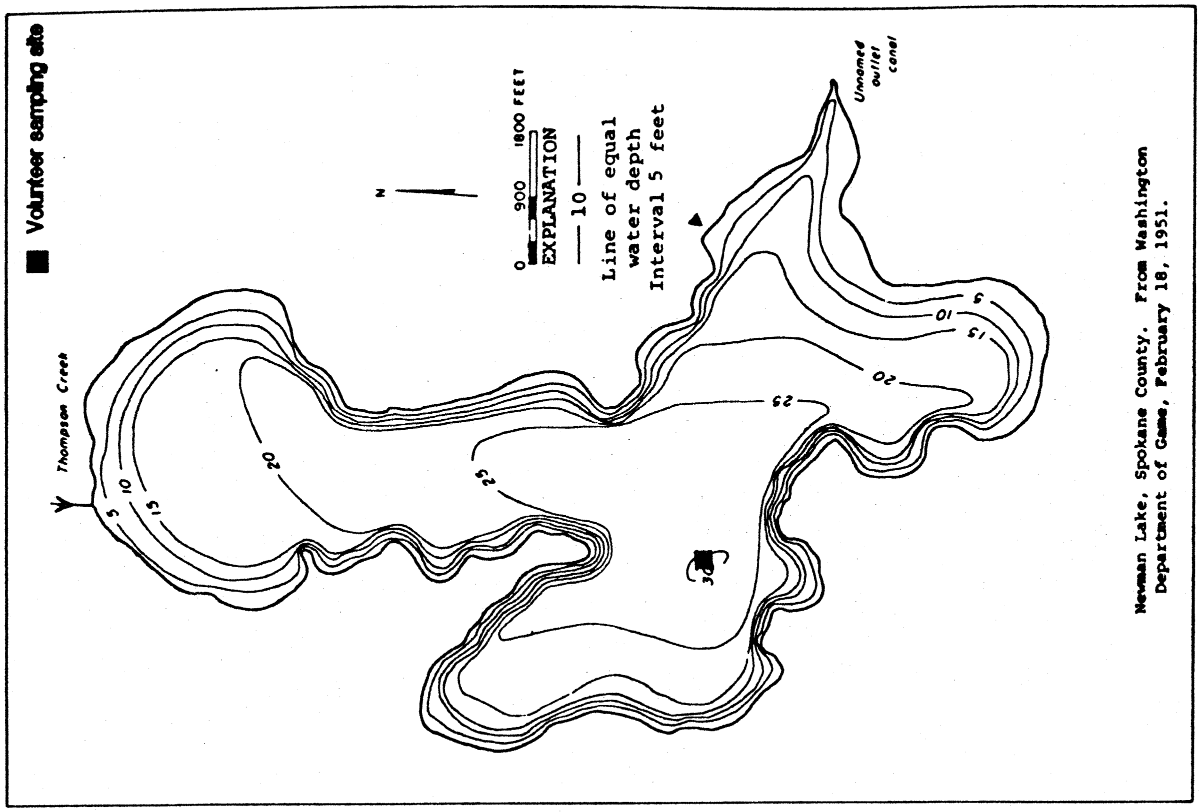
Residential development of the lakeshore has increased since 1974; the USGS reported that in 1974, there were 316 nearshore homes (Dion *et al.*, 1976).

Newman Lake --Spokane County

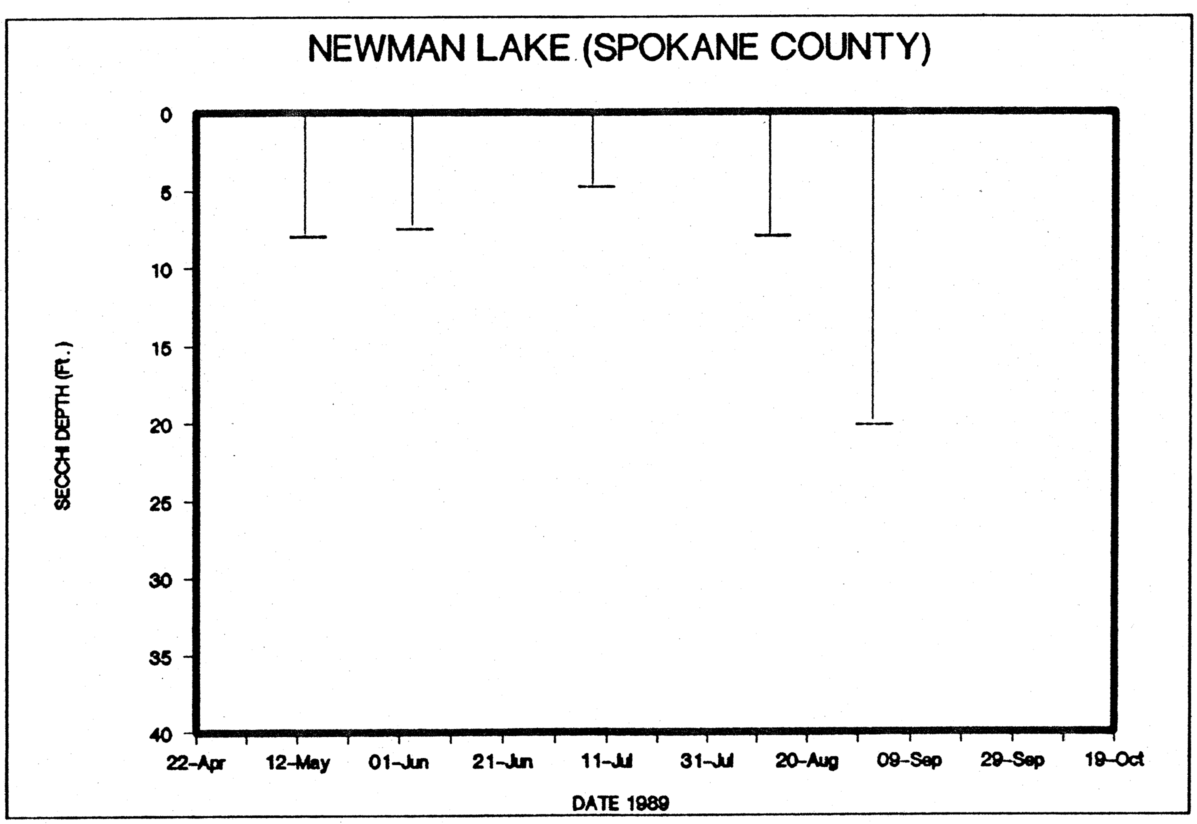
## Comments

The last Secchi reading, taken after the alum treatment, significantly affected the calculated trophic status (Secchi) of Newman Lake. The trophic state index calculated from the four pretreatment Secchi readings is 50, indicating that prior to treatment, Newman Lake was eutrophic. Until restoration efforts at Newman Lake are complete, future estimates of trophic status should be based on chemical data instead of transparency data.

There is a relationship between mean depth and trophic state among the lakes monitored for the program. With one exception, all of the lakes monitored that have a mean depth of less than 20 feet are mesotrophic or eutrophic. As a result, Newman Lake would be expected to be at least mesotrophic.



Newman Lake, Spokane County. From Washington Department of Game, February 18, 1951.



Lake Osoyoos -- Okanogan County

Lake Osoyoos is located one mile north from Oroville. It is ten miles long and extends north into Canada. The total size of the lake is 5729 acres; 3693 acres lie in British Columbia, Canada, and 2036 acres lie in the U.S. Lake Osoyoos is fed principally by the Okanogan River in Canada and drains via the Okanogan River south to the Columbia River in the U.S.

| | |
|---|---|
| Size (acres) | 5729 |
| Maximum Depth (feet) | 208 |
| Mean Depth (feet) | 46 |
| Lake Volume (acre-feet) | 266,000 |
| Drainage Area (miles$^2$) | 3150 |
| Altitude (feet) | 911 |
| Shoreline Length (miles) | 29.73 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 47 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/20 | 1547 | Green | Sunny | 19.0 | 10.08 | Medium algae bloom. |
| 06/03 | 1440 | Green | Sunny | 22.0 | 11.00 | Algae bloom. |
| 07/02 | 1410 | Bl-Gr | P Sunny | 23.0 | 8.71 | High winds have prevented mid-June testing. |
| 07/21 | 1345 | Bl-Gr | Sunny | 25.0 | 8.25 | |
| 08/03 | 1515 | Green | Sunny | 25.0 | 6.42 | |
| 09/03 | 1345 | Green | Sunny | 25.0 | 6.42 | Winds/rains prevented Aug. 15-20th testing. |
| 09/24 | 1420 | Bl-Gr | P Sunny | 23.0 | 6.87 | |

There was a gradual decrease in clarity over the summer that leveled off from August through September. The volunteer monitored two stations. Station 1 is south of Boundary Point, and station 2 is north of Boundary Point. Data from both sites were virtually identical. Water color was blue-green to green throughout the monitoring period.

Summary of Questionnaire Results and Information From the Volunteer

The questionnaire on lake and watershed uses was not returned.

Results of Intensive Monitoring/Summary of Other Available Information

Lake Osoyoos was sampled by Ecology south of the International Boundary and Boundary Point at a site about 50 feet deep. Although the bathymetric map indicates that the lake is 75 feet deep near this point, we were unable to find this depth in 1989. The survey results confirm that

Lake Osoyoos -- Okanogan County

Lake Osoyoos is mesotrophic, as indicated by moderate Secchi disk transparency and epilimnetic concentrations of total phosphorus and chlorophyll *a*. The lake was stratified during June but had turned over and was mixing when sampled during September. Because the lake was mixing, the temperature, dissolved oxygen, and pH were relatively stable from the surface to the bottom. The very low readings at the deepest part of the lake are probably in error; most likely, the instrument was sitting on the lake bottom. The pH was much higher during June than during September; the higher overall pH and higher concentrations of dissolved oxygen from 2 to 6.5 meters during June probably resulted from algae growth. During June, the water color was green and a mild algae bloom was observed in the water (Brower and Kendra, 1990).

Lake Osoyoos was also shown to be mesotrophic in 1974 (Dion *et al.*, 1976) and 1981 (Sumioka and Dion, 1985), based on Secchi disk transparency, concentrations of total phosphorus, and very low concentrations of dissolved oxygen near the bottom of the lake.

As part of the toxics monitoring portion of the Lake Monitoring Program, sediment and largemouth bass samples were collected from Lake Osoyoos. No unusual concentrations of metals or organics were detected from bottom sediments. Compared to other lakes sampled, fish tissues in Lake Osoyoos contained elevated concentrations of selenium (0.95 mg/Kg) and total DDT compounds, primarily in the form of degradation by-products (210 ppb). The elevated concentrations of DDT compounds suggest that there was significant historical use of DDT in the drainage basin. Although concentrations of DDT and selenium are within levels considered acceptable for human consumption, it was recommended that Lake Osoyoos fish be included in Ecology's annual Biological Monitoring Program (Johnson and Norton, 1990).

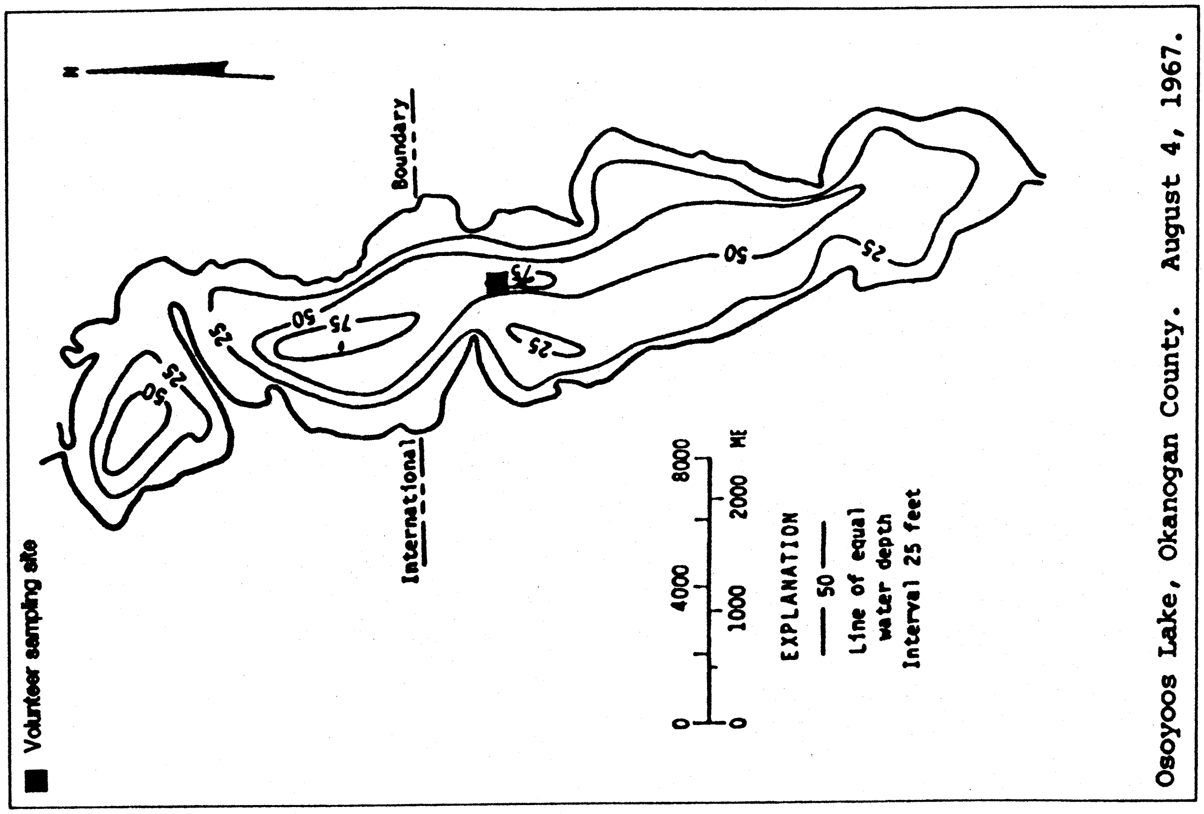
Eurasian water milfoil was introduced into Lake Osoyoos, and was first reported in 1975 (Gibbons *et al.*, 1984). Mechanical harvesting of the milfoil was proposed but did not occur because the hydraulic permit was denied by the Departments of Fisheries and Game (Hamel, pers. comm.). Chemical treatment of the milfoil has been tried in experimental test plots, but local and international concern about the use of herbicides has preempted chemical control of the water milfoil. Any effort to control the milfoil is now at a standstill (Hamel, pers. comm.).

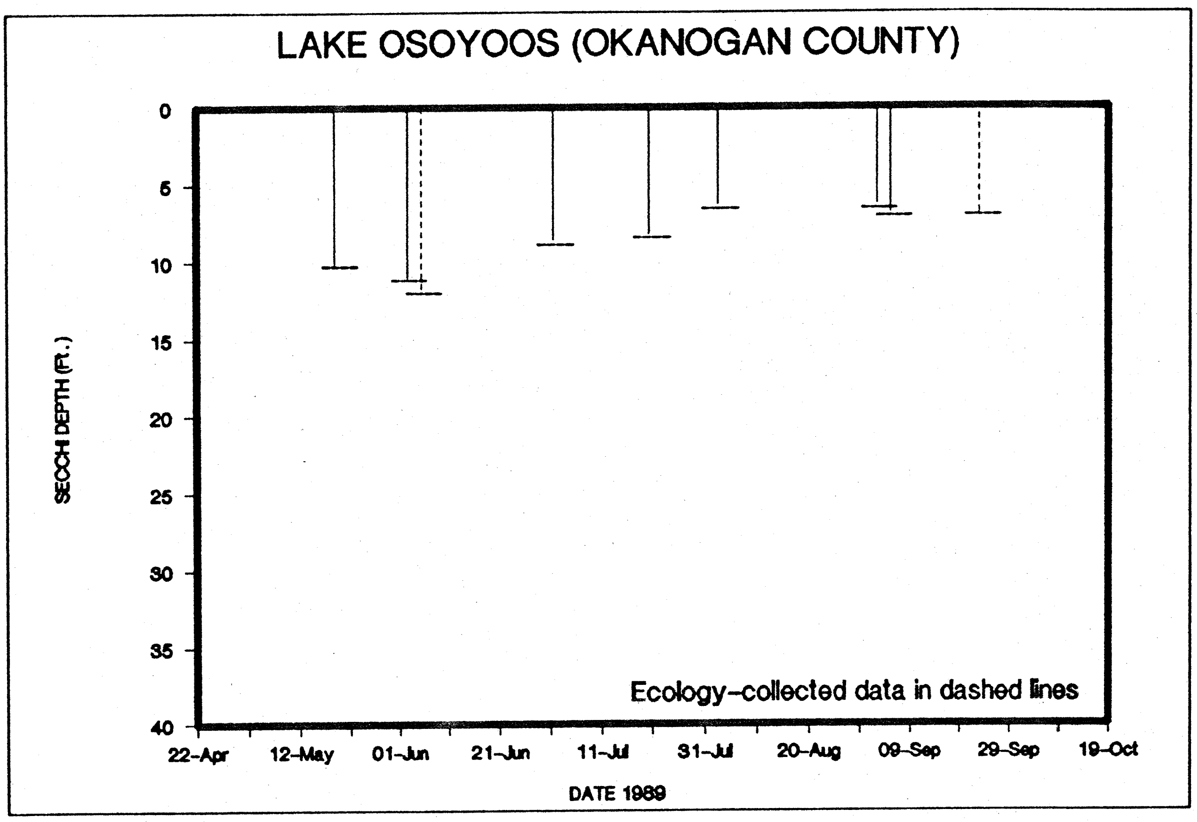
Algal growth in Lake Osoyoos was studied by the University of British Columbia in 1968-69 because there were concerns that Lake Osoyoos, which is pumped for domestic water use, had the potential to exhibit water quality problems observed in Skaha Lake (Couthard and Stein, 1969). Lake Osoyoos receives water from Skaha Lake via the Okanagan River, and secondary sewage effluent from the town of Oliver is pumped into the Okanagan River about 3 miles north from Lake Osoyoos. The south Lake Osoyoos stations did not exhibit the extent of blue-green algal growth as Lake Skaha and the northern Lake Osoyoos stations. Point source discharges from primary and secondary wastewater treatment facilities, and cannery and packing house wastes, as well as runoff from agricultural lands, were cited as nutrient sources to be studied further (Coulthard and Stein, 1969).

Lake Osoyoos -- Okanogan County

<u>Comments</u>

There is a relationship between mean depth and trophic state among the lakes monitored for the program. In general, lakes with a mean depth greater than 20 feet are oligotrophic. However, there are six lakes in the program, including Lake Osoyoos, that are mesotrophic despite having a deeper mean depth. All these lakes are showing signs of cultural eutrophication and two have undergone lake restoration.


Osoyoos Lake, Okanogan County. August 4, 1967.
Volunteer sampling site
International
Boundary
N
25
50
75
EXPLANATION
— 50 — Line of equal water depth
Interval 25 feet
0
4000
8000
0
1000
2000


LAKE OSOYOOS (OKANOGAN COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed lines
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Packwood Lake -- Lewis County

Packwood Lake is located in the Gifford Pinchot National Forest, five miles east of Packwood. It is a natural lake that has been stabilized at the outlet by a dam built in 1963. Water from the outlet has been diverted since 1964 to a hydroelectric power plant located near the town of Packwood. The main inlet, Lake Creek, enters at the southeast corner of the lake. Packwood Lake drains via Lake Creek to the Cowlitz River. The watershed is forested and has been protected by wilderness status since 1984.

| | |
|---|---|
| Size (acres) | 400 |
| Maximum Depth (feet) | 120 |
| Mean Depth (feet) | 71 |
| Lake Volume (acre-feet) | 28,000 |
| Drainage Area (miles$^2$) | 19.20 |
| Altitude (feet) | 2858 |
| Shoreline Length (miles) | 4.26 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic* |
| Mean Trophic State Index: | 37 |

*See Comments section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 06/30 | 1230 | Green | P Sunny | 14.0 | 9.62 | Took reading between dock and the island. Raining and sunny at same time today. |
| 07/19 | 1515 | Bl-Gr | Sunny | 15.0 | 15.58 | Lake struck by lightning 3:30 am July 15th. Three fish dead on 07/19, two dead on 7/20. |
| 08/18 | 1320 | Bl-Gr | P Sunny | 18.0 | 26.28 | Mostly stormy and overcast since the last reading. Reading taken in the wind. |

There was a very dramatic increase in water clarity from May/early June through August. September data collected by Ecology indicates that the clarity decreased but this may have been because it was too windy to get a very good reading. The water color was green in late June, then turned more blue-green later in the summer.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Packwood Lake is used for fishing, swimming, canoeing/rowing, picnicking, camping, and hiking. There is a picnic area, a camping area, one resort, one USFS cabin with facilities, and a beach on the lakeshore. Motor boats and float planes are prohibited on the lake. Lake water is used for drinking and other domestic uses, and for hydroelectric power generation. There are three summer cabins on the lakeshore; all are on septic systems. There are wetlands associated with the lake. In the opinion of the volunteer, the worst water quality problem in Packwood Lake is garbage on the lakeshore left by lake and shoreline visitors.

Results of Intensive Sampling/Summary of Other Available Information

Packwood Lake is oligotrophic, determined primarily by the September, 1989 data. Usually, the three parameters used to estimate trophic status (Secchi disk transparency and epilimnetic concentrations of total phosphorus and chlorophyll *a*) will yield similar trophic state index values. This was the case for the September data collected from Packwood Lake; however, this was not the case during June. The values for total phosphorus, and especially Secchi depth, during June are much higher than would be expected given the low concentrations of chlorophyll *a*.

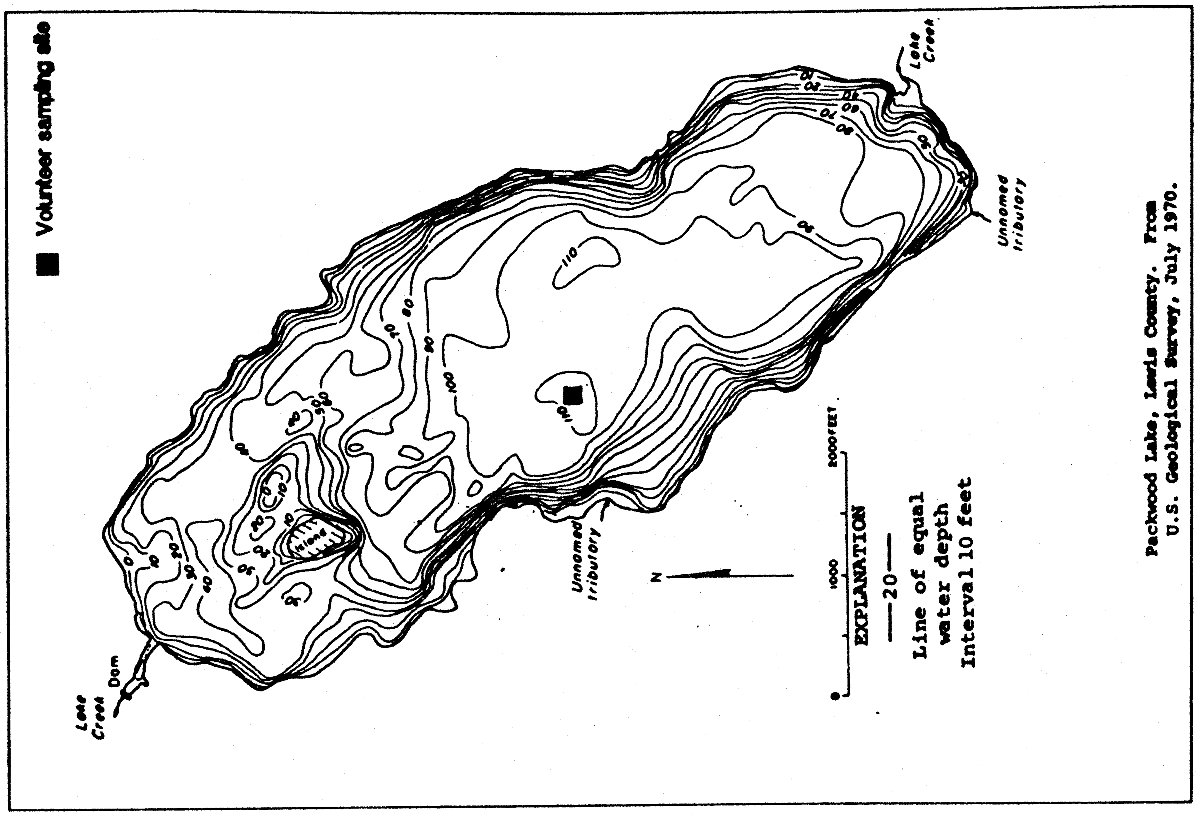
The phosphorus may have entered the lake adsorbed onto particles of glacial silt. Absorbed phosphorus would not be taken up by algae and would settle with the particles to the lake bottom. Silt in glacial meltwater, as well as frequent winds in the area, are probably responsible for the high turbidity and correspondingly low Secchi disk readings in the spring and early summer.

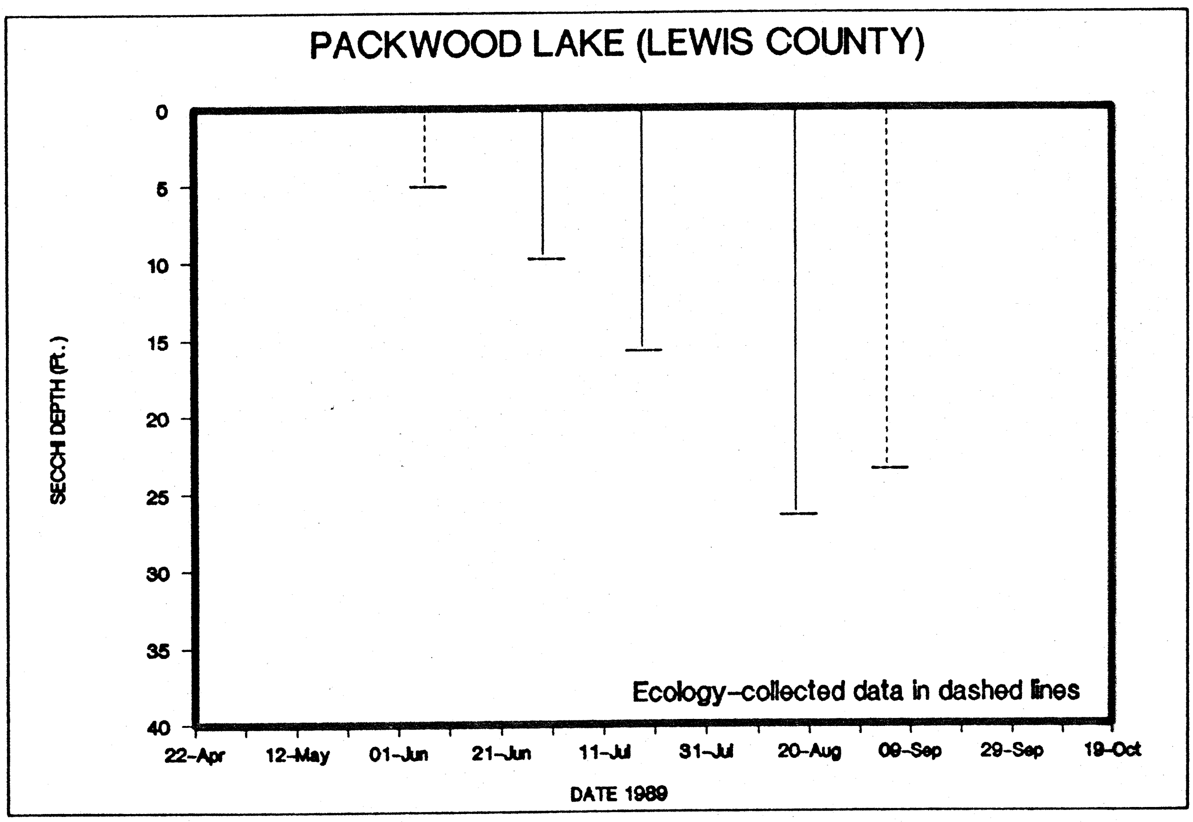
Compared with data collected in 1970 (Collings, 1973; Bortleson *et al.*, 1976), the water quality of Packwood Lake was similar in 1989. Dissolved oxygen concentrations remain high throughout the water column and nutrient concentrations are low.

From Lucas (1989): The composition of the lake bottom is ash, mud and rock. There is no aquatic vegetation in the lake, but there is a moderate number of logs in the lake. To preserve the genetic integrity of the Packwood rainbow trout, no fish have been stocked in Packwood Lake since 1965, with the exception of the progeny of fish collected in 1979. Tributaries, including the outlet, have been closed to fishing.

Comments

Compared with other lakes monitored for the program, the water quality of Packwood Lake is very good. Because the Secchi disk transparency appears to be affected by glacial meltwater and winds, future estimates of trophic state should be based on chemical data.


Volunteer sampling site
Lake Creek
Dam
Lake Creek
Unnamed tributary
Unnamed tributary
Island
0
1000
2000 FEET
N
EXPLANATION
20
Line of equal water depth
Interval 10 feet
Packwood Lake, Lewis County. From U.S. Geological Survey, July 1970.


PACKWOOD LAKE (LEWIS COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed lines
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Patterson Lake -- Thurston County

Patterson Lake is located six miles southeast from Olympia. It consists of two basins separated by a narrow neck. The northwest half is 74.6 acres and the southeast half is 182.4 acres. The lake is fed by Hicks Lake and drains to Long Lake and ultimately to Henderson Inlet via Himes/Woodland Creek. Patterson Lake is also known by local residents as Pattison Lake.

| | |
|---|---|
| Size (acres) | 190 |
| Maximum Depth (feet) | 19 |
| Mean Depth (feet) | 13 |
| Lake Volume (acre-feet) | 2500 |
| Drainage Area (miles$^2$) | 3.77 |
| Altitude (feet) | 154 |
| Shoreline Length (miles) | 4.60 |

| | |
|---|---|
| Estimated Trophic State: | meso-eutrophic |
| Mean Trophic State Index: | 47 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/15 | 0900 | -- | P Cloudy | 13.7 | 6.65 | Cloudy, hot last few days. |
| 04/23 | 1400 | -- | Sunny | 14.7 | 7.79 | Clear, sunny. Small chop |
| 04/30 | 1115 | -- | Sunny | 16.6 | * | Clear, sunny, calm. |
| 05/06 | 1130 | -- | P Sunny | 22.0 | * | Partly cloudy, hazy, small ripple, light breeze. |
| 05/14 | 1030 | -- | Sunny | 17.7 | 13.75 | Clear, sunny, small chop, light breeze. |
| 06/10 | 1130 | -- | Sunny | 22.2 | 13.75 | Sunny, calm, light ripple. Bloom - Nostoc(?) clumped balls. |
| 06/24 | 1115 | -- | Sunny | 23.5 | 4.35 | Sunny, light ripple. |
| 07/29 | 1515 | -- | P Sunny | 24.5 | 6.32 | Slightly overcast, calm. Lake treated around 6/28/89. |
| 08/06 | 1110 | Green | Sunny | 23.8 | 7.33 | Sunny, light ripple. Lake treated on 08/01/89. |
| 08/13 | 1100 | Green | P Sunny | 23.0 | ** | Secchi started to go in weeds at around 4.0 feet. Lake treated on 9/11/89. |
| 08/26 | 1440 | Green | Sunny | 23.0 | ** | Water color lime green. Secchi sitting in weeds. |
| 09/03 | 1530 | Green | Sunny | 21.0 | ** | Secchi sitting in weeds at 5.0 feet. Mild bloom of *Anabaena* occurring. |
| 09/17 | 1400 | Green | P Sunny | 20.5 | ** | Secchi sitting in weeds at 4.5 feet. |
| 10/01 | 1000 | Green | P Cloudy | 18.5 | 5.41 | Water color dark green. Surface algal bloom of last two weeks is almost one. |
| 10/15 | 1300 | Green | Cloudy | 16.5 | 13.75 | |

* Secchi hit bottom.
** Secchi disappeared in weeds

The volunteer monitored the southern basin only, so monitoring results are not representative of the upper basin. The water clarity fluctuated considerably over the course of the monitoring season, and readings were affected by both algae and aquatic plants. Submerged aquatic plants were very prolific in the lake, as documented from August through mid-September when the Secchi disk disappeared into weed beds. Although these readings cannot be used to determine the trophic status of the lake, they were graphed to show the extent of the plant growth. The readings also show that the weeds and algae cleared up by late September.

Patterson Lake -- Thurston County

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Patterson Lake is used for fishing, swimming (although the volunteer reports that "often the water quality is too poor"), canoeing/rowing, sailing, and picnicking (in the upper basin). There is a speed limit of five mph for motor boats, and the public access is limited to the fishing season (April 23 - October 31, 1989). Currently the watershed is used for agriculture (both crops and animal raising) and the lakeshore is being developed further for residences. The shoreline was altered in the past along the passage between the two basins; presently there are train tracks over this passage. There are 71 houses on the shore of the north basin and 100 houses on the shore of the south basin; all are on septic systems, and 95% of these houses are occupied year-round. The upper basin has been treated with alum and possibly copper sulfate in the past to control algae. This year, the lake was chemically treated around June 28, August 1, and September 1, 1989 to control weeds growing near the boat ramp of the southern basin. Fish are stocked in the lake. The lake has wetland areas. In the opinion of the volunteer, the worst water quality problems in the lake are 1) algal blooms, and 2) weeds. These problems are bad during most of the summer, but especially during mid-September when there was a severe algae bloom identified by the volunteer as the blue-green algae genus *Anabaena*. The volunteer suggested that septic systems contributed to the water quality problems.

The volunteer identified water lilies and cattails in wetland areas and along shores of both basins near the passage between the basins. Coontail *(Ceratophyllum)* and pontweed *(Potamogeton praelongus)* cover most of the lower basin. The volunteer also noted that floating mats of *Ceratophyllum* are common during the summer in the lower basin, whereas there are only a few small mats in the upper basin. Algae blooms occur throughout the lower basin. Two eagles, an adult and a juvenile, hunt in the lower basin in spring-summer.

Summary Of Other Available Information

Severe algal growth and other water quality problems in Patterson Lake has been documented during several surveys. A 1968 survey found Secchi disk transparency in Patterson Lake was only 4.75 feet, and the lake was described as a "moderately eutrophic lake which supports algal blooms from midsummer to early fall" (Lee, 1969). Moderate to heavy blooms of algae, low Secchi disk transparency and very low concentrations of dissolved oxygen near the bottom of the lake were reported in 1971 (Bortleson *et al.*, 1974). In 1974, the lake was likely to be eutrophic because there were high concentrations of total phosphorus and chlorophyll *a* and low Secchi disk transparency, blue-green algae (*Aphanizomenon*) dominated the algal populations during June, and dissolved oxygen concentrations were depleted near the bottom of the lake (Bortleson *et al.*, 1976). In 1981, concentrations of total phosphorus and nitrogen were very high (Sumioka and Dion, 1985).

Patterson Lake -- Thurston County

From Entranco Engineers (1987): In 1978 a Phase I Diagnostic/Feasibility study of Hicks, Patterson, Long and Lois Lakes in Thurston County was conducted by Entranco Engineers. Blue-green algal blooms and prolific aquatic plant growth in Patterson Lake were increasing, public concern about Patterson Lake. In 1983, alum as applied to the lake to precipitate phosphorus

from the water column, and mechanical harvesting of the plants occurred from 1983-84. Harvesting was stopped because of pressure from lakeshore residents. Secchi disk transparency increased and total phosphorus concentrations decreased in 1984-85 following the lake restoration efforts.

In 1985 coontail *(Ceratophyllum demersum)* was the dominant aquatic plant in the denser weed growth areas beginning in August. During September, 1985 both *C. demersum* and *Elodea canadensis* dominated in the south basin, indicating that the population of *E. canadensis* increased substantially from August to September (Entranco Engineers, 1987).

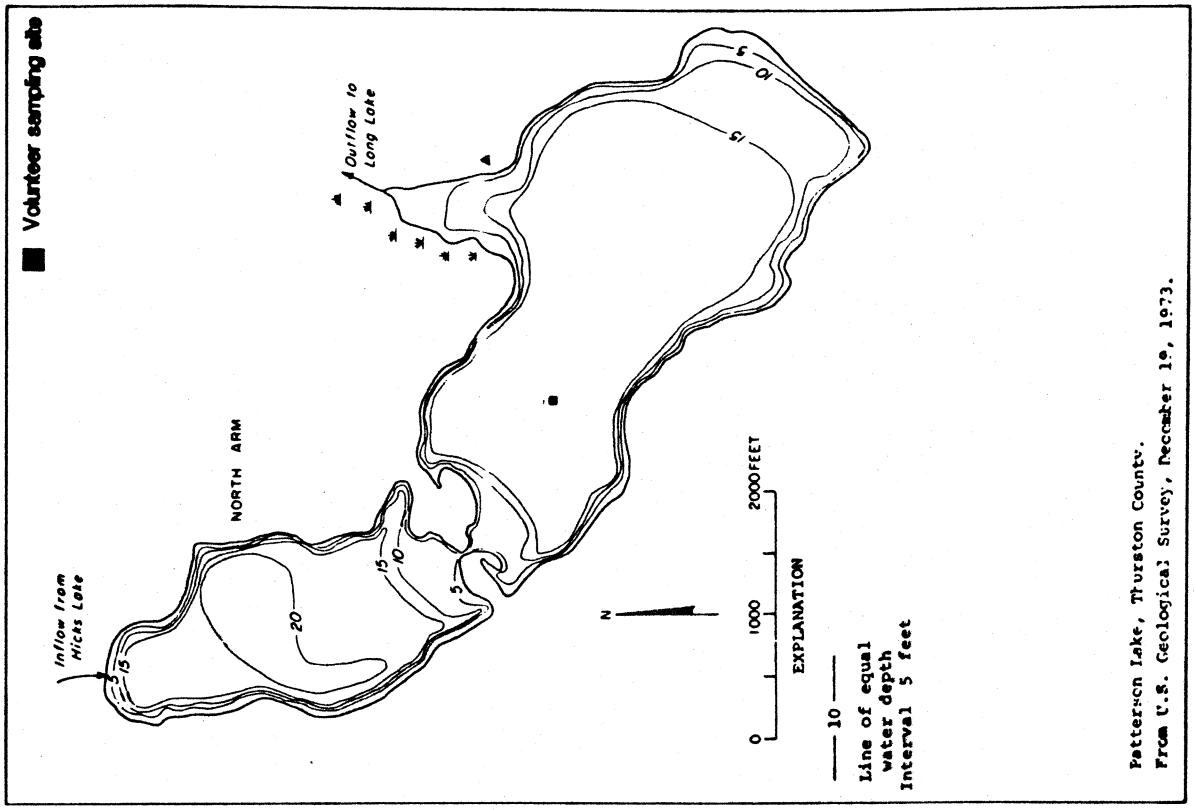
Residential development of the south basin of Patterson Lake has increased since 1981; the USGS reported that in 1981 there were 85 nearshore homes (Sumioka and Dion, 1985).

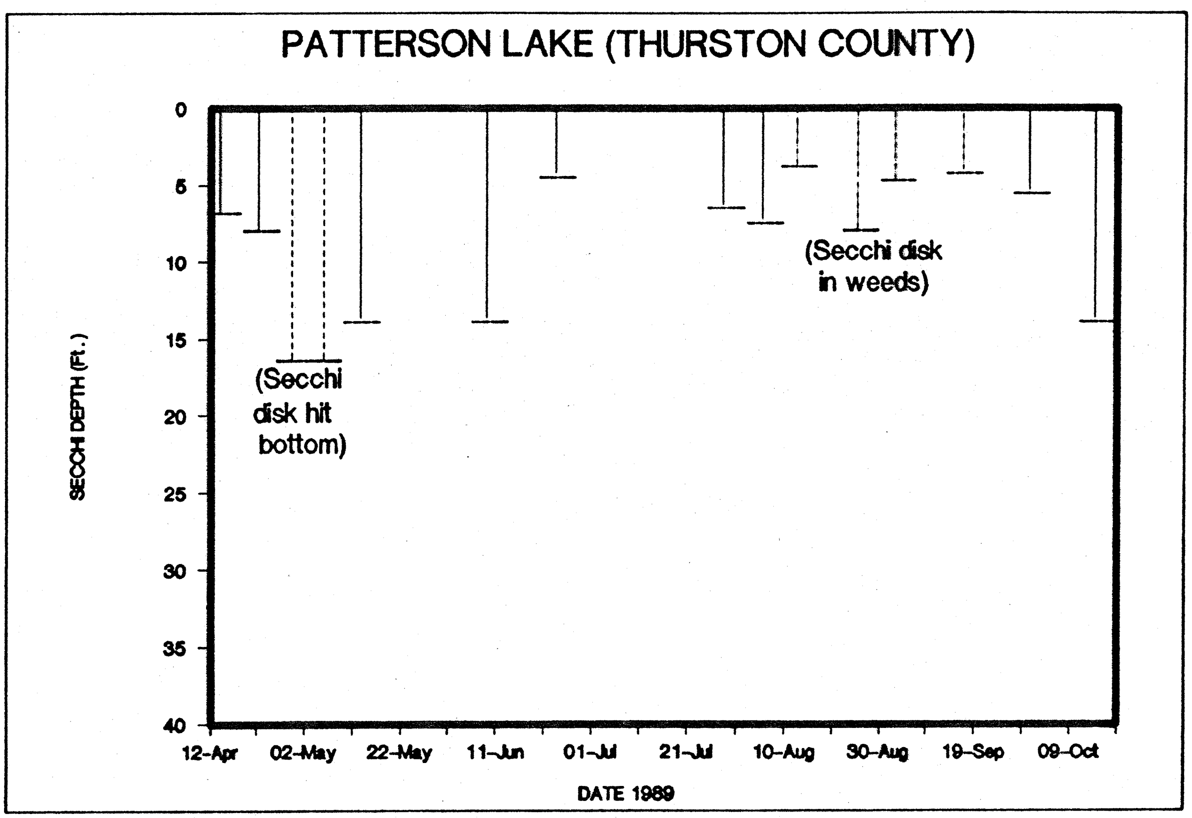
Water quality variance records with Ecology indicate that Patterson Lake was treated with Rodeo on June 28, August 1, and September 11, 1989 to control lily pads growing near the boat ramp of the southern basin.

Comments

Compared to other lakes monitored for the program, the water quality of Patterson Lake is not very good. All of the lakes in the program with a mean depth of less than 16 feet are mesotrophic or eutrophic; most are meso-eutrophic like Patterson Lake. Compared with nearby Long Lake, which is larger but is also choked with plant growth and has similar maximum and mean depths as Patterson Lake, the water clarity in Patterson Lake is somewhat worse. There is concern among local Long Lake residents that nutrient-rich water from Patterson Lake is fertilizing plant growth in Long Lake.

Overall, there is considerable variability in the lower basin of the lake, which could be influenced by the use of herbicides in the lower basin to control macrophytes or by the restoration activities occurring in the upper basin. Because plant growth in the lower basin hinders Secchi disk transparency measurements, future estimates of trophic state index values should be based on chemical data. Plant growth in the lower basin as well as the upper basin should be mapped yearly to document the duration and extent of the growths.


Volunteer sampling site
Outflow to Long Lake
NORTH ARM
Inflow from Hicks Lake
0 1000 2000 FEET
EXPLANATION
10
Line of equal water depth
Interval 5 feet
Patterson Lake, Thurston County.
From U.S. Geological Survey, December 19, 1973.


PATTERSON LAKE (THURSTON COUNTY)
SECCHI DEPTH (Ft.)
DATE 1989
(Secchi disk hit bottom)
(Secchi disk in weeds)
12-Apr 02-May 22-May 11-Jun 01-Jul 21-Jul 10-Aug 30-Aug 19-Sep 09-Oct

Phillips Lake -- Mason County

Phillips Lake is located seven miles north from Shelton. It has no inlet and drains via Campbell Creek through a marshy area to Oakland Bay.

| | |
|---|---|
| Size (acres) | 110 |
| Maximum Depth (feet) | 25 |
| Mean Depth (feet) | 16 |
| Lake Volume (acre-feet) | 1800 |
| Drainage Area (miles$^2$) | 0.5 |
| Altitude (feet) | 188 |
| Shoreline Length (miles) | 2.63 |
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 42 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 08/04 | 0930 | Green | P Cloudy | 21.0 | 11.00 | Grass on bottom. |
| 08/21 | 0930 | Green | Sunny | 21.0 | 11.92 | Bottom - mud and grass - light rain last night. |
| 09/07 | 0945 | Green | Sunny | 19.5 | 11.92 | Wind NE. Muddy bottom and grass. Large log removed to shore at boat launch. |
| 09/21 | 0930 | Green | Sunny | 19.0 | 11.46 | Wind NNE. Clear sky - muddy weed bottom. |
| 10/05 | 0945 | -- | P Cloudy | 16.0 | 10.38 | Windy northeast - foggy. |

Secchi disk readings were taken only during August and September, and did not vary much at all. More readings will be needed to evaluate patterns of algal growth in the lake, although there were sufficient readings to estimate the trophic state of the lake.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteers' remarks and questionnaire responses. Phillips Lake is used for fishing, swimming, boating, jet skiing, picnicking, and hiking. There is a beach on the lakeshore, and there are no restrictions on motor boat use. Water is withdrawn for domestic uses, and to fill county and fire tank trucks. Currently, the watershed is used for logging and agriculture (animal grazing and feeding), and the lakeshore is being developed further for residences. The shoreline has been altered in the past. There are about 153 houses on the lakeshore; all are on septic systems and about 60 of the homes are occupied year-round. Fish are stocked in the lake. The lake has been treated with rotenone in the past for eliminating rough fish and will be treated again this year. In the opinion of the volunteer, the worst water quality problem in Phillips Lake is aquatic plant growth, which is the worst during the summer. The volunteer is concerned about possible water quality effects from motor boats and the increasing number of houses and people at the lake.

Phillips Lake -- Mason County

The volunteer noted bulkheads on most beaches and docks on most lots. Most of the lake bottom is covered with submerged weeds, although there are none on the surface. The volunteer stated that in 1989 most of the bottom of the lake is now mud and "grass;" according to the map completed for the questionnaire, "underwater grass" is now found on about 55% of the lake bottom. Water iris (probably *Iris pseudacorus*) is noted in a small area along the south shore, and about 40% of the shoreline is covered with natural vegetation brush. There are wetland areas near the outlet and the boat launch.

In October there was a water quality complaint stemming from 24-25 bait-filled nylon bags located off a residential dock. These were investigated by an Ecology inspector, and have since been removed. The volunteer reported an oil slick near the boat launch in January. Department of Game personnel took water samples and apparently did not find any problems.

Summary of Other Available Information

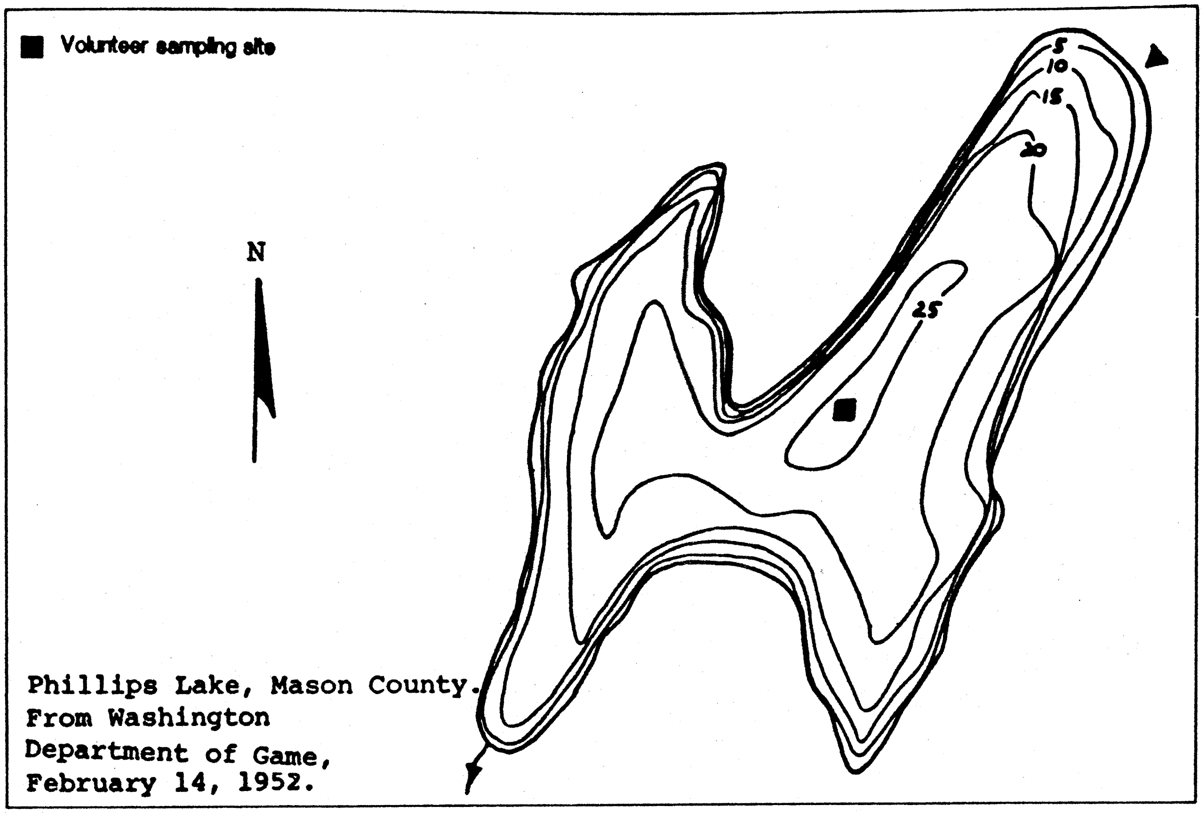
A 1970 (Funk *et al.*, 1972) survey of Phillips Lake showed Secchi disk transparency ranging from 10 to 20 feet, with lowest transparency occurring during May, June and November, 1970. A blue-green algal bloom was observed during October, 1970 (Funk *et al.*, 1972).

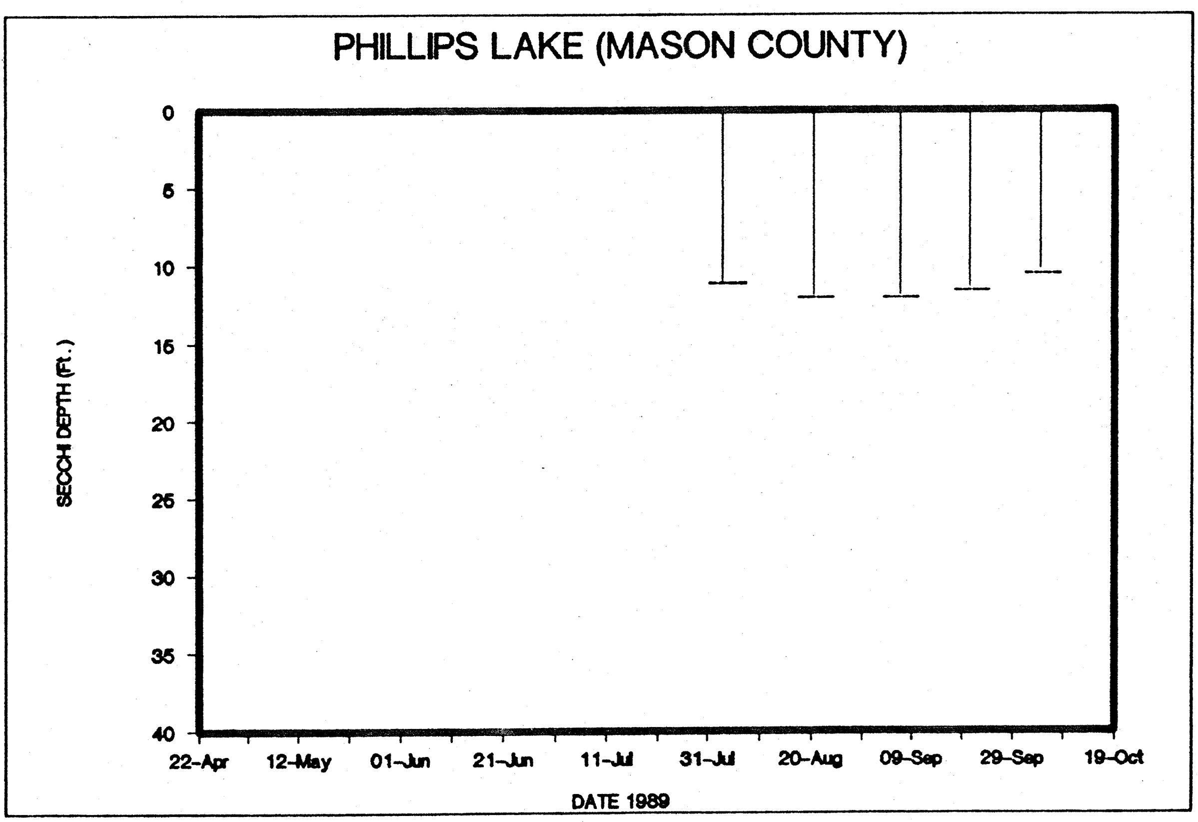
In 1972, Phillips Lake was likely to be oligo-mesotrophic because of Secchi disk transparency ranging from 12 to 16 feet, and concentrations of total phosphorus and chlorophyll *a* that ranged between the oligotrophic and mesotrophic ranges (Bortleson *et al.*, 1976a). Dissolved oxygen concentrations were high throughout the water column.

Residential development along the shore of Phillips Lake has increased since 1972; the USGS reported that in 1972 there were 125 nearshore homes (Bortleson *et al.*, 1976b). The amount of aquatic plants have also increased since 1972; very few rooted aquatic plants were growing on the sand and gravel littoral bottom of Phillips Lake were reported by Bortleson *et al.*, 1976b.

Comments

Compared with other lakes monitored for the program, the water quality of Phillips Lake is fairly good. Although most lakes in the program with a mean depth of less than 20 feet are mesotrophic or eutrophic, Phillips Lake is much clearer than most of the other shallower lakes. Although most other Mason County lakes in the program (Mason Lake, Lake Wooten, and Island Lake) are oligotrophic, these are deeper than 20 feet and fit the common tendency of being clearer. Tiger Lake in Mason County has a similar size, and maximum and mean depths as Phillips Lake. It also is used heavily by water skiing clubs. The water clarity at Phillips Lake is somewhat better than at Tiger Lake.


Volunteer sampling site
N
5
10
15
20
25
Phillips Lake, Mason County.
From Washington
Department of Game,
February 14, 1952.


PHILLIPS LAKE (MASON COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Lake Samish -- Whatcom County

Lake Samish is located 6.5 miles southeast from Bellingham. It is comprised of two basins which are connected by a narrow isthmus. The west arm is a small deep bay and the east arm is a larger shallow bay. There are several small inlets that flow into the lake, including Barnes Creek. Lake Samish drains via Friday Creek to the Samish River.

| | |
|---|---|
| Size (acres) | 814 |
| Maximum Depth (feet) | 140 |
| Mean Depth (feet) | 71 |
| Lake Volume (acre-feet) | 33,100 |
| Drainage Area (miles$^2$) | 3.70 |
| Altitude (feet) | 273 |
| Shoreline Length (miles) | 1.80 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 41 |

Volunteer - Collected Data

**Station 1**

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/22 | 1430 | Bl-Gr | P Sunny | 16.0 | 16.04* | East arm of lake is at second lowest level, on this date, in last ten years. |
| 06/07 | 0955 | Bl-Gr | Sunny | 20.0 | 16.96 | Lake level dropped 3" in last four days; hole ripped in beaver dam in Friday Creek. |
| 06/21 | 1045 | Bl-Gr | Cloudy | 16.5 | 15.58 | |
| 07/10 | 1015 | Green | Cloudy | 19.0 | 15.35 | |
| 07/26 | 1015 | Bl-Gr | Sunny | 21.5 | 10.54 | Water was surprisingly cloudy today. Murkier than we have seen this summer. |
| 08/10 | 1005 | Bl-Gr | P Cloudy | 21.0 | 9.17 | Lake is falling about 1/4" a day. |
| 08/25 | 1345 | Bl-Gr | P Sunny | 20.0 | 8.25 | |
| 09/07 | 1330 | Bl-Gr | Sunny | 20.0 | 11.00 | |
| 09/20 | 1000 | Bl-Gr | Sunny | 19.0 | 10.08* | |
| 10/04 | 0950 | Bl-Gr | Cloudy | 16.0 | 10.08 | Lake level at its lowest level so far this year. |

**Station 2**

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/22 | 1510 | Bl-Gr | P Sunny | 16.0 | 18.33 | Lake level down 1-5/8" since 5/15/89. Rainfall: 0.7+ inches since 5/15/89. |
| 06/07 | 1025 | Bl-Gr | Sunny | 19.0 | 18.56 | Lake level changing considerably due to rain and condition of beaver dam. |
| 06/21 | 1100 | Bl-Gr | Cloudy | 18.0 | 16.96 | |
| 07/10 | 1040 | Bl-Gr | Cloudy | 19.5 | 11.23 | Solid overcast. |
| 07/26 | 1030 | Bl-Gr | Sunny | 21.5 | 11.00 | Reading on 7/10 may not have been much affected by lack of sunlight as I expected. |
| 08/10 | 1035 | Bl-Gr | P Cloudy | 22.0 | 10.54 | |
| 08/25 | 1420 | Bl-Gr | Sunny | 20.0 | 10.08 | |
| 09/07 | 1413 | Bl-Gr | Sunny | 20.0 | 11.46 | |
| 09/20 | 1040 | Bl-Gr | Sunny | 19.0 | 12.37 | |
| 10/04 | 1020 | Bl-Gr | P Cloudy | 16.0 | 12.14 | |

*Limit for quality assurance test has exceeded for this data point.

Lake Samish -- Whatcom County

Volunteers established two sampling stations on the lake, at the deep site of each basin. Station 1 is in the larger east arm, and Station 2 is in the deeper west arm. The water clarity was generally a bit better in the deeper basin. Although the water clarity pattern was similar at both stations, it appears that algal growth at Station 2 began earlier and was more stable than at Station 1. Because flow from the lake is from west to east, it is possible that the flow carries algae and/or nutrients from the west basin to the east basin.

Summary of Questionnaire Results and Information From the Volunteers

The following is from the volunteers' remarks and questionnaire responses. Lake Samish is used for fishing, swimming, boating, jet skiing, picnicking, and hiking. There is a picnic area, parks, and a beach along the lakeshore. Motor boat use in nearshore areas is restricted. Lake water is withdrawn for drinking and other domestic uses. Currently the watershed is used for logging and agriculture (crops), and residential development along the lakeshore is occurring. In the past, the watershed was logged, mined, the lake was dredged, and the shoreline was altered. There are 227 houses on the lakeshore (plus another 175 in the watershed near the lake). All of the homes are occupied year-round, and all but two residences are sewered. There are "dozens" of storm drains draining to the lake. The worst water quality problems, in the opinions of the volunteers, are 1) weeds, 2) algal blooms (from early July through September), 3) lake level, 4) sediments suspended in the water, and 5) rough fish. According to the volunteers, tapeweed (identified by the Whatcom County Extension Service as *Vallisneria americana*) grows along the entire shoreline except for where the shoreline drops abruptly into deep water. It was first noticed by one of the volunteers in 1983 and has been spreading rapidly since. Cattails (*Typha*), small oval-pad lilies (possibly *Brasenia*) and large round pad lilies (possibly *Nymphaea odorata*) were mapped in shallower areas near Lake Creek, Wefer Creek, and Friday Creek. The volunteers noted that growth of a variety of weeds is rapidly spreading along the shoreline in water up to ten feet deep.

The volunteers were interviewed for an article printed in the Bellingham Herald on July 12, 1989. The article reported that the Lake Samish shoreline was sewered in 1976-77, and the volunteers commented that the lake water was clearer after the sewers were installed. Local residents are concerned about water quality effects from roadside spraying, potential spills along Interstate 5, and motor oil from boats.

Intensive Monitoring Results/Summary of Other Available Information

Because only one station per lake was sampled for the conventional parameter monitoring, the larger, more central east arm of Samish Lake was sampled by Ecology in 1989. The data collected confirm that Lake Samish is mesotrophic (Brower and Kendra, 1990). This estimation is based on the September data which show that concentrations of dissolved oxygen were depleted near the lake bottom. As a result, phosphorus may have been chemically reduced in the sediments and re-released into the water column. This is indicated by the increased conductivity and concentrations of total phosphorus and ammonia in the hypolimnion that were detected during September, 1989. An October 1968 survey described Lake Samish as oligotrophic, and concentrations of dissolved oxygen decreased, but were not depleted, near the bottom of the lake (Lee, 1969). Dissolved oxygen was depleted near the bottom of the lake in July 1971 (Bortleson *et al.*, 1974).

Compared with data collected by the USGS in 1971 (Bortleson *et al.*, 1976), nutrient concentrations in 1989 were very similar. Compared with other intensively monitored lakes, Lake Samish had high concentrations of nitrate/nitrite during June, and on both sampling dates, low concentrations of orthophosphorus. In 1971, 26-50% of the shoreline was covered by submerged plants, including *Vallisneria* (Bortleson *et al.*, 1974). Macrophyte coverage in Lake Samish appears to be increasing; in 1989 approximately 90% of the shoreline is covered by *Vallisneria americana.*

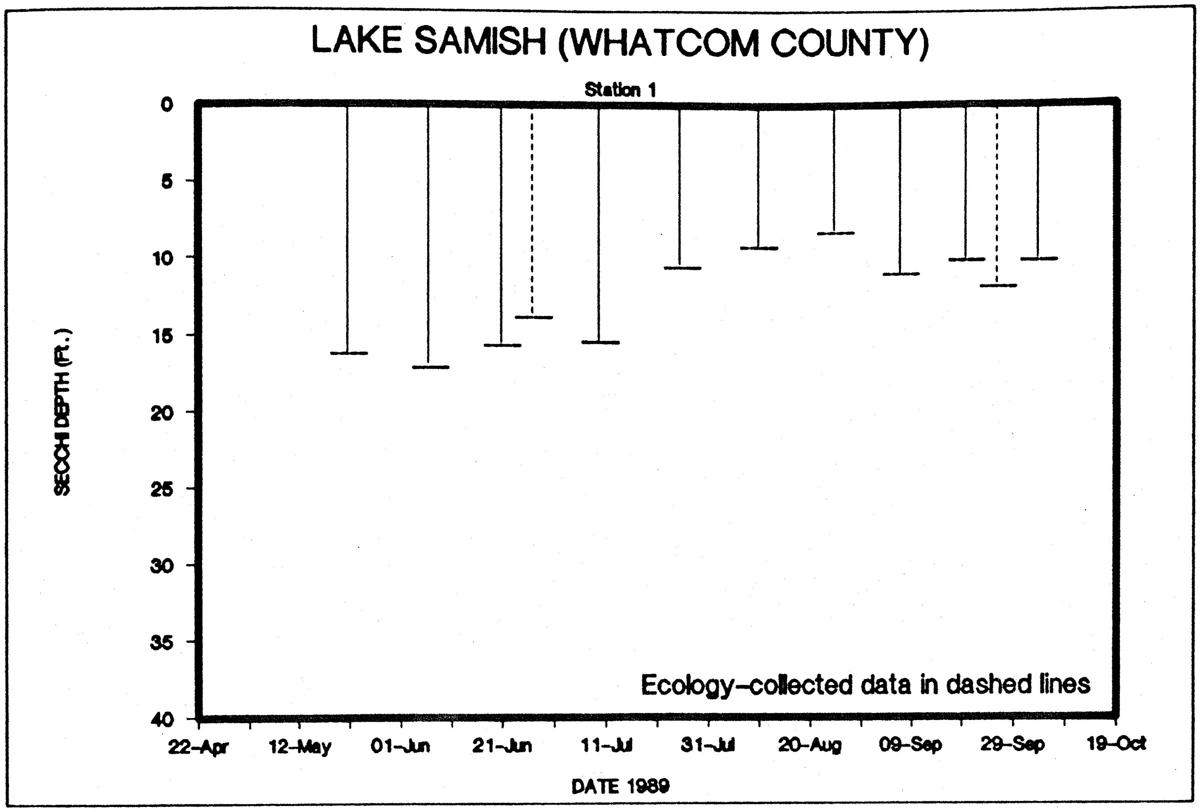
In 1989 Ecology staff collected sediment and largemouth bass samples from both basins, and analyzed the samples for selected heavy metals and organic pollutants. No unusual concentrations of metals and no organochlorine pesticides or PCBs were detected in the fish samples (Johnson and Norton, 1990). Sediments contained arsenic (21.0 mg/Kg), 4-methylphenol (1500 mg/Kg), and polyaromatic hydrocarbons (PAH; 81-110 $\mu$g/Kg). The concentrations found are not high enough to warrant further study. Possible sources of the 4-methylphenol are natural degradation biological material, auto exhaust, asphalt, and domestic sewage. The most likely sources of PAH are urban runoff and combustion of fossil fuels (Johnson and Norton, 1990).

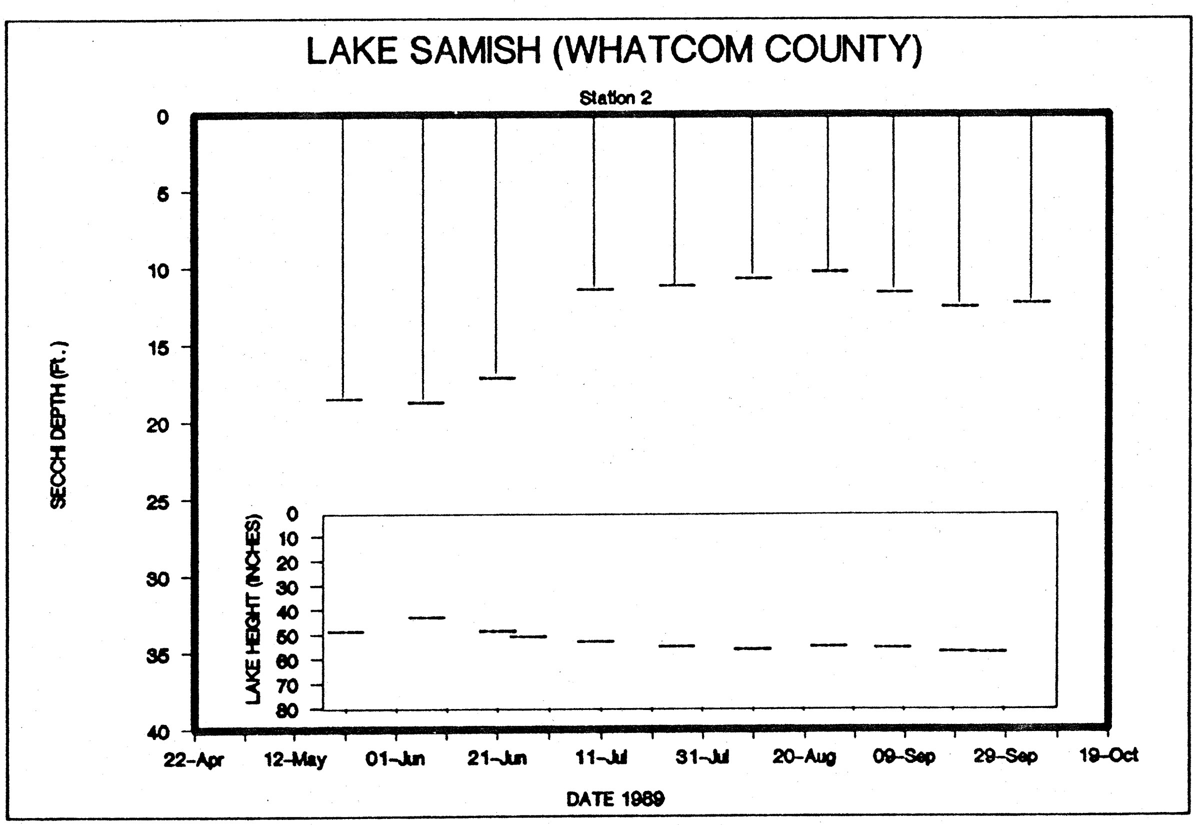
The Water Resources Program of Ecology has been monitoring the lake stage because of an ongoing controversy over water withdrawal permits. Residential development around the lake is currently limited by a lack of drinking water. The lake level is affected considerably by beaver dams.

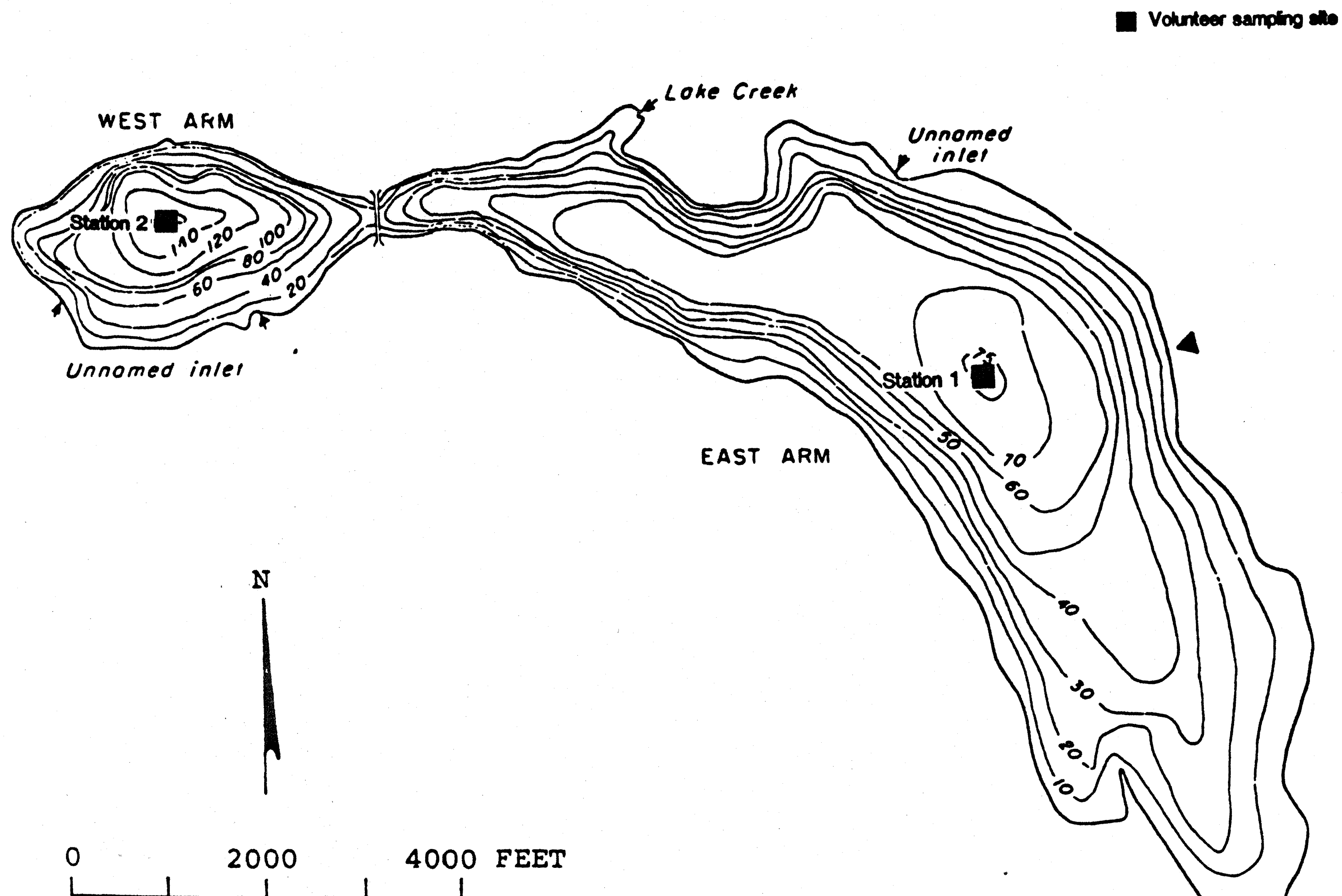
Residential development of the lakeshore has increased since 1954; in 1954, the USGS reported there were 142 nearshore homes (Bortleson *et al.*, 1974).

Comments

Compared with the other lakes monitored by volunteers, the water clarity of Lake Samish is good. However, the rapid colonization of aquatic plants reported by the volunteers warrants continued monitoring and documentation.


LAKE SAMISH (WHATCOM COUNTY)
Station 1
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed lines
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989


LAKE SAMISH (WHATCOM COUNTY)
Station 2
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
LAKE HEIGHT (INCHES)
0
10
20
30
40
50
60
70
80
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989




Lake Samish, Whatcom County

From Washington Department of Game, 1956.

Starvation Lake -- Stevens County

Starvation Lake is located 9.75 miles southeast from Colville, and 14.25 miles north from Chewelah. An outlet stream drains to the southeast and disappears into the ground. Approximately one-third of the lake is located in the Little Pend Oreille National Wildlife Refuge.

| | |
|---|---|
| Size (acres) | 30 |
| Maximum Depth (feet) | 14 |
| Mean Depth (feet) | 8 |
| Lake Volume (acre-feet) | 233 |
| Drainage Area ($miles^2$) | 3 |
| Altitude (feet) | 2375 |
| Shoreline Length (miles) | 0.88 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 43 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/15 | 1155 | Green | Sunny | 17.2 | 7.33 | Oil slicks in NW edge of lake. Power boats and grazing cattle are contaminating the water. |
| 05/30 | 1321 | Blue | Sunny | 15.0 | ** | Oil slick growing larger. Algae and lilies growing rapidly. Highest level in 3 yrs. |
| 06/15 | 1101 | Green | P Sunny | 21.0 | ** | Cattle grazing entire perimeter. Heavy water skiing use. Floating scum/algae |
| 07/01 | 1228 | Green | Cloudy | 20.5 | 11.00 | Water color dark green. |
| 07/17 | 1434 | Green | P Sunny | 25.0 | 11.00 | Aquatic growth matting on surface. Level down about 10". Cattle causing erosion. |
| 07/30 | 1343 | Brown | P Cloudy | 22.8 | 10.08 | Cattle are destroying the shoreline and nearshore trees, and are contaminating the lake. |
| 09/04 | 1245 | Green | P Cloudy | 20.0 | 11.92 | |

** Secchi hit bottom

Secchi disk readings and volunteer remarks indicate that algal growth affected water clarity during early May and July. Low water clarity in May was likely the result of a spring algal growth occurring after the lake thawed; spring algal blooms occurred in many other higher elevations in Eastern Washington lakes monitored for the program.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Starvation Lake is used for fishing, swimming, boating, picnicking, camping, hiking, and is a hunting base camp. There is a picnic area and a camping area along the lakeshore. There are no restrictions on motor boat use. Currently the watershed is used for logging and animal grazing. In the past, the lake was dredged and the shoreline was altered. There are five houses on the lakeshore; all are on septic systems, and four are occupied year-round. Starvation Lake was treated in 1985 with rotenone to eliminate rough fish. The worst water quality problems, in the opinion of the volunteer, are 1) cattle wastes, 2) weeds, 3) garbage, debris, cans, bottles, 4) algal blooms, and 5) suspended sediments in the water. The problems are worst from May through September. The volunteer is also concerned about motor boat use in the lake.

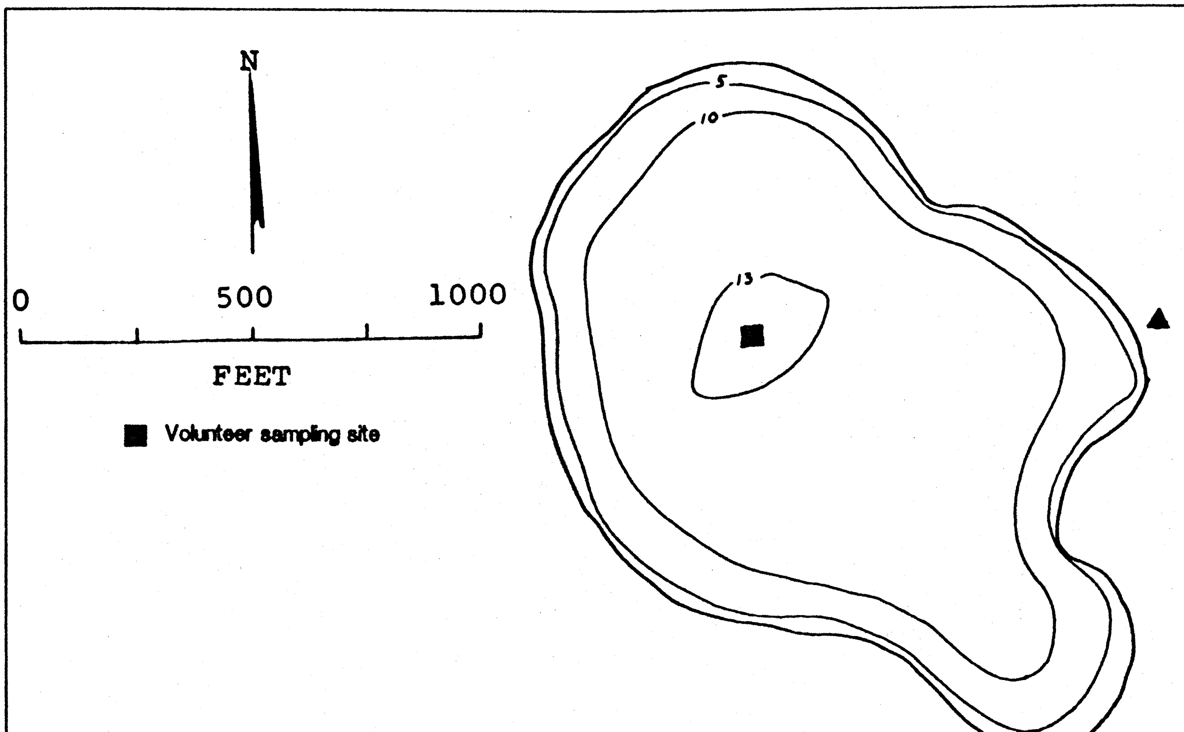
Much of the shore near the outlet is a wetland. Lily pads grow along the entire shoreline in areas up to ten feet deep, and submerged weeds cover about 15% of the lake bottom in water 10 to 13 feet deep. Plant growth in the boat ramp area is probably controlled by boat traffic. Cattails grow along the southeast end of the lake near the wetland and extend further out, covering about 30% of the shoreline.

## Summary of Other Available Information

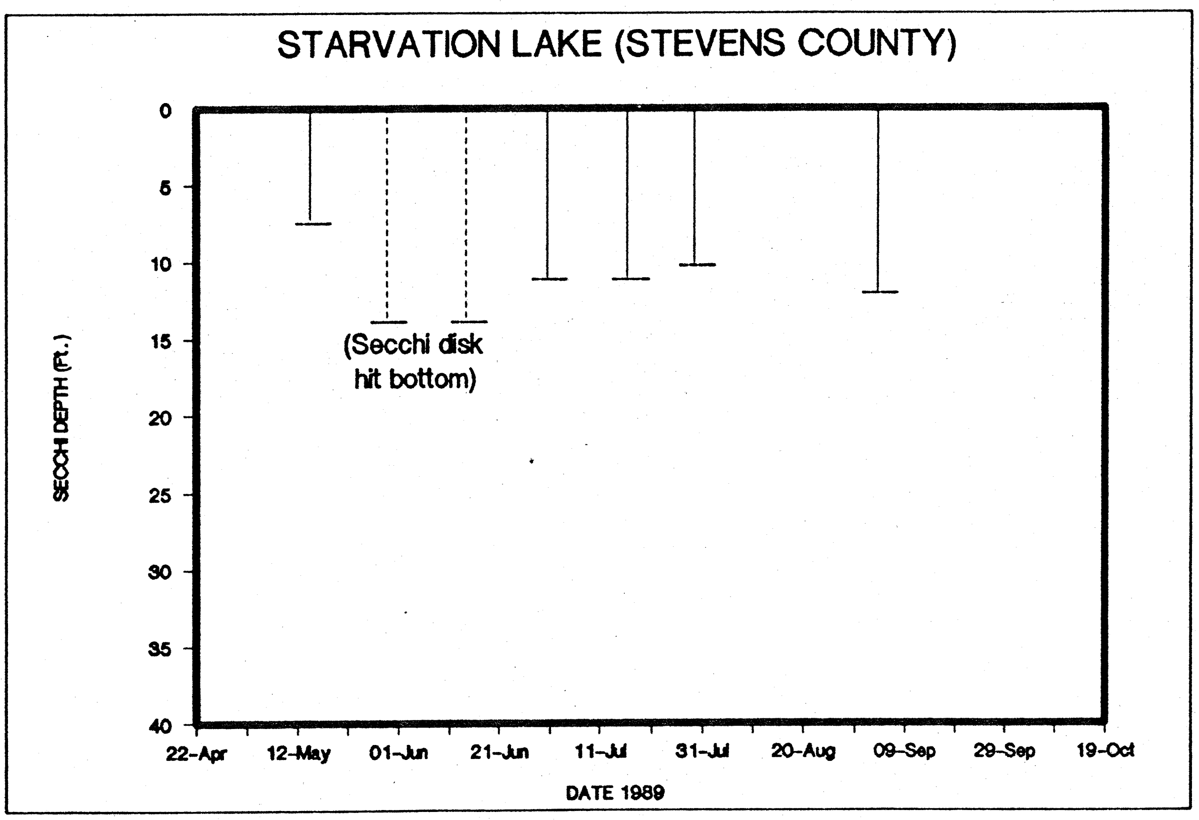
Data collected by the USGS in 1974 (Dion *et al.*, 1976) are similar to 1989 Starvation Lake data. In 1974, the Secchi depth was reported as " greater than 13 feet," indicating that the Secchi disk either hit the lake bottom or disappeared in a bed of aquatic plants. About 76-100% of the shoreline was covered with dense beds of emergent aquatic plants (yellow lily, sedge, and cattail), and the lake bottom was completely covered with *Chara*, a submersed aquatic plant. Algal growth was noted to be moderately high. The concentrations of total phosphorus was very high, and indicate that Starvation Lake is probably eutrophic. Also noted was that the lake is periodically aerated to raise dissolved oxygen concentrations (Dion *et al.*, 1976).

## Comments

Compared to other lakes monitored for the program, the water clarity of Starvation Lake was average. There were 22 lakes in the program that had worse average water clarity. However, of the six lakes in Steven County that were monitored for the program (Deep Lake, Deer Lake, Starvation Lake, Loon Lake, Thomas Lake, and Black Lake), Starvation Lake was the smallest, shallowest, and had the worst average water clarity.




Starvation Lake, Stevens County. From Washington Department of Game, January 28, 1947.



Lake St. Clair -- Thurston County (North Arm)

Lake St. Clair is located 6.5 miles northwest from Yelm. It is an irregularly shaped lake with steep sides, numerous narrow arms and four small islands. The lake is fed by Eaton Creek and drains to the Nisqually River. The south arm of Lake St. Clair is a deep conical-shaped depression.

| | |
|---|---|
| Size (acres) | 180 |
| Maximum Depth (feet) | 70 |
| Mean Depth (feet) | 28 |
| Lake Volume (acre-feet) | 5100 |
| Drainage Area (miles$^2$) | 6.40 |
| Altitude (feet) | 73 |
| Shoreline Length (miles) | 7.50 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Mean Trophic State Index: | 46 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/12 | 1230 | Rust | P Sunny | 17.0 | 4.58 | Water is clear but dark; little or no algae. |
| 05/30 | 1330 | Brown | P Cloudy | 19.0 | 5.50 | Same conditions as last report. |
| 06/25 | 1215 | Brown | Sunny | 25.0 | 6.87 | Temp is about 7 degrees warmer. |
| 07/22 | 1230 | Rust | Sunny | 21.0 | 9.17 | Windy - surface rough. |
| 08/08 | 1530 | Rust | Sunny | 26.0 | 10.08 | Temp taken approx 18 to 20" below surface. |
| 08/22 | 1230 | Brown | P Cloudy | 21.0 | 8.25 | Lake level is quite low. Dark day; water appears quite clear. |
| 09/10 | 1300 | Rust | Sunny | 21.0 | 7.79 | A small trace of algae in the water. |
| 09/19 | 1100 | Brown | Sunny | 19.0 | 9.17* | |
| 10/03 | 1145 | Brown | Sunny | 18.0 | 8.25* | An algae bloom on top, small grey-green particles. |

* Limit for quality assurance test was exceeded for this data point.

The Secchi readings were taken in the north arm, near the public access area. The water clarity was lowest during May, September and October, indicating that spring and fall algal growth affected water clarity. The water color was noted as rust or brown throughout the sampling period.

Summary of Questionnaire Results and Information from the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Lake St. Clair is used for fishing, swimming, boating, and jet skiing. There are two boat ramps, and except for the main part of the lake, there is a speed limit of 5 mph for motor boats. Water is withdrawn for drinking and other domestic uses. Currently the watershed is used for agriculture (both crops and animal grazing) and the lakeshore is being developed further for residences. In the past, the watershed was logged, and there is a large fill where the bridge crosses on Peninsula Drive. There are about 450 houses on the lakeshore; all are on septic systems and about 90%

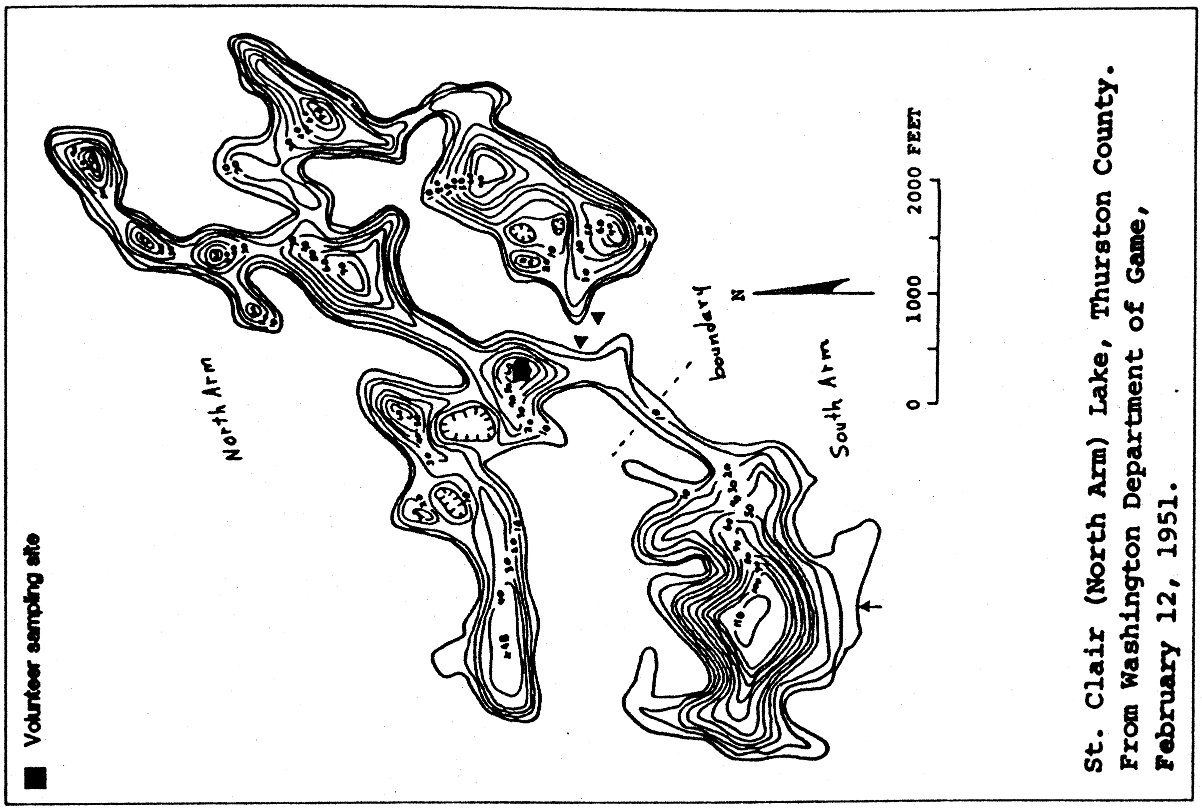
of the houses are occupied year-round. Fish are stocked in the lake. There is a wetland area near the southern inlet. The worst water quality problems identified by the volunteer are weeds (in some areas) and the lake level. According to the volunteer, the lake level was unusually low in August, and the passage under the bridge is too shallow for some boats to navigate through. Most of the aquatic plants grow in the larger and shallower embayments and near the islands. The volunteer is concerned about possible water quality effects from agricultural and road runoff, older septic systems, lakeshore development, and logging.

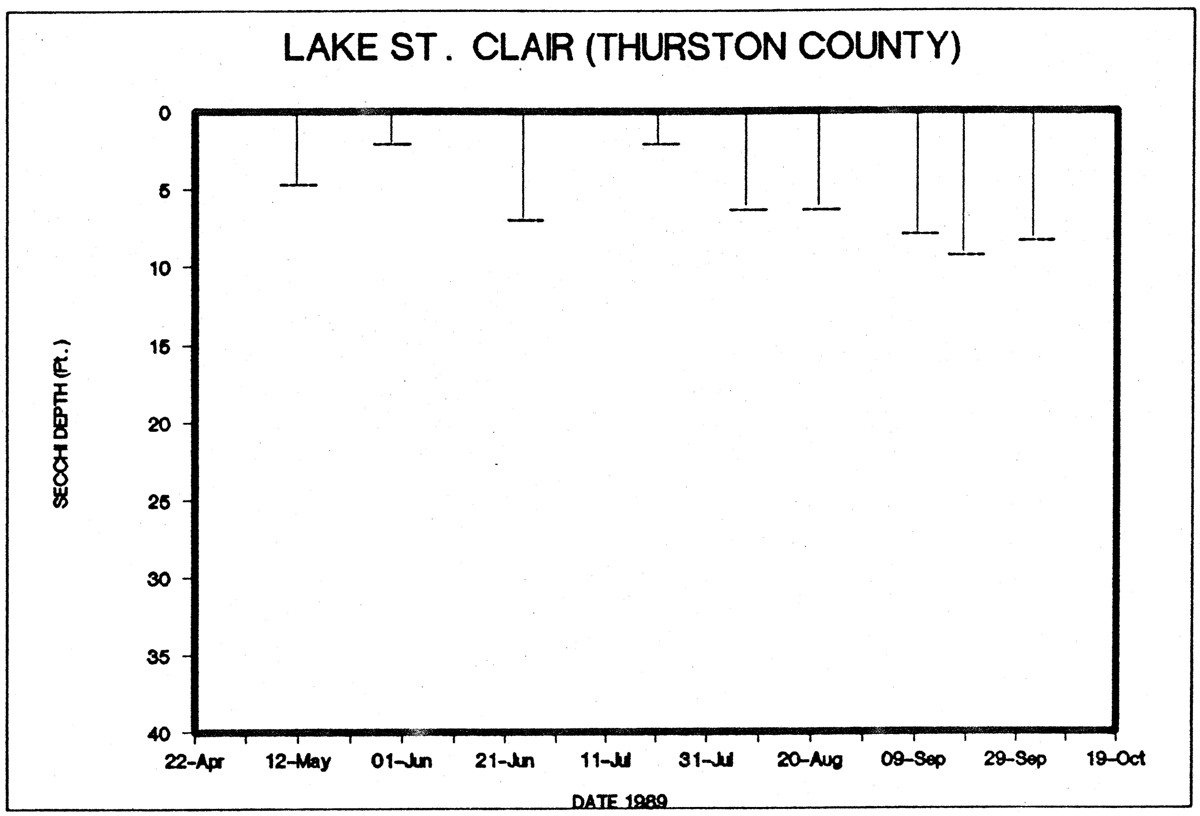
## Summary of Other Available Information

Total phosphorus, chlorophyll *a*, and Secchi disk transparency data collected from Lake St. Clair in 1972 (Bortleson *et al.*, 1976) indicate that in 1972 Lake St. Clair was mesotrophic. Total phosphorus and Secchi disk transparency data collected in 1981 (Sumioka and Dion, 1985), however, indicate that the lake was eutrophic and approaching hypereutrophy. Since Secchi disk readings collected during 1989 are characteristic of mesotrophic lakes, it may be necessary to confirm the trophic state of the lake using chemical data.

## Comments

The water clarity of Lake St. Clair is comparable to other lakes monitored for the program with a relatively long shoreline length. Considering the dense residential development around some parts of the lake and the agricultural use of part of the watershed, the water clarity of Lake St. Clair is fairly good.


Volunteer sampling site
North Arm
South Arm
boundary
N
0
1000
2000 FEET
St. Clair (North Arm) Lake, Thurston County.
From Washington Department of Game,
February 12, 1951.


LAKE ST. CLAIR (THURSTON COUNTY)
SECCH DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Lake Steilacoom -- Pierce County

Lake Steilacoom is located three miles east from Steilacoom. It is an urban lake fed by Clover Creek and Ponce de Leon Creek, and drains via Chambers Creek to Puget Sound.

| | |
|---|---|
| Size (acres) | 320 |
| Maximum Depth (feet) | 20 |
| Mean Depth (feet) | 11 |
| Lake Volume (acre-feet) | 3500 |
| Drainage Area (miles$^2$) | 89.4 |
| Altitude (feet) | 210 |
| Shoreline Length (miles) | 5.70 |

| | |
|---|---|
| Estimated Trophic State: | eutrophic |
| Mean Trophic State Index: | 52 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/27 | 1130 | Brown | P Cloudy | 17.0 | 3.67 | Water smells fishy. |
| 06/11 | 1400 | Green | Sunny | 23.0 | 6.42 | Last week of May, 4 dead suckers washed to shore in various stages of decay. |
| 06/24 | 1300 | Green | Sunny | 23.0 | 7.33 | Snail bloom, floating about 1 every 20 ft. |
| 07/08 | 1130 | Green | P Cloudy | 21.0 | 9.62 | Snail bloom gone. Water clear greenish - best it's been yet. |
| 08/26 | 1130 | Green | P Sunny | 22.0 | 3.44 | |

The water clarity increased from May through early July. This increase may have resulted from the copper sulfate that was applied on June 17th to control algae growth. Unfortunately, there is a gap in the data from July through August. More regular readings might have shown the immediate response of the algae to the copper sulfate treatment, as well as how long the treatment was effective. The snail bloom noted by the volunteer on June 24, 1989 was likely dead snails killed by copper sulfate.

Summary of Questionnaire Results and Information from the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Lake Steilacoom is used for fishing, swimming, boating, and jet skiing. There is a length restriction for motor boats, and jet boats are not allowed on the lake. The lake water is used by a salmon hatchery downstream from the lake. Currently the watershed is used for industrial development and the nearby McChord airstrip, and the lakeshore is being developed for residences. The lake has been dredged in the past. There are about 330 houses on the lakeshore; all are occupied year-round, and the lakeshore is fully sewered. The lake is chemically treated almost every year to control weeds, algae and snails which carry the swimmer's itch parasite. Copper sulfate is the predominate treatment chemical used. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are 1) algal blooms (mainly during June and July), 2) weeds (mainly during August), and 3) suspended sediments in the water. The volunteer suggested that water quality may be affected by runoff, and that water clarity may be affected by motor boats.

Following the copper sulfate treatment of the lake on June 18th, the volunteer noted a "snail bloom, floating about 1 every 20 feet" on June 24th, and later that the ". . . snail bloom had gone about 2 days after (the) 6/24 reading. Water (is) clear greenish - best it's been yet."

Results of Intensive Monitoring/Summary of Other Available Information

Intensive monitoring during 1989 confirm that Lake Steilacoom is eutrophic, as determined by low Secchi disk transparency and relatively high epilimnetic concentrations of total phosphorus and chlorophyll *a* (Brower and Kendra, 1990). Because of heavy algae growth in the lake, the water color was green and the Secchi disk readings were very low on both sampling dates. The increase in dissolved oxygen at 3.5 meters during June indicate there was increased algal growth at this depth. Because algae cannot always thrive in the intense light at the surface of the water and nutrients are usually more abundant nearer the hypolimnion, algal blooms often occur at lower depths during the summer.

High concentrations of total nitrogen and nitrate-nitrogen during June declined by September, whereas the concentrations of chlorophyll *a* and total phosphorus approximately doubled from June to September. A comparison of the concentrations of total nitrogen and total phosphorus show that phosphorus may have been limiting during June and nitrogen may have been limiting during September (note that "limiting" refers to whichever nutrient will limit the growth of algae, since both nitrogen and phosphorus need to be available for algae to grow).

Nutrient data collected by the USGS in 1971 (Bortleson *et al.*, 1976) and 1981 (Sumioka and Dion, 1985) were similarly high, although concentrations of most nutrients were slightly lower in 1989 than during the 1981 and 1971 studies. However, dissolved oxygen concentrations at the bottom of the lake were much lower in 1989 than in 1971 and 1981. In July, 1971 the dissolved oxygen concentrations were relatively high (greater than 10 mg/L) at the top and the bottom of the lake, whereas in 1981 dissolved oxygen concentrations were greater than 10 mg/L at three feet and 5.0 mg/L at 16 feet. In 1989 dissolved oxygen concentrations at the bottom of the lake were 3.5 mg/L in June, and 0.5 mg/L in September. Oxygen depletion results from the bacterial decomposition of organic material (such as plants and algae).

Ecology collected one sediment sample in 1989 from the north basin to screen the lake for copper contamination. The copper concentration was extremely high (1010 mg/kg) when compared to concentrations of 20 - 50 mg/kg found in most of the other nine lakes sampled in 1989 (Johnson and Norton, 1990). The high concentration of copper in the single sediment sample and the history of copper sulfate treatments in Lake Steilacoom warrants additional study to evaluate potential adverse biological effects on benthic invertebrate populations. A study by Ecology has been planned for 1990.

Lake Steilacoom -- Pierce County

A report to the residents and members of the Lake Steilacoom Lake Improvement Club report also mentions that the lake has been treated since 1955, but has been treated with the "present treatment" (presumably, copper sulfate) for the past 15 years (Report of the Steilacoom Lake Improvement Club, Inc., June 1989).

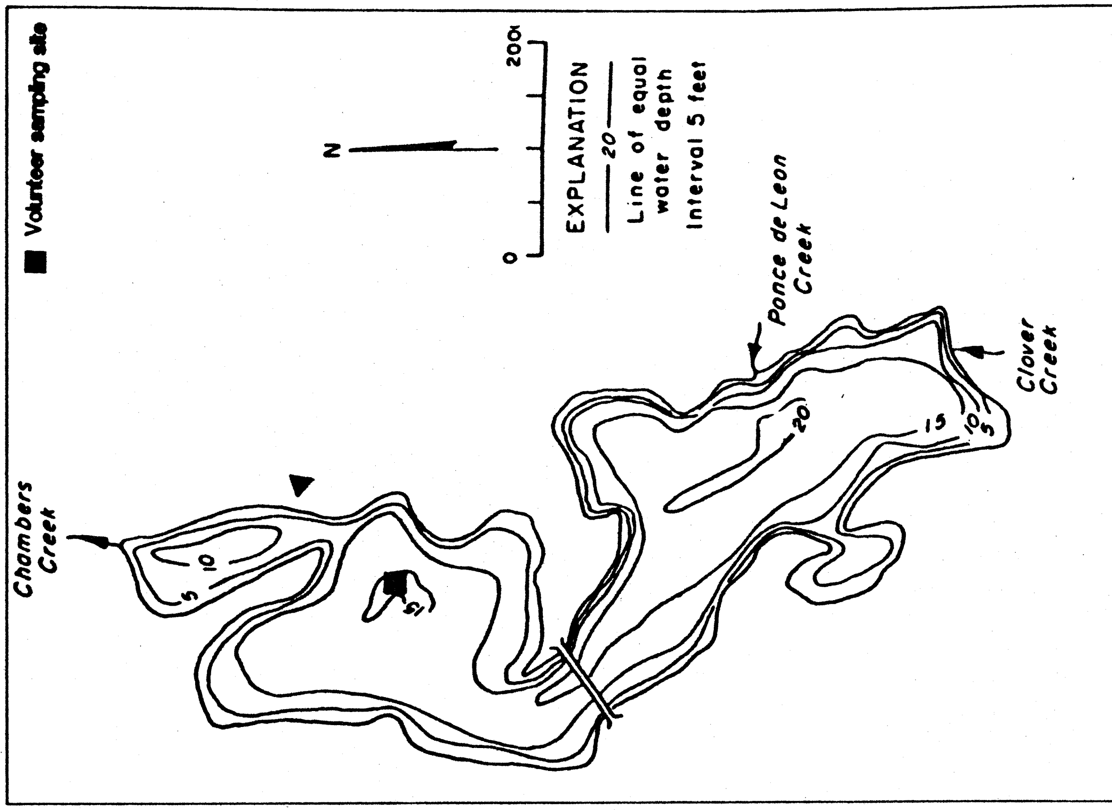
There have been various unusual observations at the lake, some of which have resulted in complaints being filed with Ecology. On August 31, 1989, following a copper sulfate treatment, about 12 fingerlings were reported dead, presumably due to high pH and temperatures. Also noted was a foam on the lake on July 28-29, 1989, following which a brown sludge was reported on the sediments to about 20 feet from shore. Ecology was also criticized for not following up on a complaint about Clover Creek (3 feet of foam was reported in the creek).

Residential development of the lakeshore has increased since 1971; the USGS reported there were 285 nearshore homes in 1971 (Bortleson, *et al.*, 1976).

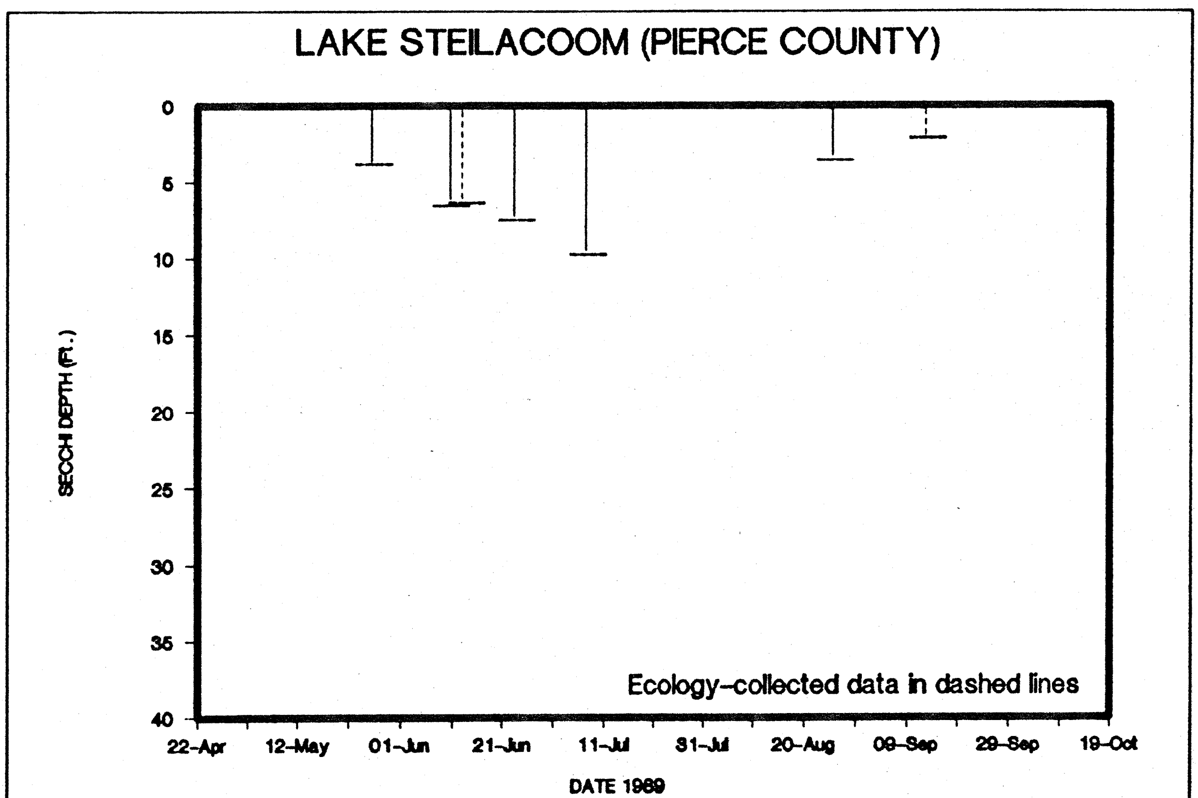
Comments

Compared with other lakes monitored for the program, the water quality of Lake Steilacoom is poor. Despite chemical treatment to control algae, the water clarity is low. Aquatic plants were also treated later in the summer which would cause nutrients to be released into the water as the plants died. This can result in secondary algal growth and may explain the decrease in water clarity from late August through September. Long Lake in Thurston County has a similar size, and maximum and mean depths as Lake Steilacoom, and is also divided into two basins by a narrow channel. Long Lake does not receive urban runoff, although it does receive residential runoff, and does not experience extreme algal blooms. The water clarity at Long Lake is much better than at Lake Steilacoom, most likely due to different activities within the watersheds.

Although copper sulfate treatment has been the method choice for controlling algae in Lake Steilacoom, long-term use has many disadvantages. Research has shown that five lakes in Minnesota treated with copper sulfate for 58 years sustained many undesirable side effects as a result of the treatments (Hanson and Stefan, 1984). Dissolved oxygen depletion, copper accumulation in the sediments, shifts in algae species to those more tolerant of higher copper sulfate concentrations (and shifts from green algae species to more undesirable blue-green species) and reductions in benthic macroinvertebrates were among the documented effects. These effects may have already occurred in Lake Steilacoom, and should be investigated further. Alternative lake management options should be explored. Management options may include nutrient source controls (to reduce stormwater and other runoff) and controlling internal recycling of phosphorus from sediments. Application for a grant from Ecology's Centennial Clean Water Fund is strongly recommended to partially fund lake restoration.




Steilacoom Lake, Pierce County. From Washington Department of Game, June 2, 1950.



Sullivan Lake -- Pend Oreille County

Sullivan Lake is located 4.3 miles southeast from Metaline Falls. It is a natural lake that was enlarged by a dam built in Harvey Creek in 1931. The lake is 3.55 miles long and averages 0.6 miles in width. Sullivan Lake drains to Sullivan Creek and the Pend Oreille River. There are campgrounds at both the north and south ends of the lake.

| | |
|---|---|
| Size (acres) | 1380 |
| Maximum Depth (feet) | 332 |
| Mean Depth (feet) | 193 |
| Lake Volume (acre-feet) | 267,000 |
| Drainage Area (miles$^2$) | 51.20 |
| Altitude (feet) | 2583 |
| Shoreline Length (miles) | 8.89 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 30 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/30 | 1212 | Green | Sunny | 12.5 | 22.46 | Very calm day. |
| 05/14 | 1305 | Green | P Sunny | 13.0 | 16.50 | Surface a little rough. Much pine pollen on water and woody debris in water. |
| 05/30 | 1240 | Green | Sunny | 14.0 | 16.27 | Calm and sunny. |
| 06/13 | 1205 | Green | P Cloudy | 22.0 | 19.25 | Bright overcast sky. Much pollen on water. |
| 06/26 | 1355 | Green | P Cloudy | 19.5 | 19.02 | South wind 15 - 25 mph. Some whitecaps. |
| 07/11 | 1230 | Green | P Sunny | 21.5 | 26.58 | Bright calm day. No wind or waves. |
| 07/25 | 1115 | Green | Sunny | 24.0 | 27.50 | Very slight ripple on water. Wind about 3 mph. Clear sky with slight haze. |
| 08/10 | 1305 | Green | Sunny | 23.0 | 35.29 | Bright calm day. Over 2 inches rain in last 1-1/2 days. |
| 08/23 | 1250 | Bl-Gr | P Cloudy | 16.0 | 29.33 | Hazy sun. North wind 5 - 10 mph. Some waves 6 - 8 in. high. |
| 09/04 | 1107 | Green | Sunny | 19.5 | 33.46 | Calm. Wind 2 - 3 mph. Water smooth. |
| 09/19 | 1250 | Green | P Cloudy | 16.0 | 26.58 | Wind 10 - 15 mph, a few whitecaps. |
| 10/02 | 1350 | Green | Sunny | -- | 30.25 | Wind 5 to 10 mph. Slight chop. |

The water clarity was lowest during May and increased in general throughout the summer. Low water clarity during May was documented at many other high elevation lakes in Eastern Washington that were monitored for the program. Spring algal growth, and possibly pine pollen, decreased the water clarity during the spring. Noticeable decreases in water clarity during August and September may be due to algal growth, but are more likely due to poor visibility in choppy water.

Summary of Questionnaire Results and Information from the Volunteer

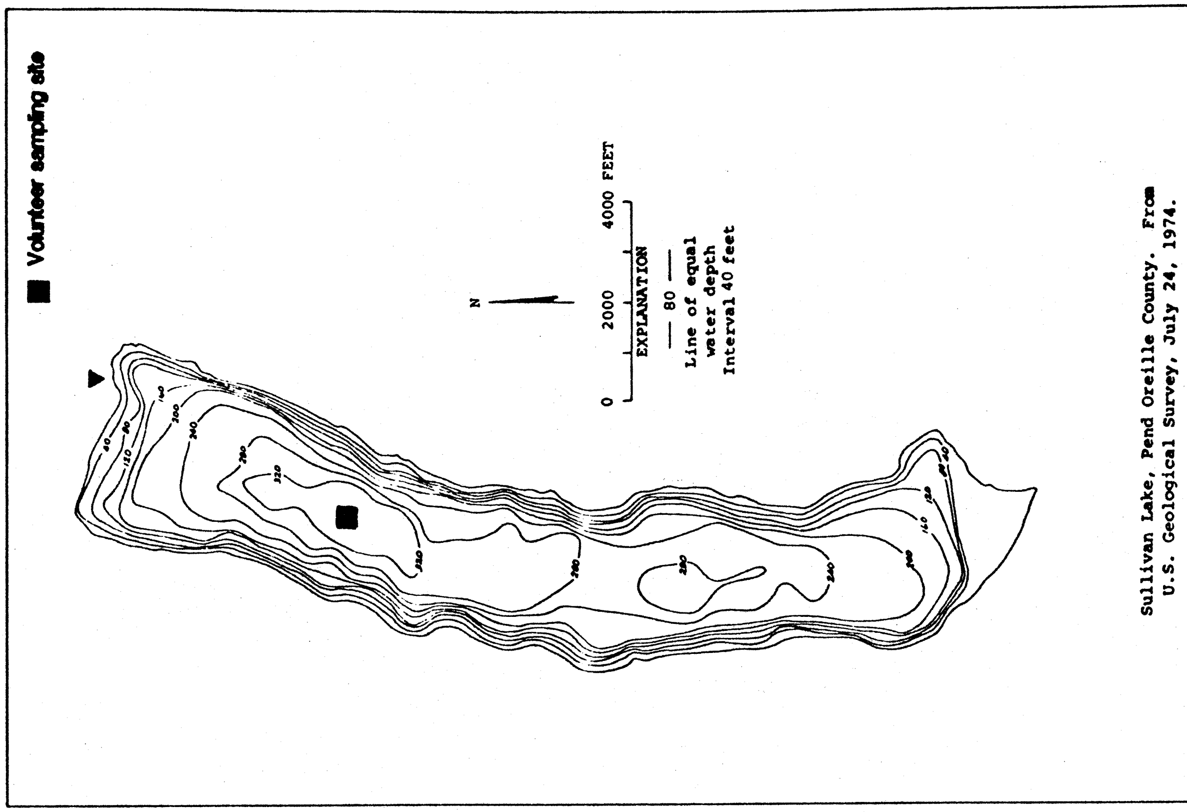
The following is from the volunteer's remarks and questionnaire responses. Sullivan Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a picnic area, camping area, two boat ramps, and a beach along the lakeshore. The lake water is used for hydroelectric power generated for Seattle City Light. Currently the watershed is used for logging and a small amount of animal grazing, and some residential development is occurring on the lakeshore. In the past, the watershed was mined and logged. There are 16 houses on the lakeshore; all are on septic systems. There are no wetlands associated with the lake, fish are not stocked, and at present the volunteer reports no water quality problems in the lake.

## Summary of Other Available Information

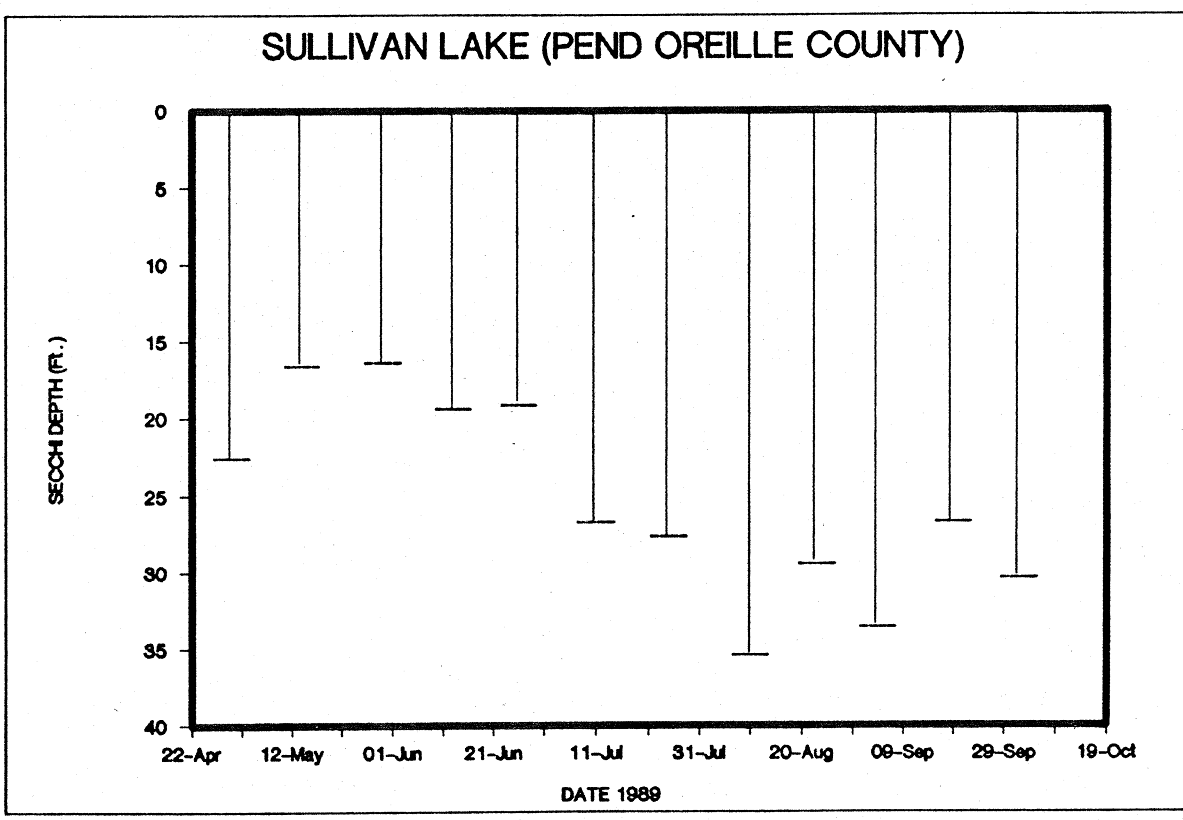
Data collected by the USGS during 1974 (Dion *et al.*, 1976), are similar to data collected during 1989. In 1974, nutrient concentrations were very low, Secchi disk transparency ranged from 16 to 21 feet, and no aquatic plants were observed (Dion *et al.*, 1976).

## Comments

Compared with other lakes in the program, Sullivan Lake is very clean and clear. Crescent Lake in Clallam County was the only lake monitored for the program that was clearer than Sullivan Lake. The mean Secchi disk value for Crescent Lake was 72 feet, compared to 25.2 feet in Sullivan Lake.




Sullivan Lake, Pend Oreille County. From U.S. Geological Survey, July 24, 1974.



Summit Lake -- Thurston County

Summit Lake is located in a steep forested valley nine miles west from Olympia. It is two miles long. It is fed by intermittent streams, seeps and springs, and drains via Kennedy Creek to Oyster Bay in Totten Inlet.

| | |
|---|---|
| Size (acres) | 530 |
| Maximum Depth (feet) | 100 |
| Mean Depth (feet) | 53 |
| Lake Volume (acre-feet) | 28,000 |
| Drainage Area (miles$^2$) | 2.82 |
| Altitude (feet) | 500 |
| Shoreline Length (miles) | 5.61 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 31 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/31 | 1350 | Green | P Sunny | -- | 31.62 | Wind 10 mph+ from east. No sun at time of readings. |
| 06/27 | 1105 | Green | P Sunny | -- | 22.00 | Wind 5 mph. |
| 07/09 | 0945 | Green | Sunny | 19.0 | 22.00 | Calm. |
| 07/24 | 1150 | Green | Sunny | 21.0 | 22.00 | Wind SW 5 mph. |
| 08/06 | 0940 | Green | Sunny | 21.5 | 22.46 | Calm/clear. |
| 08/26 | 1100 | Green | Sunny | 21.0 | 29.33 | Wind east 5 mph. Many small suspended particles. |
| 09/04 | 1100 | Green | Sunny | 20.0 | 27.50 | East wind 5 mph. No small particles in suspension. |

The water clarity was highest during late May, and was stable from June through early August. Algae do not appear to grow to bloom portions in Summit Lake.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Summit Lake is used for fishing, boating, swimming, jet skiing, picnicking, camping, and hiking. There are two boat ramps on the lakeshore, and there are speed restrictions and time restrictions for motor boating. Lake water is withdrawn for drinking and other domestic uses, and for irrigation. Currently the watershed is logged and is used for animal grazing. In the past, the watershed was logged and the shoreline was altered. There are about 400 houses on the lakeshore; all are on septic systems and about 200 of the houses are occupied year-round. The lake has been chemically treated in the past with rotenone to remove rough fish, and presently fish are stocked in the lake. Homeowners harvest aquatic plants from their lakeshore areas. There are wetlands associated with the lake. The worst water quality problems, in the opinion of the volunteer, are 1) fecal coliform bacteria levels, and 2) lake level. The problems are worst during the winter months. The volunteer is concerned about possible water quality effects from septic systems and storm runoff. A Lake Management District has been formed.

Summit Lake -- Thurston County

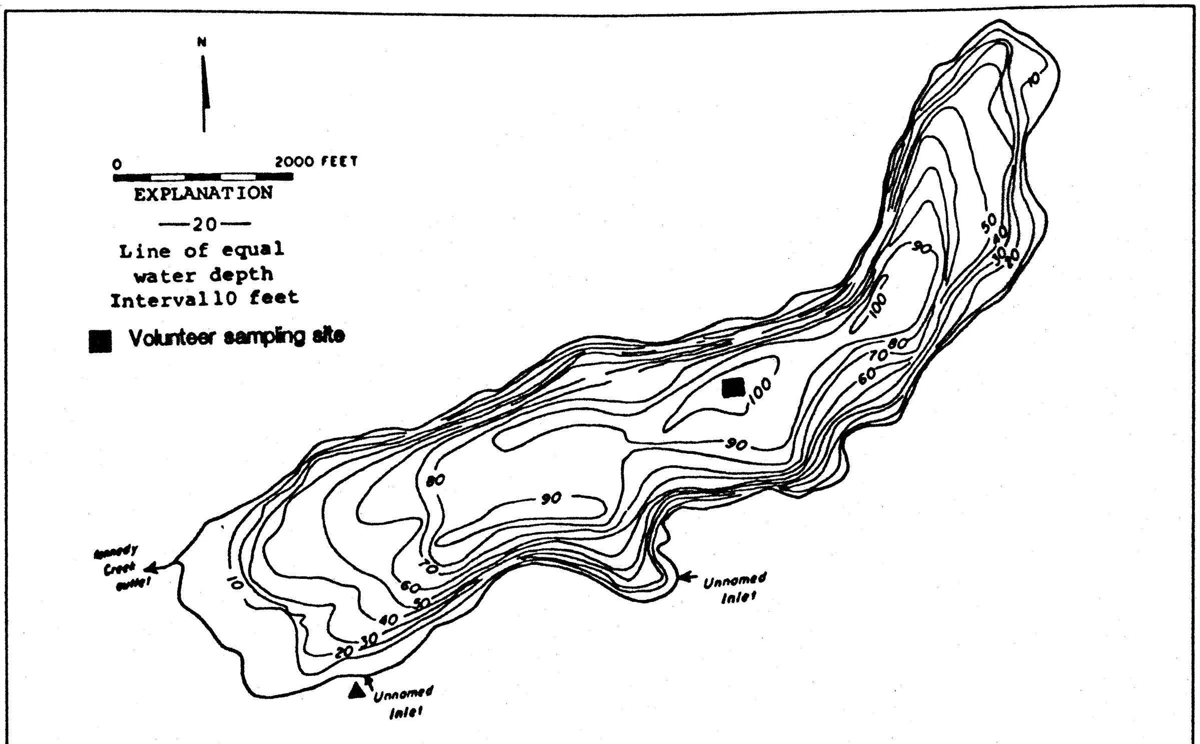
Results of Intensive Sampling/Summary of Other Available Information

Intensive monitoring data collected during 1989 confirm that Summit Lake is oligotrophic, based on high Secchi disk transparency and relatively low epilimnetic concentrations of total phosphorus and chlorophyll *a*. The only water quality concern appears to be the near depletion of dissolved oxygen concentrations near the bottom of the lake during September; oxygen is depleted by the bacterial decomposition of organic material (such as algae, aquatic plants, and woody debris). Low dissolved oxygen concentration (less than 1 mg/L) were also detected near the bottom of the lake in 1968 (Lee, 1969). Secchi disk transparency and nutrient data collected by the USGS in 1971 (Bortleson *et al.*, 1976) were similar to data collected during 1989. The Thurston County Health Department will begin collecting water samples in 1990 from the inlet, outlet, and in-lake from the deep site in-lake to determine nutrient loading to the lake.

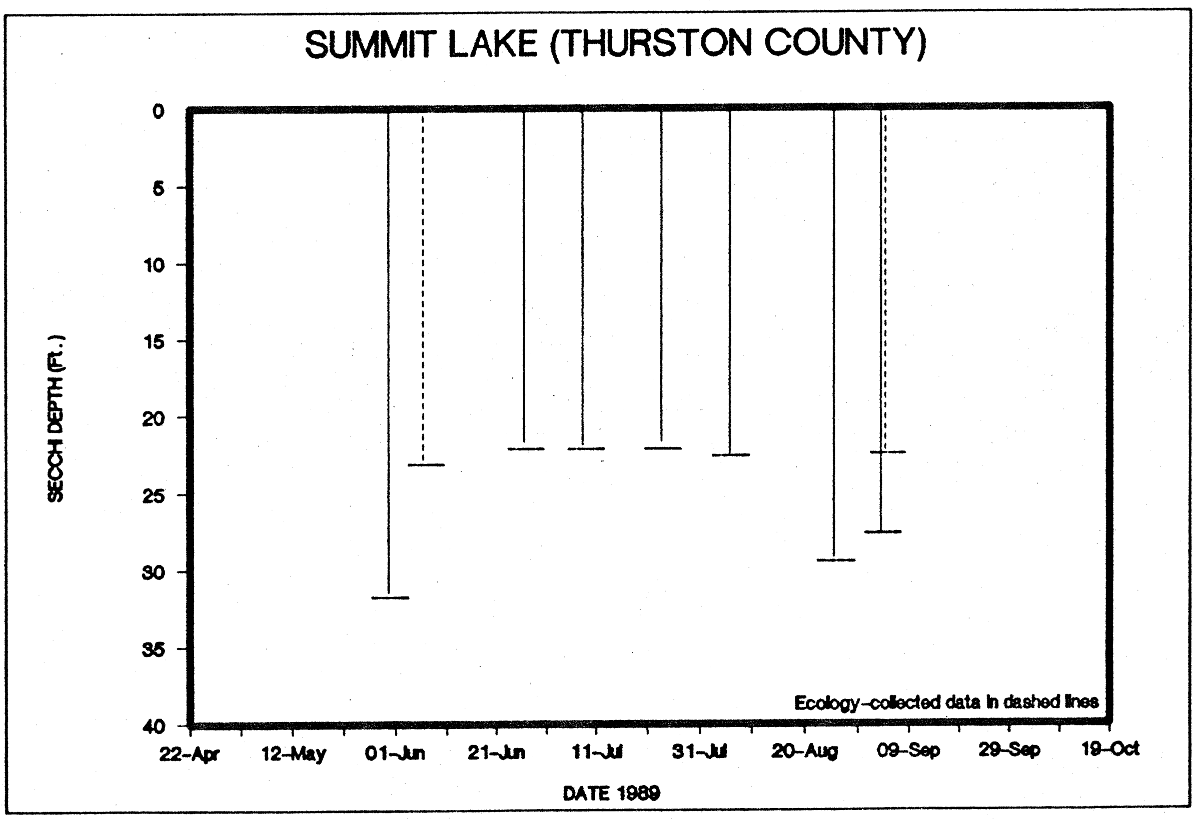
Residential development of the lakeshore has increased since 1971; the USGS reported there were 290 nearshore homes in 1971 (Bortleson *et al.*, 1976).

Comments

Compared with other lakes monitored for the program, Summit Lake had low nutrient concentrations and very good water clarity. Of the Thurston County lakes monitored for the program (Black Lake, Clear Lake, Long Lake, Lake St. Clair, Summit Lake), the water clarity of Summit Lake was considerably better.




Summit Lake, Thurston County. From Washington Department of Game, June 23, 1952.



## Lake Sutherland -- Clallam County

Lake Sutherland is located 12 miles west from Port Angeles. The lake is fed principally by Falls Creek, and drains via Indian Creek to the Elwha River. Many springs and small streams feed the lake on both the north and the south shores.

| | |
|---|---|
| Size (acres) | 369 |
| Maximum Depth (feet) | 86 |
| Mean Depth (feet) | 57 |
| Lake Volume (acre-feet) | 20,800 |
| Drainage Area (miles$^2$) | 7.4 |
| Altitude (feet) | 501 |
| Shoreline Length (miles) | 4.92 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Mean Trophic State Index: | 33 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 08/02 | 1000 | Bl-Gr | Cloudy | 19.0 | 20.62 | Water color blue to dark green. Ambient air temp 18°. |
| 08/14 | 1300 | Green | P Sunny | 20.0 | 21.08 | Light chop on water, ambient air temperature 20 °C. There are a number of boats on the water. |
| 08/30 | 1100 | Green | Sunny | 20.0 | 22.00 | Water calm, ambient air temperature 18°. |

Water clarity readings by the volunteer began in late July. The June reading was taken by Ecology staff during the intensive sampling. Although there are not enough readings to evaluate any pattern in water clarity; there are sufficient readings to estimate the trophic state of the lake.

### Summary of Questionnaire Results and Information From the Volunteer

Lake Sutherland is used for fishing, swimming, and canoeing/rowing. There are two boat ramps to the lake, and water skiing is not allowed on the lake. In the past the shoreline has been altered. Currently the watershed is logged and the lakeshore is being developed further for residences. There are about 300 houses on the lakeshore, and all are on septic systems. Recreational use of the lake is light. Fish are stocked in the lake. Presently there are no water quality problems in the lake; according to the volunteer, the lake is clear and clean, and ". . . it appears the (lakeshore residents) take great pride in their lake, no bottles, cans or trash in the water." Trash around the public access area on the south shore, however, was noted.

### Results of Intensive Monitoring/Summary of Other Available Information

Intensive survey data from 1989 confirm that Lake Sutherland is oligotrophic, based on high Secchi disk transparency and relatively low epilimnetic concentrations total phosphorus and chlorophyll *a*. On both sampling dates, there were odd fluctuations in the pH and dissolved oxygen profiles. Dissolved oxygen concentrations typically increase with depth as water temperatures decrease, because of the solubility properties of oxygen in water. Near the bottom of the lake, dissolved oxygen was depleted and the pH decreased, most likely due to bacterial decomposition of organic matter such as woody debris, aquatic plants, and algae.

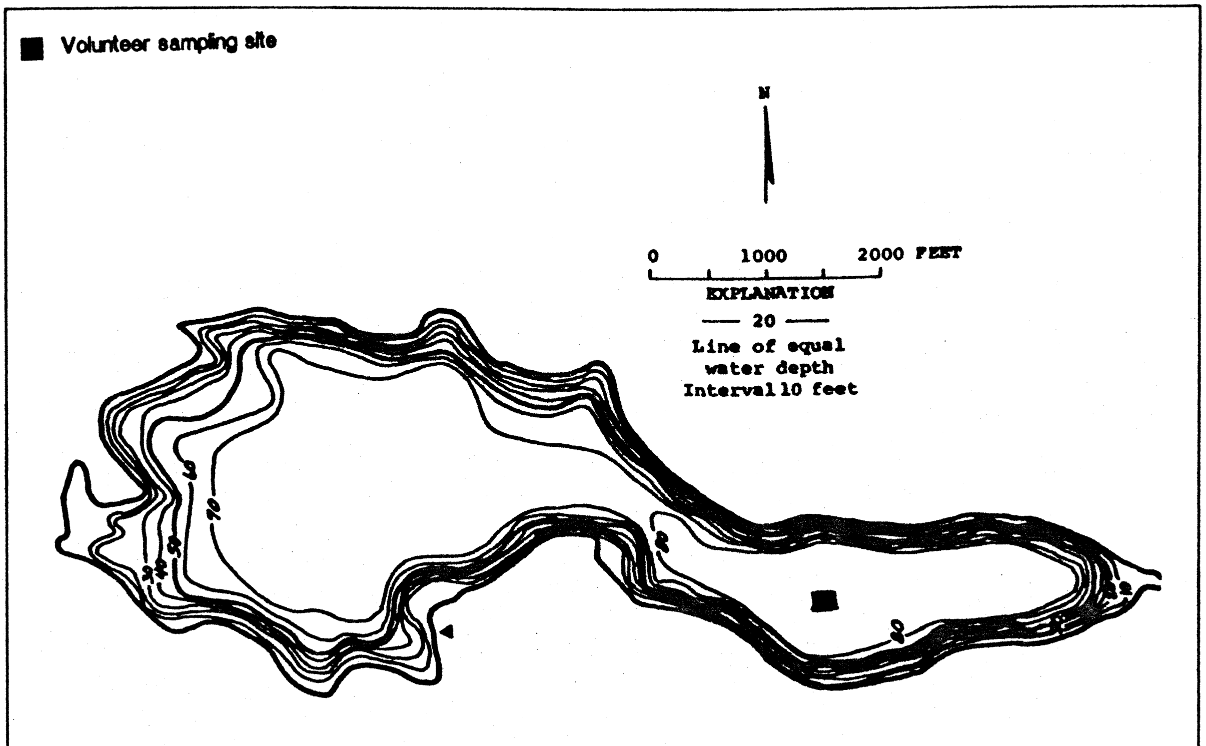
Compared to other lakes surveyed by Ecology in 1989, Lake Sutherland had low concentrations of nutrients and chlorophyll *a* (chlorophyll *a* is a plant pigment and indicates the volume of algae growing in the water). Algal growth in Lake Sutherland appears to be limited by factors other than the amount of phosphorus in the water. Algal growth in most Pacific Northwest lakes is limited by phosphorus.

Comparing 1989 data (Brower and Kendra, 1990) with those collected by the USGS in 1974 (Bortleson *et al.*, 1976), the concentrations of total phosphorus and ammonia at the bottom of the lake were higher in 1989. Concentrations of these nutrients are typically higher in lake bottoms when dissolved oxygen concentrations are depleted. In September 1989, the concentration of dissolved oxygen was less than 1 mg/L from 18 meters down to the bottom of the lake; whereas in August 1974, the concentration of dissolved oxygen was 6.6 mg/L at 66 feet (about 20 meters). The Secchi depth in 1974 (33 feet) was also much deeper than any of the Secchi disk measurements collected during 1989.

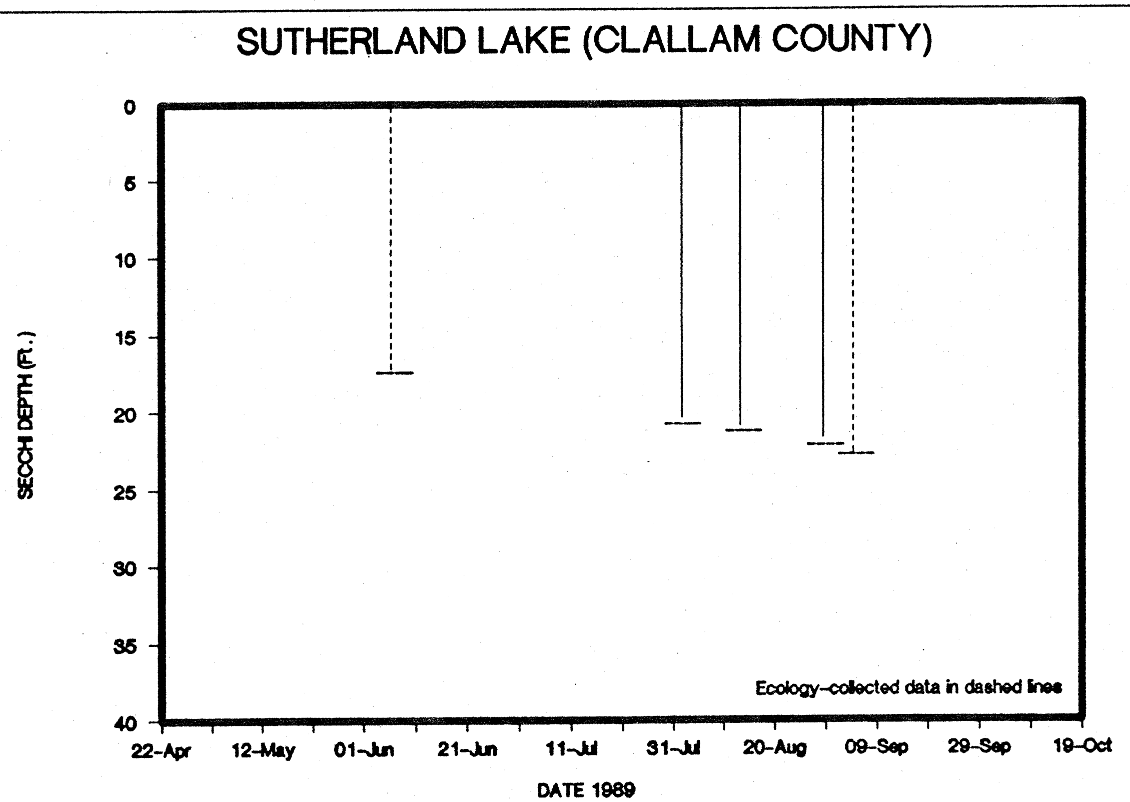
Residential development of the lakeshore has apparently doubled since 1974; the USGS reported that in 1974 there were 152 nearshore homes (Bortleson *et al.*, 1976).

## Comments

Compared with other lakes monitored for the volunteer lake monitoring program, the water clarity of Lake Sutherland is very good. The low dissolved oxygen concentrations near the bottom of the lake is of concern. Low dissolved oxygen concentrations are not characteristic of oligotrophic lakes, although spring-fed lakes may have low dissolved oxygen concentrations near the bottom of the lake during satisfaction




Sutherland Lake, Clallam County. From U.S. Geological Survey, March 26, 1974.



Thomas Lake -- Stevens County

Thomas Lake is located 17 miles northeast of Colville. Thomas Lake is in the Little Pend Oreille chain of lakes. It is fed by Heritage Lake and drains south to Gillette Lake and from there to Lake Sherry, and ultimately to the Little Pend Oreille River.

| | |
|---|---|
| Size (acres) | 170 |
| Maximum Depth (feet) | 55 |
| Mean Depth (feet) | 23 |
| Lake Volume (acre-feet) | 4000 |
| Drainage Area (miles$^2$) | 12.70 |
| Altitude (feet) | 3147 |
| Shoreline Length (miles) | 3.31 |

| | |
|---|---|
| Estimated Trophic State: | oligo-mesotrophic |
| Mean Trophic State Index: | 40 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/16 | 1356 | Brown | P Sunny | 14.0 | 7.79 | Lake is darker in color than usual. |
| 05/30 | 1156 | Green | Sunny | 15.0 | 10.38 | Can see disk deeper by being more careful in observing, getting out of glare. |
| 06/13 | 1214 | Green | P Cloudy | 22.0 | 13.75 | Lots of lodge pole pine pollen on water. |
| 06/27 | 1325 | Brown | P Cloudy | 17.0 | 14.67 | |
| 07/11 | 1040 | Brown | Sunny | 18.0 | 13.75 | |
| 07/26 | 1214 | Brown | P Sunny | 22.0 | 13.29 | |
| 08/08 | 1400 | Brown | P Cloudy | 21.0 | 11.00 | Overcast day. South wind steady. |
| 08/22 | 1200 | | P Cloudy | 17.0 | 11.46 | Steady south wind blowing. |
| 09/05 | 0915 | Brown | Sunny | 0.0 | 13.75 | |
| 09/19 | 1115 | Brown | Sunny | 14.0 | 14.67 | |
| 10/01 | 1105 | Brown | Sunny | 13.0 | 17.87 | Very little boat traffic on lake for many days. All water skiing stopped. |
| 10/15 | 1045 | Brown | Sunny | 10.0 | 15.58 | |

Like other high elevation lakes in Eastern Washington monitored for the program, the water clarity was lowest during May. The frequent and regular readings show a very obvious pattern of increased algal growth during spring and late summer; this pattern is common for oligotrophic and mesotrophic lakes.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Thomas Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, hiking, and waterfowl hunting. There is a picnic area, camping area, beach, National Forest campground, and a church camp on the lakeshore. There is no boat ramp on the lake, but it is accessible from the other lakes in the Little Pend Oreille chain. Water is withdrawn for drinking and other domestic uses. Currently the watershed is logged and the lakeshore is being developed further for residences. In the past, the watershed was also used for agriculture and mining, and an area at the north end of the lake near the inlet was dredged. There are 92 houses on the lakeshore, and all are on septic systems. Rotenone has been used to eliminate rough fish, and was last used on October 26, 1988. In 1989 about two acres of the lake were treated with Rodeo to control water lily and water shield. Fish are stocked in the lake. There are wetland areas on the north end of the lake near the inlet. The volunteer did not identify any water quality problems in the lake, but suggested that outhouses, cesspools, and septic tank drainfields may affect the water quality. The volunteer is also concerned about shoreline devegetation and erosion.

Summary of Other Available Information

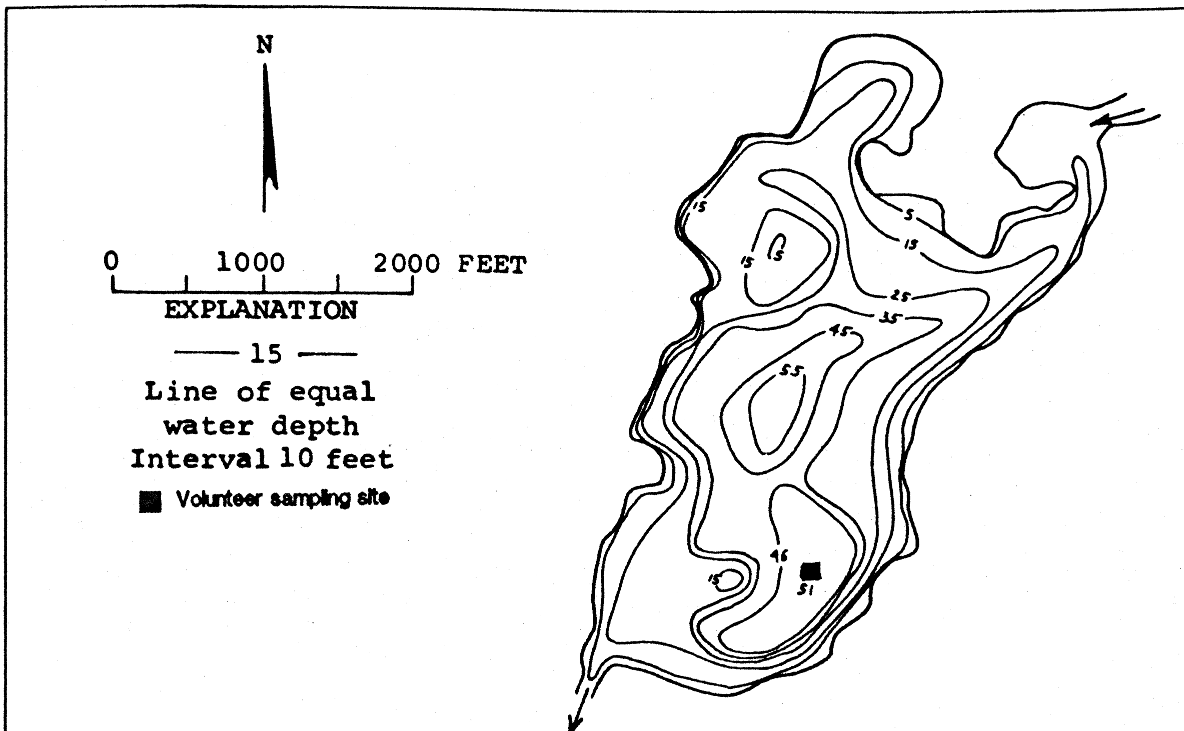
In 1972, Secchi disk transparency and concentrations of total phosphorus and chlorophyll *a* indicate that Thomas Lake was likely to be mesotrophic (Bortleson *et al.*, 1976). Although lower nutrient concentrations and high Secchi disk readings (all in the oligotrophic range) occurred during June and August, 1972, the concentrations of dissolved oxygen were depleted near the bottom of the lake during each of the four sampling dates. The lack of dissolved oxygen near the bottom of a lake is not characteristic of oligotrophic lakes. Heavy growth of emersed aquatic plants, especially water shield (*Brasenia* sp.), and a moderate amount of submersed aquatic plant growth was noted during 1972 (Bortleson *et al.*, 1976).

In 1981, Secchi disk transparency and chlorophyll *a* data were in the range associated with oligo-mesotrophic lakes (Sumioka and Dion, 1985). Again, the concentration of dissolved oxygen near the bottom of the lake was depleted and higher total phosphorus concentrations were reported.

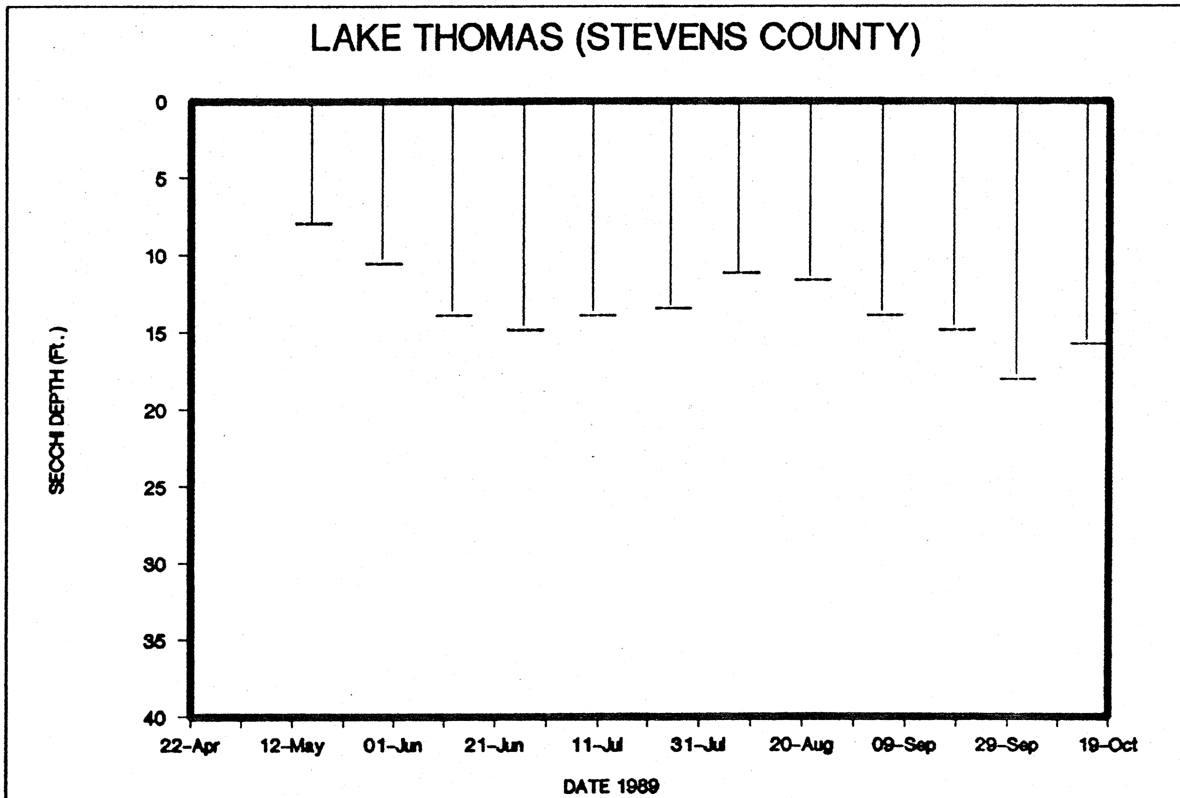
Residential development of the lakeshore appears to be gradually increasing. In 1972, the USGS reported there were 66 nearshore homes (Bortleson *et al.*, 1976) and in 1981 there were 80 nearshore homes (Sumioka and Dion, 1985).

Comments

Thomas Lake had average (neither exceptional or poor) water clarity compared to other lakes monitored for the program. However, compared to the other five Stevens County lakes in the program, only one lake (Starvation Lake) had lower mean water clarity. Black Lake, Deep Lake, Deer Lake, and Loon Lake were all oligotrophic. Flowing Lake in Snohomish County has similar physical characteristics (size, and maximum and mean depths) as Thomas Lake, and has the same number of houses on its shoreline and is also in a three-lake chain of lakes. Compared to Flowing Lake, the water clarity of Thomas Lake is somewhat better. Because Secchi disk transparency may underestimate the trophic status of Thomas Lake, future estimates of trophic state should be confirmed using chemical and profile data.




Thomas Lake, Stevens County. From Washington Department of Game, March 11, 1950.



Tiger Lake -- Mason County

Tiger Lake is located 9.5 miles southwest from Bremerton, with 102.8 in Mason County and 6.3 acres in Kitsap County. Tiger Lake has no inlets, and drains via Mission Creek to Hood Canal.

| | |
|---|---|
| Size (acres) | 110 |
| Maximum Depth (feet) | 40 |
| Mean Depth (feet) | 19 |
| Lake Volume (acre-feet) | 2100 |
| Drainage Area (miles$^2$) | 0.70 |
| Altitude (feet) | 496 |
| Shoreline Length (miles) | 2.46 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Average Trophic State Index: | 43 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/29 | 1715 | Green | P Cloudy | 17.0 | 11.92 | Very overcast day. Some chop on the lake, but no whitecaps. |
| 06/05 | 1555 | Green | P Sunny | 19.0 | 11.92 | |
| 06/11 | 1630 | Green | Sunny | 17.5 | 11.46 | |
| 07/04 | 1535 | Green | P Sunny | 20.5 | 9.62 | A lot of chop on water due to winds out of north, but no whitecaps. |
| 07/28 | 1515 | Green | P Sunny | 21.0 | 10.54 | |
| 08/05 | 1510 | Green | P Sunny | 23.0 | 9.62 | |

Because of the odd fluctuations in water clarity and without volunteer-collected readings after early August, it is difficult to evaluate the patterns of algal growth in Tiger Lake. However, all the water clarity measurements are within the range expected for a mesotrophic lake.

Summary of Questionnaire Results and Information From the Volunteer

The questionnaire on lake and watershed uses was not returned.

Results of Intensive Sampling/Summary of Other Available Information

The Secchi disk readings collected during both the June and September, 1989 intensive survey sampling trips, as well as the clarity readings collected by the volunteer, indicate that Tiger Lake is mesotrophic (Brower and Kendra, 1990). However, the chlorophyll *a* and the total phosphorus data from the intensive survey indicate that the lake is oligotrophic. Because the water color of the lake is green and dissolved oxygen concentrations at the bottom of the lake were depleted during both the June and the September sampling dates, Tiger Lake is more characteristic of a meso-oligotrophic lake than an oligotrophic lake.

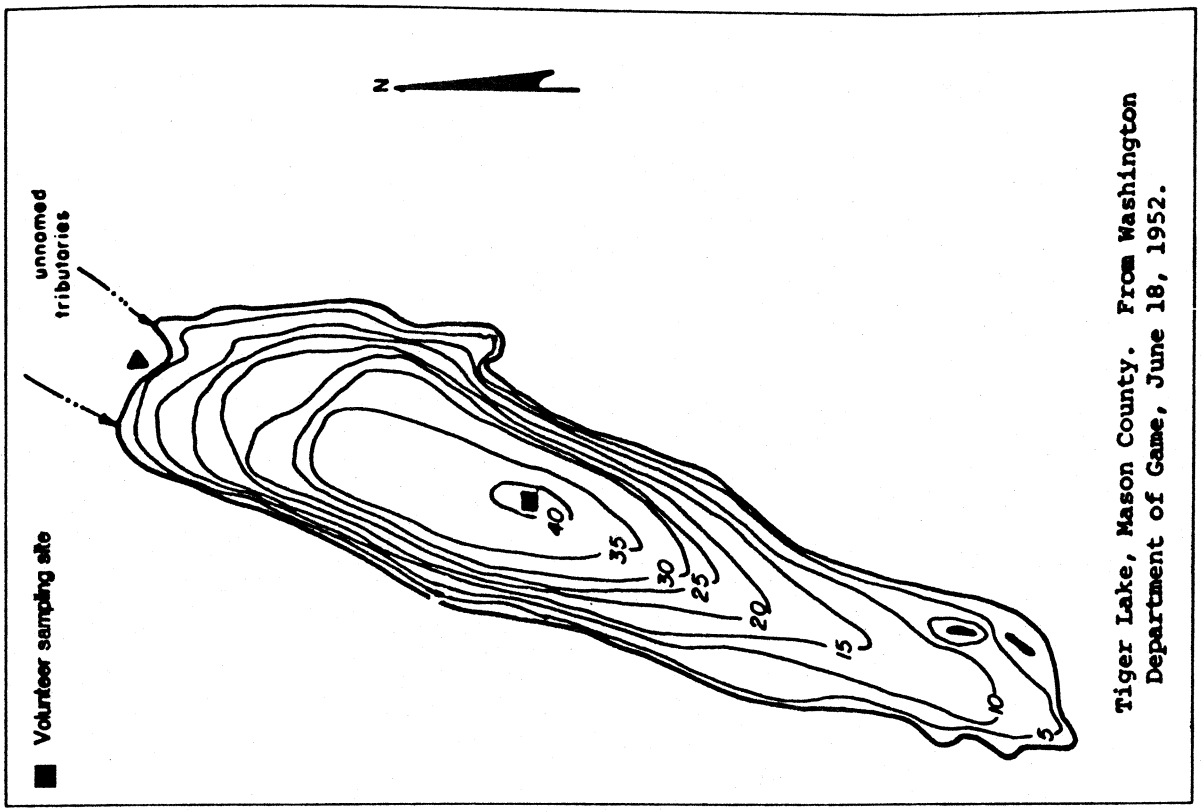
Tiger Lake -- Mason County

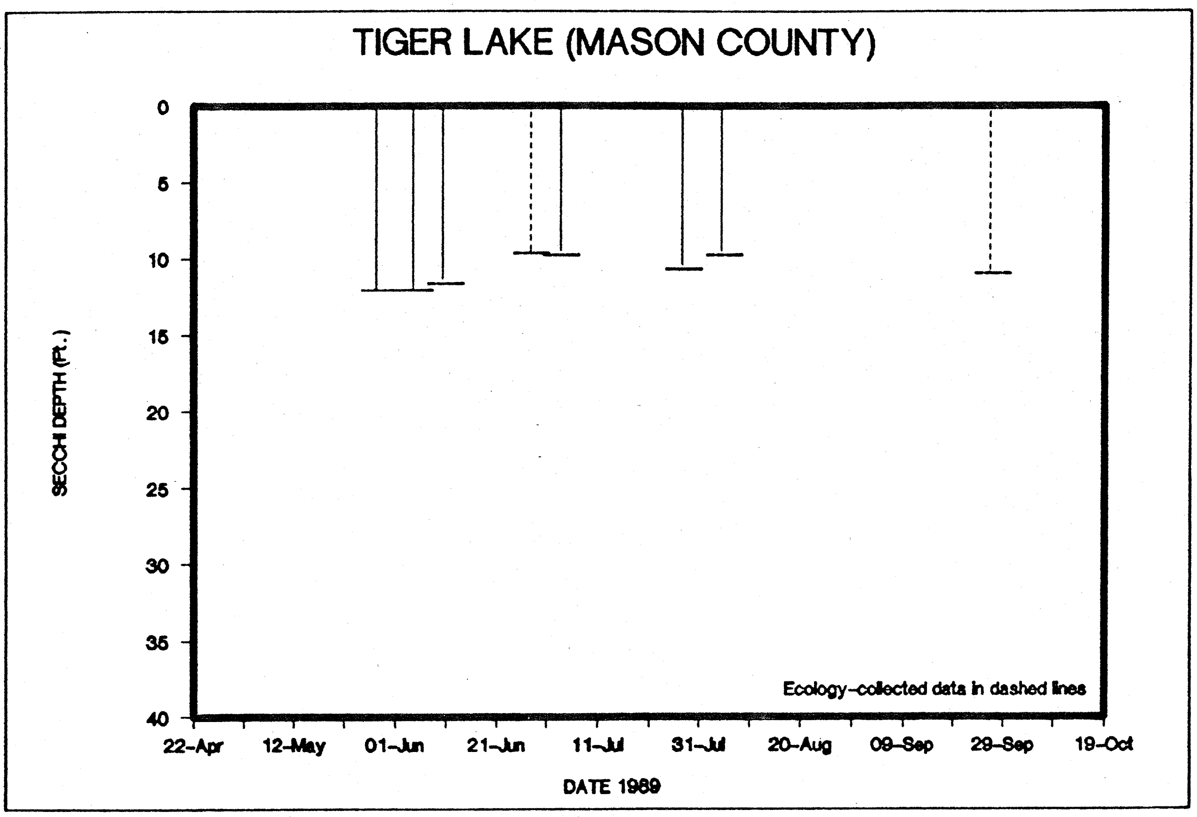
Secchi disk transparency and concentrations of total phosphorus and chlorophyll *a* were in the oligotrophic range in 1973 (Bortleson *et al.*, 1976). In June 1973, dissolved oxygen concentrations decreased, but were not depleted, near the bottom of the lake; during June and September 1989 dissolved oxygen was depleted near the lake bottom. Dissolved oxygen is depleted by the bacterial decomposition of organic material such as algae, aquatic plants, and/or woody debris. Compared to other lakes sampled in the program, the specific conductance of Tiger Lake is very low and nutrient concentrations are moderately low.

Comments

Compared to other Mason County lakes monitored for the program (Island Lake, Mason Lake, Phillips Lake, and Lake Wooten), Tiger Lake had the lowest mean water clarity. Tiger Lake also had higher concentrations of chlorophyll *a* (a plant pigment that indicates the volume of algal growth) than Mason Lake, which was also sampled for the intensive monitoring program. Although the Secchi disk data tend to consistently overestimate the trophic state of the lake, changes in the water clarity can still be used to evaluate changes in the water quality of the lake. It is recommended that evaluations of the trophic status of Tiger Lake be based on total phosphorus and chlorophyll *a* data, in addition to water clarity data.

The low dissolved oxygen concentrations near the bottom, are of concern in Tiger Lake. Because oxygen depletion often precedes accelerated eutrophication, it is very important to minimize nutrient loading into the lake in order to maintain water quality.


N
unnamed tributaries
Volunteer sampling site
40
35
30
25
20
15
10
5
Tiger Lake, Mason County. From Washington Department of Game, June 18, 1952.


TIGER LAKE (MASON COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989
Ecology-collected data in dashed lines

Lake Wenatchee -- Chelan County

Lake Wenatchee is a large, steep-sided lake located 15 miles north from Leavenworth in the Wenatchee National Forest. Lake Wenatchee is fed principally by the Little Wenatchee River and the White River, and drains via the Wenatchee River. There is a large wetland at the northeast end of the lake.

| | |
|---|---|
| Size (acres) | 2480 |
| Maximum Depth (feet) | 244 |
| Mean Depth (feet) | 147 |
| Lake Volume (acre-feet) | 360,000 |
| Drainage Area (miles$^2$) | 273 |
| Altitude (feet) | 1875 |
| Shoreline Length (miles) | 13.30 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic |
| Average Trophic State Index: | 37 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 05/26 | 1200 | Bl-Gr | P Cloudy | 8.0 | 22.00 | Tested in water at least 200' deep. Cloudy day, wind ripple slight. |
| 06/19 | 1200 | Gr-Br | P Sunny | 8.0 | 11.00 | High runoff due to warm conditions. |
| 06/30 | 1400 | Green | P Cloudy | 12.2 | 17.42 | Windy. Water colored due to runoff; clearing up since past reading. |
| 07/14 | 1400 | Green | P Sunny | 16.7 | 14.67 | Windy; water is cloudy. Water temp and clarity change with windy conditions. |
| 07/28 | 1200 | Green | Sunny | 15.6 | 13.75 | Surface water temp will vary 5 °F due to wind; wind stirred up lake again. |
| 08/15 | -- | Green | Sunny | 16.7 | 18.33 | Surface water temp will vary 5-6 °F depending on wind conditions. |
| 08/29 | 1200 | Bl-Gr | Sunny | 17.8 | 19.25 | Surface temperature warming; no wind for 24 hours. |

The water clarity was greatest in late May and early September. Lowest water clarity readings in June corresponded to green-brown water color and the volunteer's comment about high snowmelt and runoff. Algal growth decreased the water clarity during July.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Lake Wenatchee is used for fishing, swimming, boating, jet skiing, picnicking, camping, and hiking. There is a state park, one resort, two boat ramps, and a USFS campground on the lakeshore. Water is withdrawn for drinking and other domestic uses, and for irrigation. Currently the watershed is used for logging and animal grazing, and residential development of the lakeshore is occurring. There are about 400 houses on the lakeshore; of these, 65 are occupied year-round. With the exception of the USFS compound on the north shore, the area is not sewered. Salmon are stocked in the lake occasionally. There are wetland areas on the west side of the lake, near the inlets. There are no water quality problems in the lake, although the volunteer suggested that old drainfields may adversely affect water quality. Creating a sewer district for the area has been proposed.

Results of Intensive Sampling/Summary of Other Available Information

Intensive survey results from 1989 confirm that Lake Wenatchee is oligotrophic, based on high Secchi disk transparency and low epilimnetic concentrations of total phosphorus and chlorophyll *a* (Brower and Kendra, 1990). Dissolved oxygen concentrations were high throughout the water column and nutrient concentrations were low. Similar conditions were found during surveys conducted in 1968 (Lee, 1969) and 1974 (Dion *et al.*, 1976). Compared to the other 24 lakes sampled in 1989, Lake Wenatchee has very low plant and algae productivity.

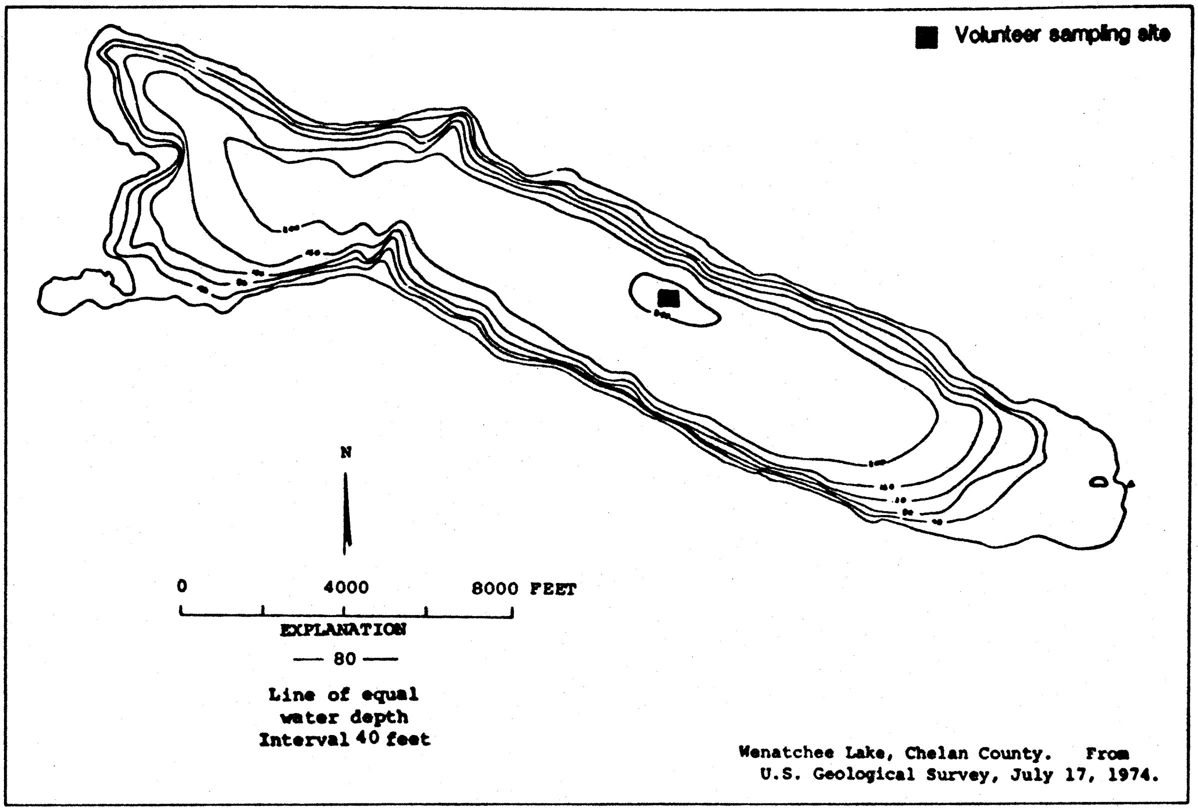
Toxics analyses of fish and sediment samples collected in 1989 indicated no significant levels of the chemicals analyzed. Sediment analysis detected low concentrations of 4-methylphenol (74 ug/Kg) (Johnson and Norton, 1990). This chemical is commonly detected in sediments and is generally considered to have low toxicity to aquatic organisms. Low concentrations of DDT compounds (24 ug/Kg) were detected in lake white fish. These fish samples were well within levels considered acceptable for human consumption.

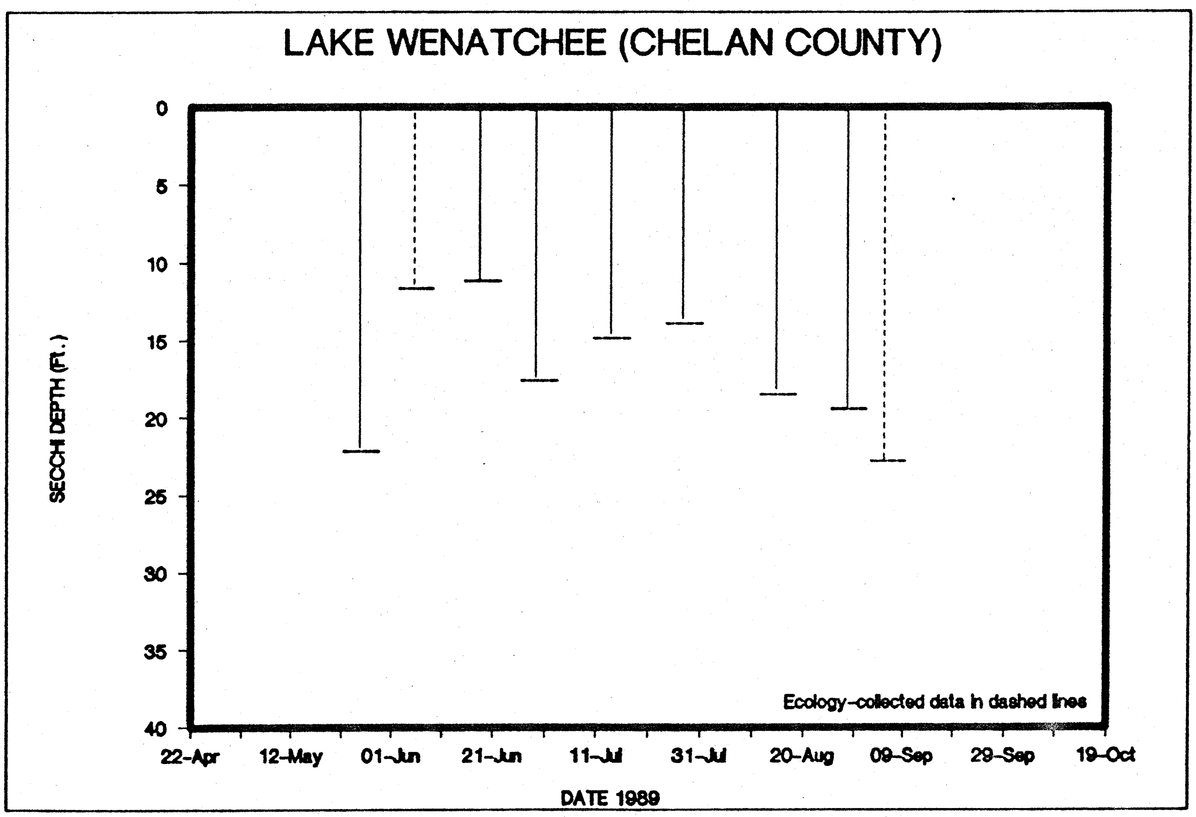
Residential development of the lakeshore has increased since 1974; the USGS reported that there were 276 nearshore homes in 1974 (Dion *et al.*, 1976).

An article from the Wenatchee World (January 9, 1989) reported that sockeye net pens will be placed in the west end of the lake. The pens will be used to hold adult sockeye salmon until they spawn.

Comments

It is difficult to take Secchi disk readings from Lake Wenatchee because the area receives strong and frequent winds. As a result, the clarity readings are somewhat erratic and tend to overestimate the trophic state index of the lake. Although changes in water clarity as determined using a Secchi disk can still be used to predict changes in the water quality of the lake, future estimates of trophic state should be confirmed using chemical data.


Volunteer sampling site
N
0
4000
8000 FEET
EXPLANATION
— 80 —
Line of equal
water depth
Interval 40 feet
Wenatchee Lake, Chelan County. From
U.S. Geological Survey, July 17, 1974.


LAKE WENATCHEE (CHELAN COUNTY)
SECCHI DEPTH (Ft.)
0
5
10
15
20
25
30
35
40
Ecology-collected data in dashed lines
22-Apr
12-May
01-Jun
21-Jun
11-Jul
31-Jul
20-Aug
09-Sep
29-Sep
19-Oct
DATE 1989

Williams Lake -- Spokane County

Williams Lake is located 11.5 miles southwest from Cheney and 12.5 miles east from Sprague. The inflow is intermittent. The outlet, which flows only during high water, drains to Downs Lake and the Palouse River watershed.

| | |
|---|---|
| Size (acres) | 320 |
| Maximum Depth (feet) | 120 |
| Mean Depth (feet) | 37 |
| Lake Volume (acre-feet) | 12,000 |
| Drainage Area (miles$^2$) | 21.80 |
| Altitude (feet) | 2052 |
| Shoreline Length (miles) | 5.30 |

| | |
|---|---|
| Estimated Trophic State: | mesotrophic |
| Average Trophic State Index: | 40 |

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/20 | 1200 | Green | Sunny | 12.0 | 5.04 | Both inlet streams flowing. No motor boat activity affecting turbidity yet. |
| 05/05 | 1200 | Green | Sunny | 18.0 | 7.79 | Fishing season open. Runoff into lake about done. |
| 06/01 | 1200 | Bl-Gr | P Cloudy | 18.0 | 11.00 | Not as sunny as previous times. |
| 06/21 | 1200 | Bl-Gr | Sunny | 19.0 | 13.29 | Water clearer. |
| 07/05 | -- | Green | Sunny | 24.0 | 11.69 | Slight scum on lake. Water quality seems to be deteriorating. |
| 07/20 | 1200 | Green | P Cloudy | 24.0 | 12.83 | Hazy with winds to 15 mph. Slight chop on water. |
| 08/09 | 1200 | Green | Cloudy | 22.5 | 13.75 | Raining hard and dark outside compared to previous reading days. |
| 08/30 | 1200 | Green | Sunny | 20.0 | 12.60 | Cooler temps. Had 1-1/2 inches rain last week. |
| 09/05 | 1400 | Bl-Gr | P Sunny | 20.0 | 11.00 | |

Like several other lakes in Eastern Washington that were monitored for the program, the lowest water clarity occurred during April and May. Increased algal growth during the spring and late summer-early fall is common for oligotrophic and mesotrophic lakes.

Summary of Questionnaire Results and Information From the Volunteer

The following are from the volunteer's remarks and questionnaire responses. Williams Lake is used for fishing, swimming, boating, jet skiing, picnicking, camping, and waterfowl hunting. There are two resorts on the lakeshore. There is a speed limit of 50 mph for motor boats (this is a county-wide law). Water is withdrawn for drinking and other domestic uses, and for irrigation. The watershed is used primarily for agriculture (both crops and animal grazing/feeding operations). In the past, the watershed area was logged and the shoreline was altered. The northeast end of the lake is densely developed. There are 28 houses on the lakeshore; 23 are located on the east end of the lake and 20 are occupied year-round. Also at the northeast end are about 125 permanent trailers, which use septic tanks, and 55 lots used seasonally by RVs that all use holding tanks. The resort on the west end of the lake was sewered in 1976 (treatment uses a lagoon system) and serves 75 trailers. The lake has been treated with rotenone several times for eliminating rough fish; the last time was in 1988. Fish are stocked in the lake. The worst water quality problems, in the opinion of the volunteer, are 1) algal blooms, and 2) weeds; these problems are worst from June through August. The volunteer is concerned about potential water quality effects from septic tanks and runoff from cattle grazing. The volunteer also reported, "I have been in business for 30 years on Williams Lake and have seen the water quality get worse every year!"

There are wetland areas on the west end of the lake. Weeds come to the surface of the water in these shallow areas and in an area deeper than 25 feet on the east end just off the public dock area. According to the volunteer, ". . . algae blooms (are) most dense in the northeast end of the lake."

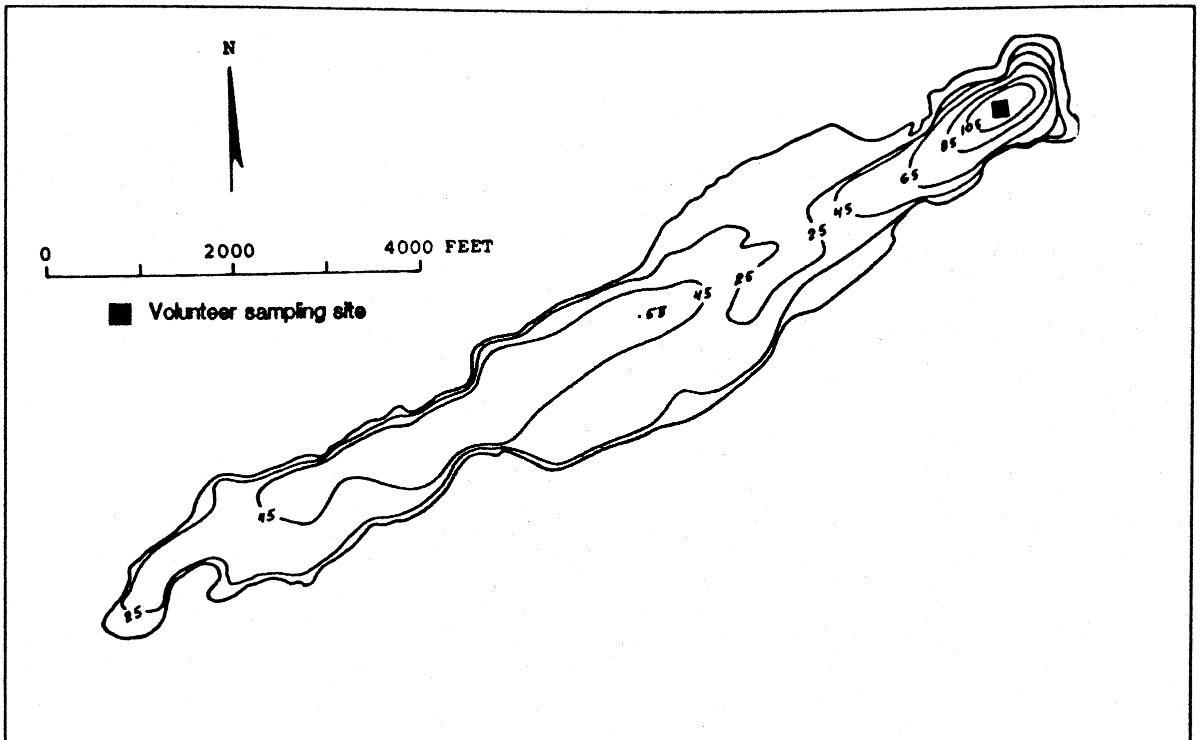
## Results of Intensive Sampling/Summary of Other Available Information

Intensive survey data from 1989 confirmed that Williams Lake was mesotrophic (Brower and Kendra, 1990). Although Secchi disk transparency and concentrations of chlorophyll *a* are in the oligotrophic range, the total phosphorus concentrations and the Secchi disk readings collected by the volunteer are characteristic of a mesotrophic lake. Also, dissolved oxygen concentrations were depleted and hydrogen sulfide was present near the bottom of the lake; these are not characteristics of an oligotrophic lake. Dissolved oxygen concentrations were also depleted near the bottom of Williams Lake in surveys conducted in 1968 (Lee, 1969) and 1973 (Dion *et al.*, 1976). Algae density was moderately high and hydrogen sulfide was also reported in 1973 (Dion *et al.*, 1976). Hydrogen sulfide is produced when bacteria decompose organic material such as algae, aquatic plants or woody debris in the absence of oxygen. Dissolved oxygen is depleted by the bacterial decomposition of organic material (such as plants and algae).

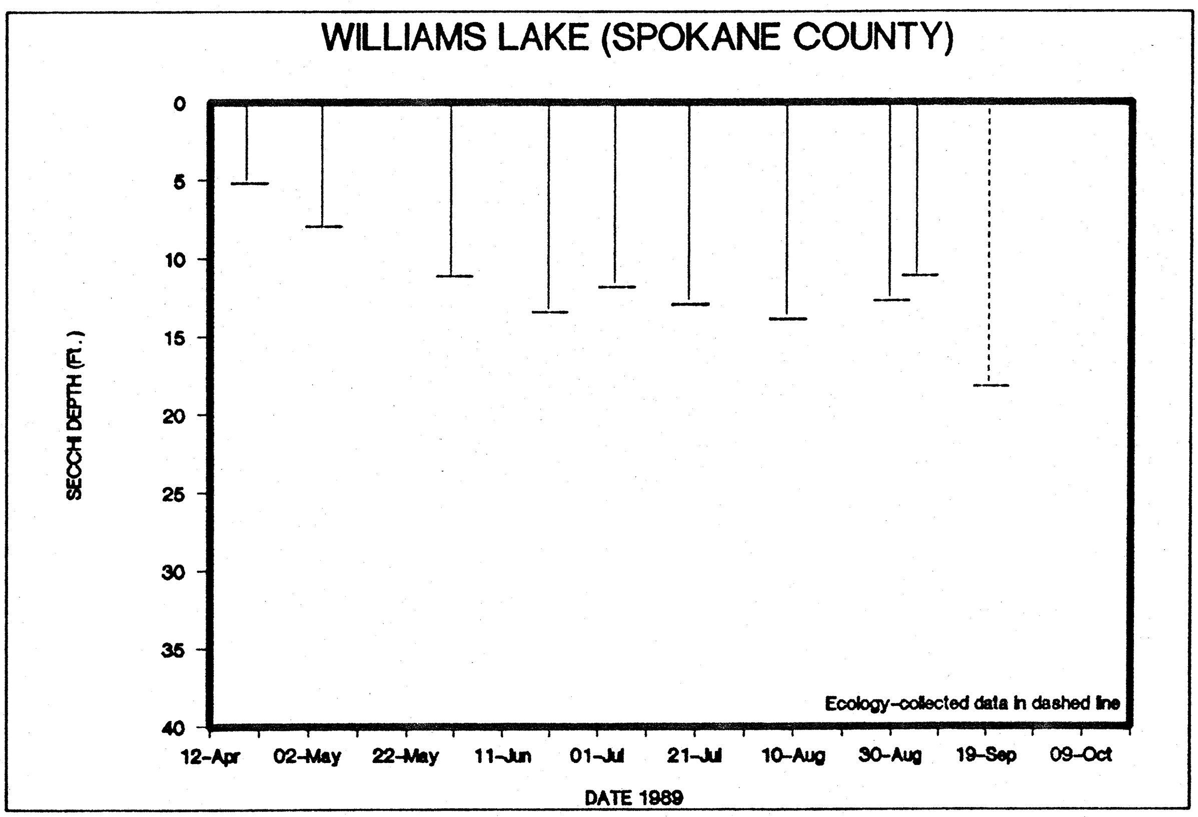
Lake sediments in Williams Lake were analyzed in 1983 to evaluate sedimentation of volcanic ash (Anderson *et al.*, 1984). Discontinuous ash layers in the sediments were found to result from ash layers breaking up and sinking into lower density, uncompacted lake sediment (Anderson *et al.*, 1984).

## Comments

Compared to other Spokane County lakes monitored for the program (Newman Lake and Liberty Lake), Williams Lake had the best water clarity. However, of the 21 other Eastern Washington lakes monitored for the program, 13 had better average water clarity than Williams Lake. Ten of these oligotrophic lakes are located in northeast Washington (mostly Stevens and Pend Oreille Counties) and the other three are located in Central Washington.




Williams Lake, Spokane County. From Washington Department of Game, January 1948.



Lake Wooten -- Mason County

Lake Wooten is located seven miles west from Belfair. The lake has no inlet and drains to Haven Lake and the Tahuya River.

| | |
|---|---|
| Size (acres) | 68 |
| Maximum Depth (feet) | 36 |
| Mean Depth (feet) | 23 |
| Lake Volume (acre-feet) | 1530 |
| Drainage Area (miles$^2$) | 0.32 |
| Altitude (feet) | 407 |
| Shoreline Length (miles) | 1.55 |

| | |
|---|---|
| Estimated Trophic State: | oligotrophic* |
| Average Trophic State Index: | 34 |

*see Results of Intensive Sampling section

Volunteer - Collected Data

| Date 1989 | Time | Water Color | Cloud Cover | Temp (°C) | Corrected Secchi (Feet) | Abbreviated Remarks |
|---|---|---|---|---|---|---|
| 04/17 | 1419 | Green | Sunny | 14.0 | 27.04 | |
| 05/01 | 1250 | Green | Cloudy | 14.5 | 23.37 | So far no algae build up to speak of. |
| 05/22 | 1230 | Green | Cloudy | 16.0 | 23.60 | |
| 06/05 | 1415 | Green | Sunny | 25.0 | 23.14* | Starting to get algae bloom. |
| 06/22 | 1410 | Green | Sunny | 20.0 | 21.31 | Algae bloom about the same. |
| 07/12 | 1550 | Green | Sunny | 22.0 | 21.77 | Increase in algae bloom. |
| 07/24 | 1430 | Green | P Sunny | 22.0 | 19.71 | Continuing to build up algae bloom. |
| 08/07 | 1345 | Green | Sunny | 24.0 | 18.56 | Rapid increase in the algae bloom growth. |
| 09/08 | 1328 | Green | Sunny | 20.5 | 17.19 | Lots of algae bloom. |
| 09/22 | 1030 | Green | Sunny | 19.0 | 16.04 | Some algae dying; wind blew masses into cove areas last week. This week it sunk. |
| 10/13 | 1300 | Green | Sunny | 16.5 | 14.89 | Algae bloom is dying off. |

* Limit for quality assurance test was exceeded for this data point.

The water clarity gradually decreased throughout the entire sampling period. Water color and the volunteer's remarks support that the water clarity was affected by algal growth, particularly in late summer. Nevertheless, the water clarity remained in the oligotrophic range.

Summary of Questionnaire Results and Information From the Volunteer

The following is from the volunteer's remarks and questionnaire responses. Lake Wooten is used for fishing, swimming, boating, and jet skiing. Water is withdrawn for drinking and other domestic uses, and for irrigation. The watershed is used for logging, and the lakeshore is being developed further for residences. The shoreline has been altered in the past. There are 63 houses on the lakeshore; all use on-site wastewater systems and six of the houses are occupied year-round. Fish are stocked in the lake. The worst water quality problem, in the opinion of the volunteer, was the algal bloom during July and August; the extent of the algal blooms have been increasing in recent years. The volunteer is concerned about possible water quality effects from septic systems. Very few aquatic plants grow along the lakeshore. Lily pads planted by a property owner grow in a small area along the north shore.

Results of Intensive Sampling/Summary of Other Available Information

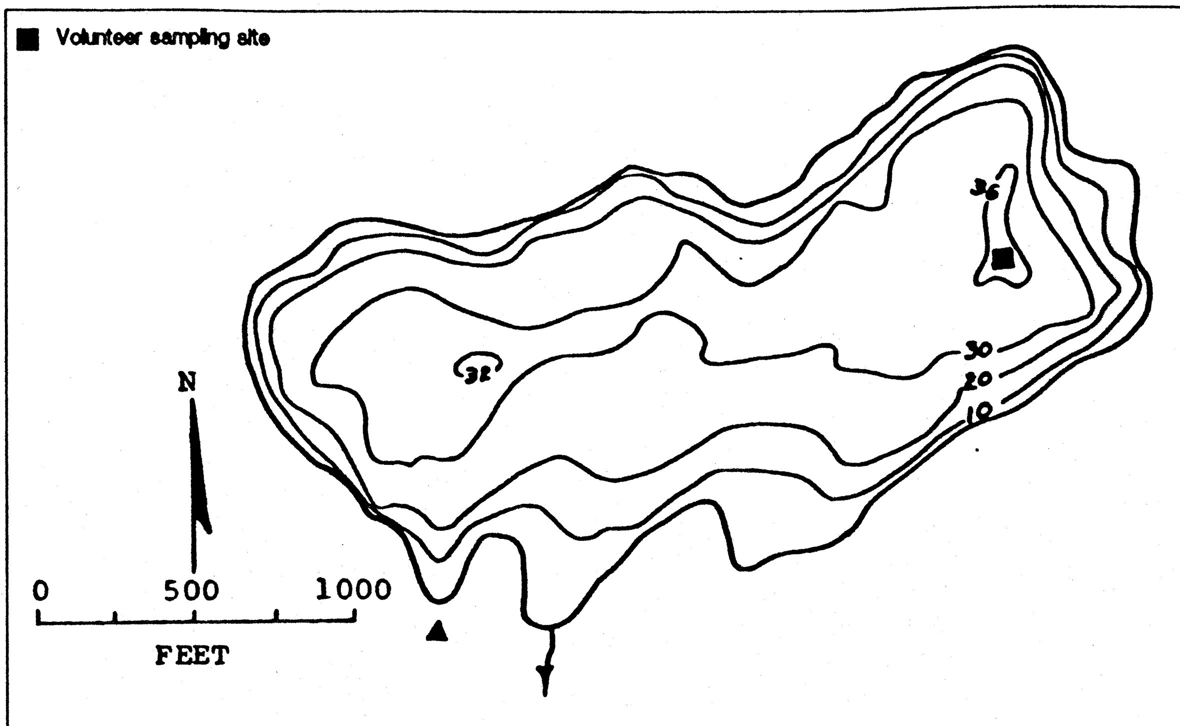
Lake Wooten was likely oligotrophic in 1974 because Secchi disk transparency was high, the concentration of total phosphorus was low, and dissolved oxygen concentrations were high throughout the water column (Bortleson *et al.*, 1976).

Intensive survey data collected in 1989 suggested that Lake Wooten is oligotrophic, based on high Secchi disk transparency and low epilimnetic concentrations of total phosphorus (Brower and Kendra, 1990). However, in September, 1989 the concentration of chlorophyll *a* was exceptionally high, at levels normally characteristic of a eutrophic lake. Chlorophyll *a* is a plant pigment and is measured to indicate the volume of algae growing in the water. The bloom-forming algae was identified as *Gloeotrichia*, a blue-green algae species. An increase in dissolved oxygen concentrations and pH at 7 - 8 meters was noted during the June sampling, and was probably due to increased algal growth at these depths (Brower and Kendra, 1990). Dissolved oxygen concentrations near the bottom of the lake were depleted during September 1989. Because of the presence of a bloom forming blue-green algae species, and dissolved oxygen was depleted near the lake bottom, in 1989 Lake Wooten was considered more mesotrophic than oligotrophic.

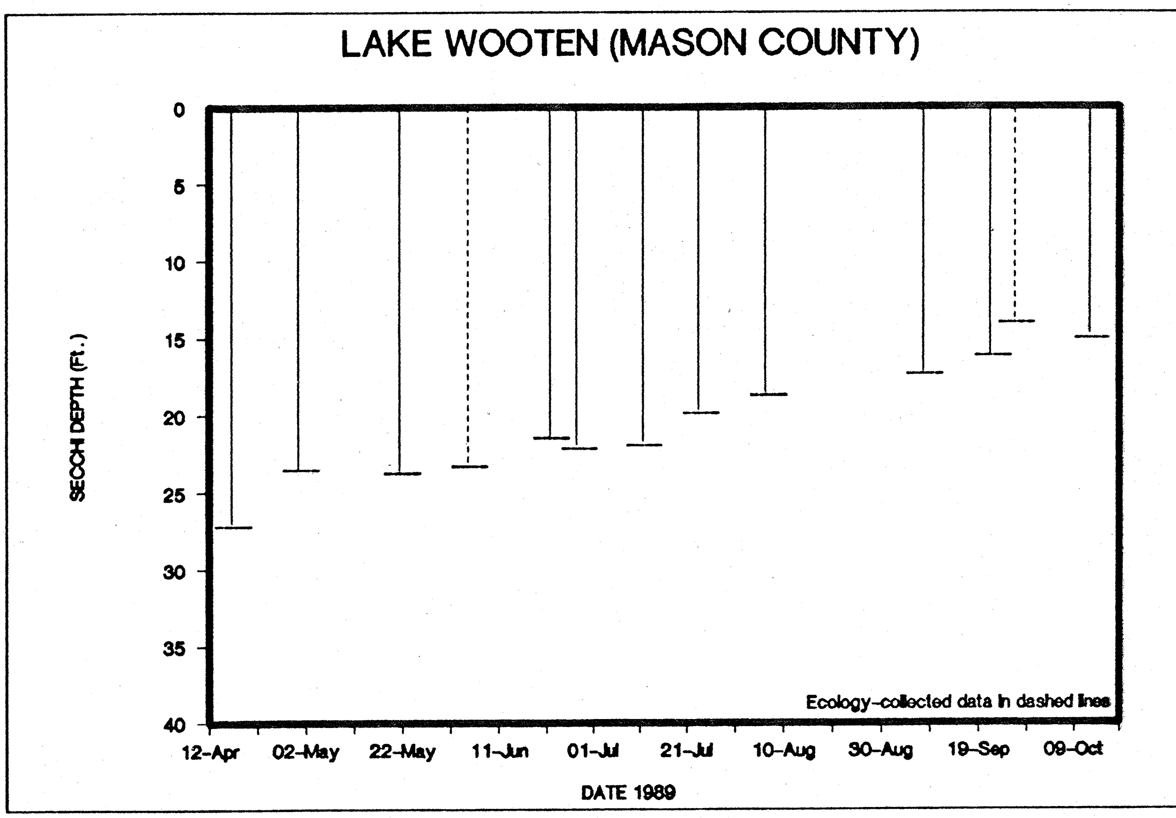
Residential development of the lakeshore has increased since 1974; the USGS reported that there were 47 nearshore homes in 1974 (Bortleson *et al.*, 1976).

Comments

The gradually decreasing water clarity measured in Lake Wooten was unusual compared to the pattern of water clarity measured in other lakes participating in the program. Most of the other lakes, including nearby Tiger Lake, showed an increase in water clarity by late summer. The volunteer believes algal growth has been increasing in severity over the past few years. In light of this and the unusually high chlorophyll concentration detected during the September sampling, it appears that the water quality of Lake Wooten is declining and should be monitored closely.




Wooten Lake, Mason County. From Washington Department of Game, July 23, 1948.



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APPENDICES

## Appendix A - Citizen monitoring project development

Methods used for project development and implementation of the citizen lake monitoring program included soliciting volunteers to participate in the program, training the volunteers, collecting data from volunteers and managing the data, maintaining communication with the volunteer monitors, making Secchi disks in-house, and assuring the quality of data used in the project.

After the funding sources were secured, there was a limited amount of time before monitoring was to start. To recruit potentially interested volunteers to monitor lakes, a form letter was sent to 72 people who had already indicated some interest in the water quality of their lakes. Names, phone numbers, and addresses of these potentially interested people, such as active members of lake associations, were obtained from the Washington Water Research Center (WWRC), the Washington Lake Protection Association (WALPA), and Ecology Regional Offices. Additionally, representatives from county agencies (primarily health departments) suggested potential volunteers, as well as suitable lakes for inclusion in the program. Forty-eight people volunteered to participate in the project as a result of the form letter. Also, several people heard about the program from various sources and contacted the department to request if they could participate. In all, people from 62 lakes throughout the state had offered to participate in the program. Of these who originally volunteered, 55 people monitored 50 lakes for the program. These were sufficient and adequate data to assess 48 of these lakes.

Volunteer monitors were trained at public meetings held in their areas during April and May, 1989. These meetings were arranged so that volunteers, and any interested neighbors and friends, from up to five nearby lakes could attend the same meeting. At least two weeks prior to a meeting, volunteers were mailed a letter explaining the purpose of the meeting, as well as three flyers to post for advertising the public meeting. With a few exceptions, all of the meetings were held during the evening in order to conform to the volunteer's work schedule, and to be able to reach a larger audience.

During the meetings, the program was explained, a slide show on lake ecology and protection was presented, and the monitoring supplies were distributed and demonstrated. Each volunteer was given a Secchi disk, a thermometer, a bathymetric map with the sampling location indicated, a lake monitoring manual prepared by the department (Appendix D), data reporting sheets and self-addressed stamped envelopes for mailing in data as they were collected. In all, 168 people attended 17 public meetings held in April and May, 1989. For various reasons, some of the volunteers were unable to attend the meetings. Several were mailed the monitoring equipment, and others were visited at their homes or businesses. These people were encouraged to read the Lake Monitoring Manual and to contact the department if they had any questions on the monitoring procedure.

The Lake Monitoring Manual prepared by the Department actually served two purposes: the first was to provide some background information on how lakes function, in order to better explain how lakes respond to lake and watershed activities. The second was to provide a step-by-step monitoring procedure. Much of this step-by-step process was patterned after the Wisconsin Self-Help Lake Monitoring Program Data Summary for 1986 (Wisconsin Department of Natural Resources, 1987).

The manual for Washington's Citizen Lake Monitoring Program was updated for the 1990 monitoring season to include procedures for sampling algae and aquatic macrophytes (which are then mailed to the Department for identification), and additional monitoring steps for the expanded monitoring program in 1990. Algae and macrophyte sampling was an optional part of the program; the identifications were done mainly as a service to the volunteers.

Data reporting sheets (Figure A-1) with Secchi depth and surface water temperature data were mailed by volunteers as they were collected. These data, including pertinent comments from the volunteers, were entered into a DBASE IV database. Data were ordered by lake, county, and sampling date. Several lakes were monitored at more than one site so the database had to accommodate station numbers as well. The database was programmed so that the data could be transformed to a LOTUS worksheet easily for printing or graphing.

Results from the questionnaires were also entered into a database for a permanent record and for use in reporting results.

It is important to reassure volunteers that the project is a cooperative program, that their time spent on monitoring is worthwhile and useful, and that they can benefit their lake in other ways besides participating in the project. These were addressed by maintaining communication with the volunteer monitors, mostly through correspondence. Questions asked on the data reporting sheets were responded to by letter. Frequently asked questions included: how to determine the effects on water quality from questionable shoreline alteration practices and stock animals grazing along shorelines; how to restrict motor boat use on lakes; and how to require regular septic tank maintenance within a watershed. A newsletter, "The Lake Monitor" was written and distributed to the volunteers to answer some of the frequently-asked questions, to report on the progress of the project, and to pass on additional interesting information on lake water quality issues. Copies of these two newsletters are included in Appendix D.

WASHINGTON'S CITIZEN LAKE MONITORING PROGRAM

DATA REPORTING SHEET

Your Name ______________________________

Lake Name ______________________________

County ______________________________

Sample Date ______________ Sample Time ______________

Water Color (circle one) clear/blue blue-green green brown

Cloud Cover (circle one) sunny partly sunny partly cloudy

Secchi Depth (to nearest 1/4 foot) ______________ feet

Did the Secchi disk hit bottom? yes no

Water Temperature (to nearest 1/2 degree) ______________ degrees

Secchi Depth (repeat reading) ______________ feet

Lake Depth (optional) ______________ feet

Field Observations

Questions and Suggestions about Project

FIGURE A-1. 1989 Data reporting sheet used to report volunteer data.

## Appendix B - Lessons Learned: Suggestions for other monitoring programs

As with any pilot program, there were many lessons learned as the planning efforts were tested during the course of the program.

One of the most important lessons learned was that it is necessary to be selective when recruiting volunteers. Because we did not determine why each individual wanted to volunteer, what they hoped to get out of volunteering, and how much time they had to devote to the project, we initially had a high dropout rate. For the most part, people dropped out because they underestimated the time commitment required, or they had unfulfilled expectations about the program. In the latter case, volunteers either wanted to do more in-depth lake monitoring tests, or expected Ecology to "take care of" perceived lake water quality problems. An interview with prospective monitors may help to find volunteers who are willing to participate and understand the monitoring objectives and parameters involved. In general, volunteers who run a business on a lakeshore (especially resort owners) are very interested in the monitoring project, but are less likely to have sufficient time to do the monitoring. Retirees, in particular, as well as people with flexible work schedules, were very reliable and consistent lake monitors during Washington's 1989 Lake Monitoring Program.

Providing stamped envelopes for mailing in the data sheets was not cost-effective. Considering that each volunteer was provided with 12 envelopes and on the average of 8 data sheets were returned for each lake, about 152 envelopes were not returned. Also, some volunteers mailed more than one data sheet in an envelope, so that some envelopes arrived postage due. Business-reply envelopes or cards were not provided in 1989 because there was not enough time prior to the start of the program to obtain them. However, business reply cards were used for the 1990 program.

Some of the volunteers were concerned that data sheets they had mailed never reached us. Also, many of the volunteers photocopied their data sheets so that they could keep their own record. Therefore, for the 1990 program we prepared a "master sheet" that the volunteers used to fill in their data for their own personal record, which also served as a backup data record in case data was lost in transit.

Finding that the Secchi disk ropes had shrunk presented quite a problem (see Volunteer Monitoring Data section). For 1990, all the ropes for new lakes added to the program were "pre-shrunk", that is, the lines were soaked in warm water and dried before marking the 1-foot increments. Although this was rather labor-intensive, we found that the ropes shrank very little, if at all, after this initial shrinking. We also found that the volunteers prefer using rope over brass chain because the chain is more difficult to roll on a spool and has a tendency to kink up.

## Appendix C - Materials

Making Secchi disks in-house was considerably cheaper than purchasing disks from a supply house. The procedure used to make the disks is pictured in Figure C-1.

The 20-cm diameter, 1/4 inch thick white acrylic disks were purchased from a plastic supply company; the 150 disks cost $3.31 each. The disks came with a glued protective paper on them; this paper was used as a masking when painting. The paper was scored with a sharp knife into quadrants. Two paper quadrants were peeled off each disk so that only the opposing quadrants to be painted were exposed. Before painting, disks were warmed under lights, the exposed quadrants were roughened with fine sandpaper, plastic dust was wiped off with a tack cloth, and the disks were painted with a water-base flat black enamel paint. A second coat of paint was applied to the cooled disks. So far, none of the volunteers requested that their disks be repainted.

For weighting the disks, steel plates weighing around 1 1/2 lbs. each (1/4 inch thick steel, about 5" X 5" with a hole drilled in the center) were ordered from a welding/steel supply store. These plates cost about $1.67 apiece. Because they were not stainless, the plates were painted with one coat of the flat enamel paint. This was done primarily for appearance and to protect the volunteers' boats from rust.

Hardware used on each disk consisted of a 5/16" X 3 1/4" eyebolt, 2 5/16" flat washers, a 5/16" locking washer and a 5/16" nut. Hardware for each disk cost $0.45.

Disks were assembled as illustrated in Figure C-1.

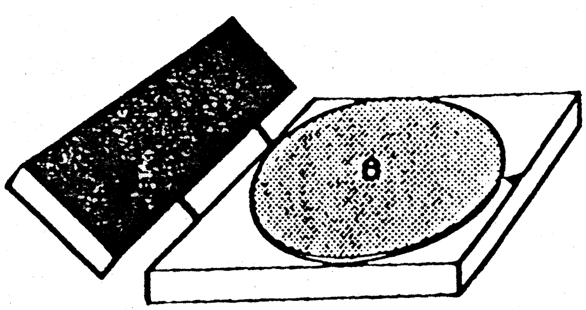
We wanted to use a solid braid rope for the disks, because braided line is easy to handle, relatively inexpensive, and easy to mark. A rope manufacturer (Wellington Puritan, based in Georgia) recommended to our vendor that we use a polyester line that would not stretch. This rope was available in 1,000 foot spools costing $58.75/each. Because of a delay in the order, a solid braid nylon rope was used for about half of the disks made (this nylon rope was more expensive, at $68/100 foot spool). The vendor assured us that this rope would also suit our purposes. The ropes were marked with Sharpie pens in 1 foot intervals in black, with a red mark every 5 feet. Cost of materials per disk varied depending on the amount and type of line used; supplies for a disk with a 40 foot nylon line cost about $8.

The pocket thermometers used for the program were ordered through scientific supply company. These thermometers seemed to break easily, because the plastic protective cover fit on so tightly that it was difficult to pull straight off. Approximately 6 thermometers needed to be replaced during the monitoring season because they were broken. We also found that many of the volunteers had difficulty relating to temperature in degrees Celsius. For the 1990 program, we ordered a different red spirit pocket thermometer. This thermometer has a wider surface that is easier to read, is in Fahrenheit, and it is much easier to remove from its protective cover.

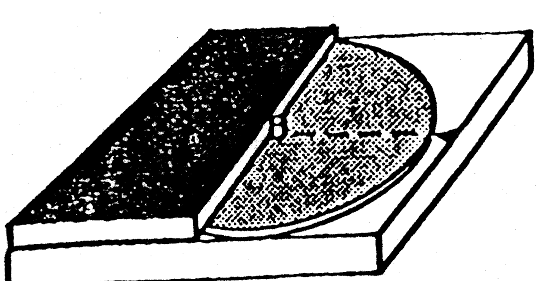
# Homemade Acrylic Secchi Disks

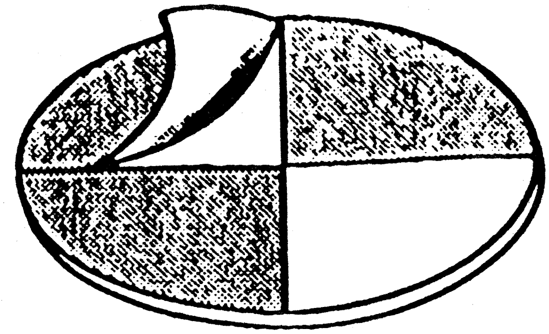
*by Julie Rector*

From a plastic supply house, order 20-cm diameter, 1/4"-thick white opaque acrylic disks with 3/8" holes drilled in center. (Disks come with paper masking on both sides.)



**1** Make a simple contraption from wood to hold the disk while scoring the paper. Upper hinged board serves as a knife guide. Bottom board has a dowel to center the disk and a mark for lining up first score mark.

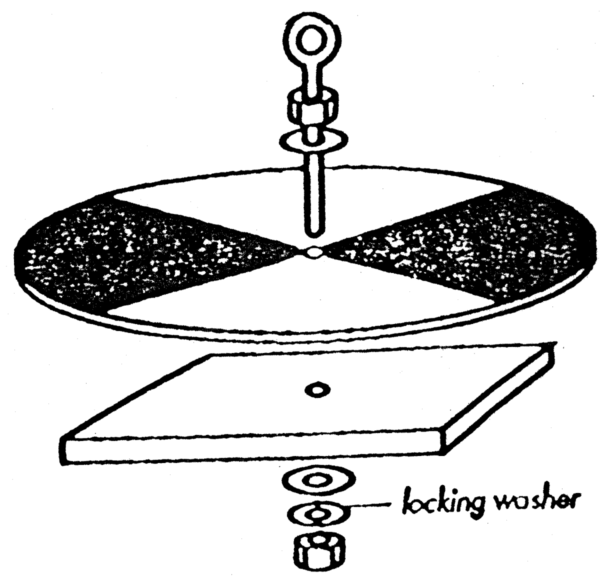




**2** After scoring paper, peel paper from opposing quadrants.

**3** Rough up exposed acrylic with fine sandpaper and warm disk under bright lights. While disk is still warm, paint quadrants with flat black enamel paint. After second coat, peel off masking. Paint takes about 2 weeks to fully harden; if disk is used during the hardening period, treat it gently to prevent chipping.

**4** To weight disk, use 1/4" steel cut to 5" x 5", with hole drilled in center (order from welding supply house). Paint steel plate to prevent rusting.




**5** Assemble disks with eyebolt (3/16" diameter). Use flat washers between disk and nut, and between steel plate and locking washer. Use 5/16" nuts at top of eyebolt, and to bolt steel plate onto disk.

*For more information, call Julie Rector at Washington's Citizen Lake Monitoring Project; (206) 586-5496.*

Figure C-1. Secchi disk design. Reproduced from The Volunteer Monitor Volume 3, No.1, Fall 1991.

## Appendix D - Information sent to volunteers
## (lake monitoring manual, newsletters, explanation of lake assessment report)

**Washington's Citizen Lake Monitoring Project**

**Lake Monitoring Manual**

**March, 1990**

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

**Washington Department of Ecology**
**7171 Clean Water Lane MS LH-14**
**Olympia, WA 98504**

## Washington's Citizen Lake Monitoring Project

## Lake Monitoring Manual

Welcome to the second year of Washington's Citizen Lake Monitoring Project! The purpose of this manual is to provide you with backgound information and detailed instructions for monitoring your lake during the 1990 sampling season.

We appreciate your commitment to collect lake data. However, if you think you will not be able to continue monitoring due to illness, schedule conflicts, or other problems, please contact the Department of Ecology as soon as possible. Also, if you are having any problems with the equipment or if you have any questions on the sampling procedure, please call Julie Rector at (206) 586-5496.

### The Monitoring Project Combines Data-Gathering With Public Involvement

Everyone shares the goal of protecting and maintaining the high quality of the 7,800 lakes, ponds and reservoirs in Washington. How do we achieve this goal? First, we need to recognize that human activities, on either land or water, may rapidly affect lake water quality. To protect our lakes, we need to spread the word on how water and land uses affect lake water quality.

Second, we need to prioritize where more intensive lake studies, public education or even lake restoration actions are needed. To do this it is necessary to gather information from all of our significant publicly- owned lakes. Efforts and resources can then be concentrated where they are most needed. The information may also be used to evaluate changes in lake water quality since earlier studies were completed. In addition, by establishing long-term monitoring programs for many of our lakes, we can make sure that the water quality from each is being maintained, or is even improving.

The Washington's Citizen Lake Monitoring Project is one step towards meeting the goal of protecting Washington's lakes. The project has been established so that you can learn more about your lake, lake ecology and lake protection. The project will also allow Department of Ecology staff to have a better understanding of the quality of many of Washington's lakes, so that problem lakes can be identified and management options developed.

### You are the field staff; Ecology is the support staff

Washington's Citizen Lake Monitoring Project is a cooperative effort between the people who live around and/or use lakes, and Ecology staff. The citizen volunteers collect the monitoring data, and Ecology staff interpret and report on the results of the monitoring.

What is involved in the project? You will be provided with field equipment and you will be trained by Ecology staff. From about mid-May through mid-October, you will measure and record Secchi disk depth (water clarity), surface water temperature and pH data from your lake at least every two weeks. You should also record field observations, such as weather conditions, lake height or changing land uses in the watershed. You then mail us your data reporting card after each sampling day.

Sometime over the summer, you will also be asked to complete a questionnaire about your lake. This questionnaire will ask you to record, among other things, the ways your lake is used, the amount of development around the lake, and the approximate amount of aquatic plant growth in the lake.

As your data are collected and mailed to us, we will enter your data into a computer database. We will then summarize how the water quality of your lake as measured by the Secchi disk changes over time. After completion of the sampling season, you will be given a report that will include the data you've collected, conclusions drawn from your data, and a description of how your lake compares with other lakes in the state and in your area.

From your experiences on your lake and the report summaries, you will learn more about the water quality of your lake as well as the manner in which lakes function. You also will have firsthand experience with basic lake sampling procedures, and an understanding of the importance of careful, regular and reproducible testing.

## What is a Lake?

Simply, a lake is a standing body of water an acre or more in size. Water naturally enters lakes from precipitation, rivers and streams, and from groundwater seeps and springs. Lakes lose water through evaporation, and may also lose water from outlet streams or underground flow.

## Lakes Will Stratify Because of Water Temperature Differences

Temperature affects the density of water, so that cool water is more dense than warm water. When there is enough of a temperature/density difference between surface water and water at the bottom of a lake, the warm (less dense) water will layer on top of cool (more dense) water. This layering is called **stratification.** While the lake is stratified, the components of the top layer do not mix with the components of the bottom layer.

Changes in seasons cause surface water temperatures (and therefore the surface water density) to change. In the fall, surface water cools and heat is carried away by winds. The temperature difference between the top and bottom layers decreases, so the forces that create the layering effect break down. Eventually, the layering will be so weakened that a windy fall day will cause the top layer to mix with the bottom layer. This mixing is called **"fall turnover".**

In western Washington, the climate is mild and temperature differences are usually only great enough to stratify lakes during the sumer. Lakes in western Washington usually mix during the fall, winter, and partly through the spring. Higher elevation lakes, including most lakes in eastern Washington, will stratify and mix twice each year. In addition to stratifying during the summer, lakes will also stratify when they are frozen over in the winter. These lakes will "turn over" in the fall, and also will mix when the ice cover melts.

During turnover, dissolved chemicals from the bottom of the lake are stirred to the surface, and can fertilize the growth of algae. It is common for lakes to have algae flourish during the spring and the fall, after the lake mixes.

### A Lake Is Affected By It's Watershed

The chemical makeup of a lake is affected by the lake's watershed. A **watershed** is all the land, both above and below ground, that drains into a lake. Rain and stream water washing over plants and dirt will carry minerals and other dissolved substances from the soil, as well as plant material, into the lake. Groundwater also can flow from areas of higher elevation, carrying dissolved substances with it, eventually ending up in a lake as a spring. Material also enters the lake from erosion of the shoreline, from trees, from wildlife and from precipitation.

## The Life Cycle of a Lake

Lakes are formed by volcanic activity, the movement of the earth's crust, landslides, the dissolving of rocks (such as limestone), river activity, damming, and the action of glaciers. Each of these processes can form depressions in the earth that fill with water. Most of Washington's lakes have been formed by glaciers or rivers.

### Lakes "Age" From Plant Growth

Over a period of thousands of years, a lake will gradually support various types of plants and wildlife. Some lakes will even fill with sediment and be covered with vegetation. When lakes are first formed, they are generally deep because they have not yet begun to fill with sediment. "Newer" lakes will also have little plant growth because the water is usually low in nutrients. **Nutrients** are plant food compounds, the most important of which are usually nitrogen and phosphorus. Lakes with low nutrient levels and limited plant growth are called **oligotrophic** lakes.

As more nutrients are washed into the lake over time, the lake can support more plant and animal life. Algae, which are microscopic green plants that are suspended in the water, are the beginning of the food chain. Microscopic animals called zooplankton feed on the algae, and the zooplankton in turn are eaten by fish. As the lake becomes richer in nutrients, more types of aquatic plants begin to grow in the lake. Floating-leaved aquatic plants such as lily pads grow on the water and provide habitat for fish. Plants such as cattails grow along the edges of the lake. These plants provide habitat for birds and other wildlife.

As the algae and other aquatic plants die and sink to the bottom of the lake, they decompose and form sediment in the lake. Sediment begins to accumulate on the lake bottom, and the lake gradually becomes more shallow. With more nutrients and plant growth in the lake, the lake is no longer oligotrophic. The lake is now called a **mesotrophic** lake.

When there is an excessive amount of nutrients available for plants, there is the potential for an algae bloom to occur. An **algae bloom** occurs when one species of algae grows in such large numbers that clumps of the algae may be visible in the water, or water transparency may be drastically reduced. Algal blooms can happen during the summer months, when light and temperatures are optimal for plant growth, and can also happen during spring and fall turnover when nutrients are mixed throughout the water column. Algae blooms can prevent sunlight from penetrating very deep into the water. By shading out plants that are deeper in the water, algae blooms can prevent underwater plants from getting the sunlight they need to photosynthesize.

An excessive amount of nutrients in the water may also cause the algae species in a lake to change. Algae species that are eaten by zooplankton and fish can be replaced by blue-green algae species, which are not eaten by animals. Large populations of blue-green algae are usually associated with polluted or threatened lakes.

As dead plant material in a lake decomposes, oxygen in the water is used up by the bacteria that break down the plants. Species of fish that need high oxygen concentrations in the water may no longer may able to survive in the lake. Often, more tolerant fish species, such as the spiny rays and other rough fish, will replace the less tolerant trout species.

**All Lakes Fill in With Sediment**

The sediment in the lake contains the organic matter from the dead plant material, as well as minerals washed in from the surrounding watershed. As dead plants decompose, the nutrients they contain are released directly into the water or, in the presence of dissolved oxygen, may be chemically bound and settle out onto the sediment. When the lake stratifies and oxygen concentrations fall, these nutrients (primarily phosphorus) may be released back into the water column from the sediments. When the lake mixes again in the fall, high nutrient concentrations may once again be made available to the algae. Essentially, most nutrients that enter a lake are at least temporarily trapped in the lake, and the nutrients are recycled as different plants take them up and then release them again.

As more plants grow and then die, the process of sedimentation is accelerated and the lake gets smaller as it fills in with sediment. The edges of the lakeshore, filled in by the nutrient-rich sediment, can support the growth of more plants and grasses. Because of the large quantities of nutrients and plants in the water, the lake is referred to as a **eutrophic** lake, meaning "well nourished". The lake is mature, and is on its way to becoming a marsh. Eventually, almost all lakes fill in and become fertile areas for the growth of plants and trees. This process is called **eutrophication.**

**Land and Water Uses Can Cause Water Quality Problems**

The life cycle of a lake can take thousands of years when allowed to occur naturally. However, human activities in lakes and within a lake's watershed will introduce nutrients and sediments into a lake that speed up the process of eutrophication. Land activities that can affect lake water quality include the following:

- Erosion from forest practices and lakeshore development can contribute nutrients and sediments. Heavy volumes of sediment may wash into the lake after a large rainstorm.

- Agricultural practices, including concentrated animal feeding operations and plant fertilizing, concentrate nutrients which are washed into lakes.

- Septic systems contribute nutrients and bacteria into the water, especially when the system is not maintained.

- Road runoff can contain oil, settled particulates from car exhaust, and other road grime.

- Direct pollution of water by heavy metals or toxic organic compounds can occur from storm sewers, road runoff, spills, illegal pesticide and herbicide application, discharge from industries and sewage treatment plants or illegal dumping.

Water uses that can affect water quality include:

- Motor boating, which can introduce visible oil and grease from the motors, and bacteria contamination from pumping bilges. In addition, sediments in shallow lake areas can be disturbed.

- Over-watering lawns and crop irrigation can wash plant fertilizers into lakes.

Water quality problems can include algae blooms, aquatic weeds, suspended sediment in the water, and premature shallowing. Poor water quality may also cause the lake to have a foul odor. All of these characteristics interfere with the aesthetic enjoyment of lake--it is not much fun swimming among the algae mats!

With the proliferation of aquatic plants and algae, fishing becomes difficult and the species of fish present may change. Large insect hatches may take place at certain times of the year. It may become expensive or even impossible to use the lake as a drinking water source. Swimming beaches must occasionally be closed when the water clarity is severely lowered by too much suspended algae or sediment in the water or when bacteria levels rise.

**Monitoring Data Are Needed to Protect Lakes**

By monitoring the water quality of a lake for a few years, we can tell how eutrophic a lake is, and how rapidly the lake is "aging", or going through the trophic stages. Usually, rapid water quality deterioration results from human activities. If a lake is threatened because of human activity, it is important to take some corrective and/or protective actions as soon as possible. However, the first step to protecting lakes is documenting whether or not an actual problem exists.

**Water clarity** is one indicator of water quality. When there is not much suspended sediment in the water, water clarity can indicate the relative amount of algae. Using water clarity tests we can scientifically classify lakes as being oligotrophic, mesotrophic or eutrophic, especially when combined with chemical analysis of the water for nutrient concentrations.

**A Secchi Disk Measures Water Clarity**

A Secchi disk is 20 centimeters in diameter and is painted black and white in alternating quadrants. A a rope marked in one-foot intervals is attached. The Secchi disk is lowered into the water and the depth at which it can no longer be seen is recorded. The more suspended material in the water, the shallower the depth before the Secchi disk disappears from view. Conversely, clearer lakes will have deeper Secchi disk readings. The procedure is a simple yet standardized measure of water clarity, and is used in all lake studies.

Most suspended material in a lake will consist of sediment and algae. For all lakes, the Secchi disk readings will fluctuate during the monitoring season. This will happen because of the various weather conditions, natural processes and human activities that cause sediment and algae to become suspended in the water.

**The Sampling Procedure**

1. Choose a sampling day

Choose a regular convenient day of the week for sampling. Consult your calendar to be able to anticipate other time commitments, and plan accordingly.

The amount of sunlight, cloud cover and waves will affect the depth at which you can no longer see the Secchi disk. Therefore, it may not be possible to sample when the weather is poor.

Sampling is best under the following conditions:

- Sunny, partly sunny or partly cloudy skies
- Calm winds (NO WHITECAPS)
- Sun is as high as possible (between 10 a.m. and 2 p.m.)

Because weather conditions are often unpredictable, there is some room for flexibility in the sampling schedule. Try to sample within two days (either side) of your regular day, and try to space samples 12 - 16 days apart.

Also, if your lake is shallow and is used extensively for motor boating on weekends, it is best not to take Secchi readings from Saturday through Monday. Boat wakes, stirred sediments and motor oil in the water may affect your Secchi depth reading. The Secchi disk is used to measure average conditions, not worse-case conditions. If weekend sampling cannot be avoided, try to take the readings on Saturday before motor boat activity affects the water clarity.

If you cannot take a reading at your normally scheduled sampling period, don't worry about it. Just try to get out as soon as possible after that time, or have one of the other volunteers for your lake take a reading. To assure that we have accurate and "valid" data, it is better to skip a reading than to risk rushing through a reading and possibly getting a false Secchi depth. However, remember that frequent data are needed to accurately document the changes in water clarity at your lake. If there are no readings for an entire month, we won't know if this was the month that would have had the lowest, or the highest, water clarity! If you'd like to collect Secchi readings more frequently than every other week, we will give you more data cards.

A few words about safety: safety is the most important concern. Be sure to have the appropriate safety gear present in your boat at all times. Do not try to collect monitoring data when the water is rough. Also, we would much prefer that you lose equipment rather than go overboard trying to rescue it!

2. Load equipment into your boat.

You will need:

Secchi disk
thermometer
pH strips
bathymetric map
an anchor
life jackets
data card
pencil/pen (a clipboard is also useful, if you have one)
A watch (for recording time of sampling)

3. Locate your sampling station

Sampling locations should usually be at the deepest part of the lake. For your first time sampling, use the bathymetric map provided by Ecology to determine where the deepest part is (marked by an "X"). The site should be far enough from the shoreline so that during the summer the water will not be choked with lily pads or other aquatic weeds.

Once you have found the sampling location, recognize and record any landmarks on the shoreline that will help you come back to the same spot every sampling day. Sampling at the same place every sampling day is very important, because we need to be able to say that any observed changes in Secchi depth occurred at the same place.

4. Anchor your boat

Be sure that you are anchored firmly. If the boat drifts while you are taking a Secchi reading, the line may not be perfectly vertical and the Secchi depth will not be accurate. This is very important; even a gentle breeze can throw off a reading!

5. Fill out the data form

Fill in the sections for lake name and county, name of the monitor(s), date, time, and any helpful description of the lake (for example, you noticed that the lake level has dropped, that there is more algae in the water, or that there has been a lot of motor boating in the lake the prior weekend). Also use the sheet if you have any special comments or have any questions (for example, you need more data sheets).

6. Record the weather and water conditions

The "percent cloud cover" tells us about the weather on the day you sampled. Circle "100%" if the sky is completely overcast, and "0%" if the sky is completely clear. When there is patchy cloud cover, use your judgment to determine whether it is 10%, 25%, 50%, 75%, or 90%.

7. Record the water color

Lower your Secchi disk to about one half of your Secchi disk reading. For example, if your reading was 8 feet, lower your disk to 4 feet. Looking at a white part of the disk, estimate the water color. Although no one color on the data card will be the exact color of your lake water, pick which color is closest. Circle the color on the data card. If there is absolutely no comparison between the color of your lake water and the colors listed in the card, go ahead and write in a description of the water color.

8. Measure the Secchi disk transparency

The Secchi disk transparency is actually an average depth between the depth where you can just barely see the disk in the water, and the depth where you can just no longer see the disk.

To measure the Secchi depth, remove your sunglasses and lean over the **shaded** side of your boat (to reduce the sun's glare). While watching the disk, lower it to the point where it is no longer visible. Then slowly raise the disk until you just catch a glimpse of it. The disk will be very indistinct at this point, so take your time, and watch for it carefully.

Read the measured line attached to the disk at the water level. The line is marked in feet. Estimate fraction of feet to the nearest 1/4 foot.

Be careful that your disk isn't disappearing into a bed of aquatic plants. If this happens, make a note on the data sheet that there were too many aquatic plants to take the Secchi reading at your regular sampling location. Then select a second station to sample that will not be overgrown with weeds. Continue sampling this location along with the other location when possible, but make sure to keep the data from both stations separate. Refer to the new station as station #2, record a site description of the new site, and mark it on your bathymetric map.

9. Record the Secchi disk transparency

Record your Secchi disk reading on the data sheet. Recording the depth on the data sheet in the field is an important practice, since it reduces the possibility of transcription errors.

If you are monitoring a shallow lake, the Secchi disk may rest on the bottom of the lake and still be visible. Or, the Secchi disk may disppear into a bed of weeds. If either of these happens, check the appropriate box on the data sheet.

10. Repeat your Secchi disk reading, and record the reading

It is always a good practice to doublecheck test results. This is especially important when there may be variable test conditions. Because Secchi disk readings will vary with the amount of sunlight, cloud cover and waves, the test should be repeated and the second result recorded as well.

If the second reading is not the same as the first reading, **don't** change your data sheet so that both readings are the same. However, if the two readings are considerably different (more than 1 foot), you may want to do a third reading.

11. Take the temperature of the surface water

Remove the thermometer from its case and hold the bulb end in the water for about 2 minutes to allow the temperature to equilibrate. To prevent losing the thermometer in the water, we suggest that you attach a string to the top of the thermometer. Holding the thermometer with the string around your wrist should reduce the chance of dropping it. Once the temperature has been allowed to equilibrate, **quickly** read the temperature. Record the temperature to the nearest 1/2 degree.

12. Take the pH of the surface water.

Dip one of the pH strips in the water, and leave it in for a couple of seconds. Pull the strip out, and wait for about a minute (do not blot or dry the strip). Compare the color shades on the strip with the chart on the pH strip box. Even if the colors do not match exactly with the chart, the gradations of color on the two lower sections of the strip will be similar. Record the pH to the nearest 0.5 unit on the data card.

13. Take up anchor, bring boat and supplies to shore.

14. Record the height of your lake.

You will need a permanent structure, such as a dock piling or a gage, to record the changes in lake height. If you have a structure available, make a permanent mark from where you will measure the lake height every time. Be sure that the mark is high enough so that it will not be submerged during the fall when the rains come! Measure the distance from the mark with a ruler or tape measure; it may be easiest for you to nail a yardstick onto your dock. Record the distance from the mark to the nearest 1/4 inch.

15. Record the day's results on your permanent log sheet.

The master sheet is for you to record all your data on one convenient sheet. Another benefit is that if your card gets lost in the mail (which has happened in the past), your sampling effort is not lost.

16. Mail the completed data card (You do not need to put postage on the card).

17. Store Secchi disk and line in a dry place.

**Water Sample Collecting During the Summer**

Someone from the Ecology staff will accompany you during the two water sampling trips next year, which will occur in late May and August. We expect to have one person to accompany monitors in western Washington, and a second person to accompany monitors in eastern Washington. Ideally, we will accompany you in your boat during one of the normal sampling days and then collect some extra data.

The water sampling will be scheduled in advance, and if the weather is uncooperative, another day will be planned. If there is no convenient way to have an Ecology staff person assist with the sampling, you will be mailed the sample bottles and detailed instructions for collecting and mailing the sample.

**Plant and Algae Samples Can Be Sent To Ecology For Identification**

If you are concerned, or curious, about a particular plant or algae in your lake, you may send a sample in to Ecology for identification. We will include any identifications in the report completed for each monitored lake.

We will provide you with a small vial containing some algae preservative so that you can collect an algae sample. Ideally, you should collect a sample when algae growth is heaviest at your lake. Using a cup or container of your own, scoop some water that has a heavy concentration of algae, and carefully pour this into the vial. Do not scoop the water with the vial, since we do not want to lose the preservative in the lake. The vial should then be labeled (we will provide you with a label to fill out and stick onto the vial), wrapped in paper, and packed in a small box or heavy envelope. Mail via first or third class mail to: Julie Rector, Department of Ecology, 7171 Clean Water Lane Building 8, MS LH-14, Olympia, WA 98504.

If you want to send in additional algae samples, it is possible to collect and mail samples without having a vial and preservative. Algae samples should be collected in any container that seals without leaking. Plastic is good because it is lighter, and less likely to break. Not very much sample is needed if it is obvious there is algae in the water; 1/8 - 1/4 cup is quite plenty. When filling the container, leave a little air space at the top. Place the container in the freezer. When frozen, wrap the container in newspaper, pack it in a box, and mail to Ecology (at the address mentioned above) via first class mail. Be sure that the container is marked with the name of the lake and county, the day the sample was collected, where in the lake it was collected, and whether sample is a surface scum or was collected below the surface.

Plant samples should include as much of the plant as possible, especially any flowers or buds that may be on the plant. After shaking off any excess water, place the freshly-collected plant in a heavy plastic bag (such as a ziplock baggie), squeeze out all the air, and then seal the bag. Be sure to mark on the bag the name of the lake, when you collected it, where you collected it, and the depth of water the plant grows in. Wrap the bag in newspaper, and then pack it in a box or heavy envelope. Mail via first class or third class mail to Ecology.

**What Else Can You Do Besides Monitoring? -- Form a Lake Organization!**

Most lakes suffer from fragmented lake management, because no individual agency oversees all activities that can affect a lake's water quality. For the most part, watershed uses, shoreline uses, and lake water uses are all treated separately by various local and state agencies.

Lake protection is really a local issue. Most lake water quality problems arise from local activity within the lake's watershed. And, most laws that protect lake water quality are created and enforced by local agencies. Often these laws are created due to public interest or demand.

One way to draw public attention to potential lake water quality problems, and draw agencies' attention to existing lake water quality problems, is to form a lake organization. A lake organization can provide the public participation and support that is needed to effectively manage a lake. And because lake management actions are often controversial, it is necessary to know that any lake management action actually reflects the majority of the people who will be affected, that the actions are legal and do not create additional harm to the lake system, and that these actions are open to public review and comment. Addressing these will entail soliciting ideas and opinions about possible lake management actions from all people and groups that have some interest in the lake. These will include local residents, lakeshore property owners, sports and recreational clubs, local officials, and people in nearby communities that use the lake in some capacity (such as recreation, drinking water, etc.). By including all interested parties, your group will be less likely to meet with opposition and may also get more creative and workable solutions to the lake water quality problems to be solved.

What kind of group should be formed? This will depend in part on what the goals of the group will be. **Lake Associations** are aften formed after a lake problem has been discovered, although some associations have been formed with foresight for protecting existing lake water quality. All that is needed to form a lake association is a small group of motivated individuals. The group's first action will be to form a committee to identify the purpose of the association and create bylaws for running the association. Thereafter, the group needs to solicit membership in the association, and establish a means of funding association projects and organizing lake protection actions. Lake associations have no taxing authority.

**Lake Mangement Districts** are enabled to collect assessments (money) from property owners within the boundaries of the district, to be used for lake protection and management activities. Lake management districts can only be created by a county after the landowners within the proposed lake management district approve the proposal by a simple majority vote. If approved, the county legislative authority will adopt by ordinance the creation of the lake management district. Votes and assessments are weighed by the amount of property held by a landowner.

Forming a **Sewer District** does not necessarily mean you will have to install a sewer system. The advantage of a sewer district is that they have the authority to reduce, minimize or eliminate pollutants in lakes, streams, groundwater and waterways. Sewer districts may fund all or part of these actions by authorizing the issuance of bonds, and may also impose rates and charges on property owners for stormwater control facilities. Some sewer districts use their ability to deny water or sewer hookup, so that development within the watershed is done to minimize water quality impacts.

Regardless of the type of group formed, it is very important to establish rules for determing a consensus for holding meetings and approving group activities.

Otherwise, the group will lose its effectiveness when disagreement between members disrupts group activities.

The effectiveness of a group will also depend on the resourcefulness of its members and the willingness of people to get involved. For example, if the group wants to address a particular water quality problem, has this problem been documented in any way? Documentation can include noting when the problem occurs and how long it lasts, taking photos of areas of the lake where the problem is worst, and describing how the problem restricts uses of the lake (for example, swimming could be limited by slimy algal mats).

Or, the group may want to preserve existing water quality by addressing activities that have harmed water quality in other lakes. For example, zoning revisions to create a minimum waterfront lot width, or requirements for stormwater runoff controls, can be used to minimize water quality impacts from development.

**Summary**

Volunteer monitoring is an important part of water resource protection. Gradually, volunteer monitoring organizations have been formed in several states throughout the country. These volunteer monitoring programs supplement the water quality data that are gathered by various local and state agencies, and are used to assess the monitored water bodies.

The interest and commitment of the public towards the environment is recognized as a valuable, usable resource. This is especially the case in view of the limited federal, state and local dollars available for water quality monitoring. Data from lakes, streams and estuaries collected by volunteers are making a difference in states that have established long-term monitoring programs. For example, lake data collected by volunteers in New Hampshire were used to support a state bill requiring septic tank inspections for lake homes.

Volunteer monitors can also help local and state agencies to identify potential sources of pollution into water resoures. Documentation of water quality problems or changes can be used to determine whether some action needs to be taken. Actions may include more intensive water quality monitoring, or more "proactive" actions such as public education or local planning. The ultimate goal of everyone is the protection of water quality **before** it degrades, and not after the problem is irreversible.

Your participation in Washington's Citizen Lake Monitoring Project is a valuable contribution to the protection of your lake. By working together, with the peope who use lakes and the people who regulate the activities within lakes' watersheds, we can all enjoy and appreciate our lakes in Washington state!

WASHINGTON STATE DEPARTMENT OF ECOLOGY

# THE LAKE MONITOR

A Quarterly Update
for
Washington's Citizen Lake Monitoring Project
June 1989

# The Project Has Begun!

## The Lake Monitor

This update will be prepared quarterly (June, September, December, and March) by Julie Rector, coordinator for Washington's Citizen Lake Monitoring Project. The purpose of this update is to provide a forum for reporting on the progress of the program, and for providing information on lake water quality and other related issues. Suggestions for feature topics and contributions of thoughts and experiences may be made to Julie at (206) 586-5496.

## Agricultural Waste Problem?

Several lakes participating in the program appear to be affected by cattle grazing on the lakeshore or along inlet streams. Animal wastes contain bacteria, nutrients and organic matter. These pollutants can cause water quality problems such as bacterial contamination, algae blooms, and decreased oxygen levels. To prevent manure from entering surface waters, animal wastes from all animal-raising operations should be properly managed. Even small operations with few cattle should isolate grazing animals from water resources, and responsibly manage animal wastes.

Complaints about animal waste pollution should be directed to the nearest regional office of Ecology. Each complaint will be investigated, and if the problem does not warrant immediate corrective action (meaning, there is no immediate public health threat), then it will be referred to a local conservation district office. The conservation district will work with the farm opeator to develop a farm management plan for minimizing water quality degradation. The plan must be completed within six months, and will list the "best management practices" that will be used. Best management practices include fencing animals from water resources, and several methods for waste diversion, storage and spreading.

Development and implementation of a farm management plan is voluntary. However, if the farm operator does not act in good faith to correct the water quality problem, then Ecology will take an appropraite enforcement action.

Ecology is working towards eventually requiring wastewater discharge permits for all farms with more than 700 animals. Although theoretically any farm may be required to obtain a permit, permits have generally been issued to large operations.

Because of growing concern about agricultural wastes, each Ecology regional office has, or will soon have, an agricultural waste specialist. Phone numbers for the regional offices are printed on the other side of this page.

**Theme for Next Quarter: People Power.**

(Continued on other side)

## Ecology Lake Sampling Schedule

Some of the lakes monitored by volunteers were sampled by Ecology staff and analyzed for nutrients (such as nitrate, nitrite, ammonia, and total phosphorus) and fecal coliform bacteria. Lakes will be sampled in both June and August. The lakes selected, and the June sampling dates, are below:

| Lake | County | Date |
|---|---|---|
| American | Pierce | 06/07/89 |
| Black | Stevens | 06/20/90 |
| Black | Thurston | 06/07/89 |
| Blackmans | Snohomish | 06/26/89 |
| Blue | Grant | 06/19/89 |
| Cle Elum | Kittitas | 06/06/89 |
| Clear | Thurston | 06/14/89 |
| Cranberry | Island | 06/24/89 |
| Duck | Grays Harbor | 06/14/89 |
| Deep | Stevens | 06/20/89 |
| Goss | Island | 06/26/89 |
| Jumpoff Joe | Stevens | 06/20/89 |
| Lone | Island | 06/26/89 |
| Mason | Mason | 06/28/89 |
| Osoyoos | Okanogan | 06/06/89 |
| Packwood | Lewis | 06/07/89 |
| Samish | Whatcom | 06/27/89 |
| Sprague | Adams | 06/21/89 |
| Steilacoom | Pierce | 06/14/89 |
| Summit | Thurston | 06/07/89 |
| Sutherland | Clallam | 06/07/89 |
| Tiger | Mason | 06/28/89 |
| Wenatchee | Chelan | 06/06/89 |
| Williams | Spokane | 06/21/89 |
| Wooton | Mason | 06/28/89 |

**Washington Department of Ecology, Regional Offices - 24-hour numbers**

**Redmond . . . . . . . . (206) 867-7000**
Island, King, Kitsap, San Juan, Skagit, Snohomish and Whatcom counties.

**Olympia . . . . . . . . (206) 753-2353**
Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Lewis, Mason, Pacific, Pierce, Skamania, Thurston and Wahkiakum counties.

**Yakima . . . . . . . . . (509) 575-2800**
Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima counties.

**Spokane . . . . . . . . (509) 456-2926**
Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman counties

**Toll Free Numbers**

| | |
|---|---|
| Hazardous Substance Information Hotline | 1-800 633-7585 |
| Recycling Hotline | 1-800 732-9253 |
| Litter Hotline | 1-800 548-8377 |
| Automobile Emissions Testing Information | 1-800 272-3780 |
| Wood Smoke Information | 1-800 523-4636 |
| Red Tide Information | 1-800 562-6000 |
| Radon Information | 1-800 323-9727 |
| Poaching Hotline (Violations Only) | 1-800 562-5626 |
| Forest Practices | 1-800 527-3305 |
| Underground Storage Tanks | 1-800 826-7716 |
| Hazardous Waste Sites | 1-800 458-0920 |
| Forest Fire Report | 1-800 562-6010 |
| Puget Sound Water Quality Authority | 1-800 547-6863 |

# THE LAKE MONITOR

A Quarterly Update
for
Washington's Citizen Lake Monitoring Project
September 1989

## Remember: Secchi Disk Readings End In Mid-October

For those monitors who will be participating in next year's sampling season, go ahead and keep the Secchi disk to use next May.

For people who will not be monitoring next year, we will need to make arrangements for returning the Secchi disk and thermometer. These arrangements will depend on where you are located (I may come and pick up the materials), whether you are close to a Greyhound station, and whether you have a replacement already.

At the end of October, I will be contacting those of you who wish to be replaced.

Data sent in by volunteers, and the data collected during my water sampling trips in June and September, will be included in the final report. This report will be distributed to all project participants sometime early next year.

Thanks to all of you for participating this year!

## Looking to Next Year's Sampling: More Water Quality Tests!

Next year we'll be adding pH tests along with Secchi disk and surface water temperature readings. Also, we are working out the logistics for having all monitors collect at least one surface water sample that will be analyzed for certain nutrients. I will be distributing the additional monitoring supplies during April.

Because of laboratory requirements, analyses will be limited to parameters that do not need to be filtered or analyzed within 24 hours of sample collection. Therefore, samples cannot be tested for fecal coliform bacteria or dissolved oxygen, for example.

## People Power!

In the last LAKE MONITOR, I gave some suggestions for what to do when animal grazing practices are affecting lake water quality. In this edition, I discuss the effectiveness of forming a group for lake protection activities. This is what I call "People Power".

Why form a group? Lake management and protection can only happen with public participation and support. And because lake management actions are often controversial, it is necessary to know that any lake management action actually reflects the majority of the people who will be affected, that the actions are legal and do not create additional harm to the lake system, and that these actions are open to public review and comment. Addressing these will entail soliciting ideas and opinions about possible lake management actions from all people and groups that have some interest in the lake. These will include local residents, lakeshore property owners, sports and recreational clubs, local officials, and people in nearby communities that use the lake in some capacity (recreation, drinking water, etc.). By including all interested parties, your group will be less likely to meet with opposition and may also get more creative or workable solutions to the lake water quality problems to be solved.

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Regardless of the type of group formed, it is very important to establish rules for determining a consensus for holding meetings and approving group activities. Otherwise, the group will lose it's effectiveness when disagreement between members disrupts group activities.

The effectiveness of a group will also depend on the resourcefulness of members and the willingness of people to get involved. For example, if a group wants to ban motor boat use on a lake, someone will first need to do some research. The group should know whether boating safety is patrolled by the county sheriff or another department or agency, whether an existing restriction is already in the county code, and if there was a previous, but unsuccessful, attempt to enact a restriction on the lake. (The County Planning Office is a good place to start.) The group also needs to get a true feeling for how all people who use or are affected by the lake feel about imposing a restriction. Members of the group should also gather evidence that shows whether motoring harms the water quality of the lake. Documentation can include the number of boats used per day, dates of heavy boat use and photographs of oil slicks. In shallow lakes, sediments may be stirred up as a result of motor boat use. Secchi disk readings can be collected and compared between periods of no motor boat use and periods of heavy motor boat use. Collected evidence can later be presented to the governing agency that has the power to restrict motor boat use, after all other needed information is gathered. Once all the information is gathered and presented to the group, the group may want to reconsider the need for a restriction. The effects from motors may be minimized if responsible fueling, motor maintenance and operation is encouraged. This would entail a public awareness effort, such as posting signs and writing letters to the local newspaper. For some high-use lakes a lot of residents may oppose a restriction. In these cases, the group members may consider negotiating for use restrictions based on time of day, area restrictions to protect shallow areas or areas prone to erosion. More research into other lakes that have motor restrictions as well as conflict resolution skills could also be useful.

For more information about getting a group consensus on lake management issues, read the NALMS Management Guide or The Lake and Reservoir Restoration Guidance Manual; both of these are available using the publications order form I sent out with the last Lake Monitor

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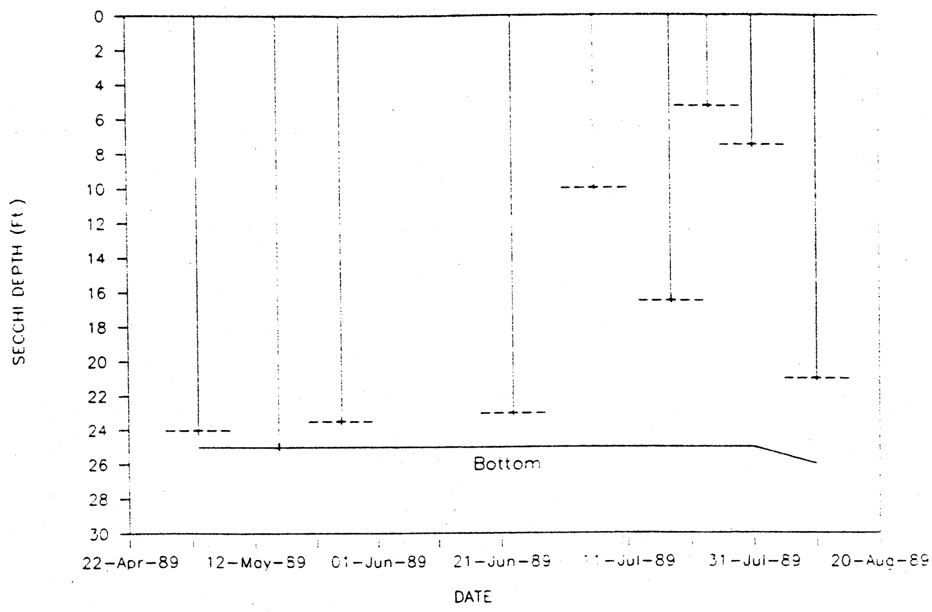
## Next Quarter: Controlling Aquatic Plants

## Progress of the Project

We are getting Secchi disk readings from anywhere between two feet (Barnes Lake in Thurston County) and 88 feet (Crescent Lake in Clallam County)! A few lakes have had severe algae blooms that have formed scums on these lakes, whereas others have remained fairly clear throughout the monitoring program. To show an example of what Secchi data can tell us, here is a graph showing the Secchi disk readings from Clear Lake in Thurston County:

CLEAR LAKE (THURSTON COUNTY)




This graph tells us that an algae bloom occurred from late June through late July, and that prior to that you could see almost to the bottom of Clear Lake. Note that if the monitor had not sampled during July, the algae bloom would have been missed entirely! By collecting Secchi measurements, the monitor has documented the severity and the duration of the algae bloom. We can also use the Secchi disk readings to estimate the trophic status (a description of aquatic productivity) of the lake. This is because there is a relationship between Secchi disk transparency and concentrations of total phosphorus (a plant nutrient) and chlorophyll (an indicator of algae volume) in lake water. Using the Secchi disk data shown here for Clear Lake, the average of a calculated trophic state "index" is 40. On a scale of 1 to 100, 1 indicates very little plant growth, anything over 60 is considered eutrophic and 100 means the lake is practically grown over with algae. Clear Lake is neither oligotrophic nor eutrophic, but is mesotrophic, because the lake has moderate plant and algae growth. This is supported by the observations made by the monitor, such as the water color. Over time, changes in the trophic state index can be used to demonstrate whether the lake is getting more productive, and to estimate the degree of productivity.

## Ecology Lake Sampling

The 25 lakes sampled by Ecology staff for conventional parameters during June were resampled during September. In addition, fish and sediment samples were collected for analysis for toxic pollutants from the following lakes:

| | |
|---|---|
| American Lake | (Pierce County) |
| Black Lake | (Thurston County) |
| Crescent Lake | (Clallam County) |
| Kahlotus Lake | (Franklin County) |
| Moses Lake | (Grant County) |
| Lake Osoyoos | (Okanogan County) |
| Lake Samish | (Whatcom County) |
| Sprague Lake | (Adams County) |
| Lake Wenatchee | (Chelan County) |
| Steilacoom Lake | (Pierce County; sediments only) |

The Lake Monitor is written by Julie Rector of the Environmental Investigations and Laboratory Services Program. Comments and Suggestions are encouraged!