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Water Quality Assessments of Volunteer Monitored Lakes Within Washington State

1998-1999

December 2002

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Water Quality Assessments of Volunteer Monitored Lakes Within Washington State

1998-1999

by
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Environmental Assessment Program
Olympia, Washington 98504-7710

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Glossary of Terms

Glossary

Action Value – a total phosphorus (TP) value established at the upper limit of the trophic states in each ecoregion. Exceedance of an action value indicates that a problem is suspected. A lake-specific study may be needed to confirm if a nutrient problem exists.

Algae Bloom – abundant growth of algae that results in mats, scums, or otherwise dense growths forming in or on the water. Not all types of algae form blooms.

Ambient Water Quality Monitoring – monitoring to collect baseline information on a water resource, which can therefore be used to determine if a water quality problem exists and how water quality is changing.

Bathymetric Map – a contour map of a lake's depth.

Blue-Green Algae – a type of algae that, when found in bloom concentrations, is usually associated with polluted or eutrophic water bodies. Most blue-green algae are considered to be nuisance species, because they may develop unpleasant scums and odors.

Chlorophyll *a* – a pigment found in the cells of photosynthetic plants. The quantity of chlorophyll *a* in a water sample indicates the amount of photosynthesizing algae per volume of water. In this report, chlorophyll *a* concentrations are reported in μg/L.

Clean Water Act (Federal Clean Water Act) – this law requires water quality to be kept at an acceptable level to support both swimming and fishing in all surface waters. The authority to enforce this law is with the EPA, but this authority can be delegated to individual states; it has been delegated to Washington.

Color – a test used to measure the color of water from which suspended matter has been removed. Color in water may result from natural metals, humus and peat materials, algae, and aquatic plants.

Conductivity – a measure of the ability of a solution to conduct electrical current. As ion content of water increases, conductivity will increase. The unit for expressing conductivity is μmhos/cm.

Cultural Eutrophication – eutrophication caused or accelerated by human activities.

CV – Coefficient of variation; calculated by dividing the standard deviation by the mean. It expresses variability relative to the mean of the sample.

Dissolved Oxygen – oxygen content in water that comes from being in contact with the atmosphere, from agitation (as in streams), or from being released by photosynthesizing aquatic plants. Oxygen is depleted by bacteria that decompose vegetation or other organic material, and from respiration by plants and animals. The unit for expressing dissolved oxygen is mg/L.

Epilimnion – the “top” (closest to the surface), warmer layer of water in a thermally stratified lake. See metalimnion, hypolimnion.

Eutrophic – describes a lake that has high nutrient concentrations, abundant plant and algae growth, and low water clarity. Eutrophication can occur naturally over time, or can be accelerated by human activities (see Cultural Eutrophication).

Fecal Coliform Bacteria – bacteria that are associated with mammal and bird feces. Fecal coliform bacteria results determine whether feces have entered and contaminated a water body. Fecal coliform bacteria results are reported in this report in colonies/100 mL.

Hydrolab® - the brand name of an instrument used to measure temperature, pH, dissolved oxygen and conductivity at various depths in water.

Hypereutrophic – describes a lake in advanced eutrophication which has very high nutrient concentrations, and very abundant plant and algae growth. In this report, hypereutrophic lakes will have a trophic state index value greater than 70.

Hypolimnion – when a lake is thermally stratified, the hypolimnion is the cooler layer of water at the bottom of the lake. See Epilimnion.

Lake Height – volunteers for this program measured the distance from a fixed point (usually on a stationary dock or piling) to the water surface. For most lakes the fixed point was above the water surface, so the greater the lake height value, the lower the water level.

Limnology – the science of lakes and streams, including the factors that influence the biology and chemistry of inland waters. (From the Greek *Limne*, which means “lake”).

Littoral zone – The shallow area that extends from shore to the lakeward limit of rooted aquatic plants.

Macrophyte – any aquatic plant larger than algae that grows on, or in, water.

Mesoeutrophic – a trophic state that is borderline between mesotrophic and eutrophic.

Mesotrophic – describes a lake that has moderate concentrations of nutrients, a moderate amount of plant and algae growth, and moderate water clarity (generally 7 to 13 feet, as measured with a Secchi disk).

Metalimnion – the middle layer of water between the epilimnion and hypolimnion of a thermally stratified lake. The metalimnion is located at the thermocline.

mg/L – milligrams per liter. A unit used to describe the concentration of a substance in solution. One mg/L is equivalent to one part per million (ppm).

Nitrogen – an essential plant nutrient that can be present in water in various forms. Common forms are nitrate, nitrite, ammonia, and dissolved nitrogen gas. Nitrogen concentrations are reported in mg/L.

Nutrients – substances, especially nitrogen and phosphorus compounds, that fertilize the growth of aquatic plants and algae. The amount of nutrients in water will affect the amount of plants and algae that can grow.

Oligotrophic – describes a lake that has low nutrient concentrations, little plant or algae growth, and very clear water.

Oligomesotrophic – a trophic state that is borderline between oligotrophic and mesotrophic.

Oxidation-Reduction Potential – "Redox" – the oxidizing or reducing intensity in water, measured in volts. In chemical reactions, electrons flow between constituents in a solution until equilibrium is reached; constituents which have gained electrons are reduced, and constituents which have lost electrons are oxidized.

pH – represents on a scale of 0 to 14 the acidity of a solution. A pH of 7 is neutral; acid solutions such as vinegar have a pH of less than 7, and basic solutions have a pH greater than 7.

Phosphorus – an important, often critical, plant nutrient that can be present in water in various forms. Phosphorus can be dissolved in water (orthophosphorus), adsorbed onto particles, or taken up by plants. Phosphorus concentrations are reported in µg/L.

Phytoplankton – Microscopic plant plankton that live unattached in water.

Piscivore – an organism that habitually feeds on fish; in lakes, piscivores generally include predator fish, birds, and freshwater mammals.

Planktivore – an organism that habitually feeds on plankton; in lakes, planktivores generally include fish, waterfowl, and plankton.

Plankton – the assemblage of suspended minute plants and animals that have relatively limited powers of locomotion, or that drift in the water subject to the action of waves and currents. Plankton forms the lowest level of the food chain, and includes zooplankton and phytoplankton.

Productivity – the amount of algae, aquatic plants, fish, and wildlife a waterbody can produce and sustain.

Profile Data – data collected at various depths of a lake to characterize a sampling site from surface to bottom. In this report, profiled parameters are temperature, pH, dissolved oxygen, and conductivity.

Riparian – Pertaining to the banks of streams, lakes, or tidewater

Runoff – water that washes over a ground surface or within the soil column as groundwater. Runoff can pick up suspended and dissolved substances from areas it has washed, and carry the substances to streams and lakes.

Secchi Disk – a black and white, 20 cm diameter disk that is attached to a rope. The disk is used to measure water transparency in open water. See Transparency.

Stratification (Thermal Stratification) – the state in which a lake forms distinct layers (the epilimnion and hypolimnion), usually because of the temperature differences between the surface and bottom of the lake. These layers do not mix while the lake is completely stratified.

Thermocline – when measuring temperature from the surface to bottom of a lake, the thermocline is characterized by a considerable change in temperature with little change in depth. It is the transition area between the epilimnion and hypolimnion.

Total Suspended Solids – measures the amount of suspended matter that is filtered out of a sample of water, and dried at a specified temperature. Nonvolatile solids are the residue remaining after the sample is ignited at a specified temperature. The units for expressing solids results are mg/L. Suspended solids do not include dissolved solids (such as salts).

Transparency – generally, water clarity of open water measured by a Secchi disk is called Secchi disk transparency. Secchi disk transparency is a measurement of the depth that sunlight can penetrate water and then reflect back up to the surface.

Trophic State – characterizes a lake according to the amount of plants that grow in a lake. Trophic state also characterizes the water clarity and the amount of nutrients in the water. See Oligotrophic, Mesotrophic, and Eutrophic.

Trophic State Index – a number that rates a lake according to the extent of eutrophication. In this report, oligotrophic lakes have lower trophic state values, and eutrophic lakes have a higher trophic state index value.

Turbidity – a measurement of the effects of light-absorbing and light-scattering substances that are suspended in water. Turbidity is determined by passing a light through a sample and measuring the amount of light that is scattered by the suspended particles. Turbidity is not the same as transparency.

Turnover (Lake Turnover) – the seasonal mixing of water layers that occurs when temperature differences lessen between the top and bottom layers of water. Turnover occurs during fall in most lakes. Lakes that freeze over during winter will also turnover after spring thaw.

Water Clarity – another term for Transparency.

Water Quality Standards – criteria established by Washington State for surface waters, cited in Chapter 173-201A WAC (Washington Administrative Code). Water quality standards (for dissolved oxygen, pH, fecal coliform bacteria, temperature, and other parameters) are established for classes of rivers, streams, and marine waters (Class A, AA, etc., depending on their characteristic uses), and lakes (Lake Class).

Watershed – all the area that collects water and drains to a lake via streams, surface runoff, or groundwater.

Winterkill – a fish kill in lakes generally caused by the depletion of oxygen in water while the lake is frozen over.

Zooplankton – microscopic animals in water that eat algae and are eaten by fish.

μg/kg – micrograms per kilogram. A unit of concentration used to describe how many micrograms of a chemical or contaminant are present in one kilogram of the analyzed substance (such as sediment or fish tissue). One μg/Kg is equal to one ppb (parts per billion).

μg/L – micrograms per liter. A unit of concentration used to describe how many micrograms of a substance are in one liter of solution. One μg/L is equal to one milligram per cubic meter (mg/m^3), and to one part per billion (ppb). One thousand μg/L is equal to one mg/L.

μmhos/cm – micromhos per centimeter. A unit used to describe conductivity measured by two electrodes 1 cm^2 in area and 1 cm apart.

Abstract

The objectives of the volunteer monitoring portion of Ecology's Lake Water Quality Assessment Program (LWQA Program) are to identify lakes that are exhibiting water quality problems, assess publicly owned lakes by estimating their trophic status, and promote public awareness of lake ecology and protection.

Volunteer monitors participating in the LWQA Program measured Secchi disk transparency, surface water temperature, pH, and other environmental parameters in 54 lakes in 1998 and in 47 lakes in 1999. The lakes were monitored bimonthly from May through October. To supplement volunteer collected data, Ecology staff collected water samples and profile data from all volunteer monitored lakes. Water samples were collected from the epilimnion layer of stratified lakes and were analyzed for total phosphorus.

Carlson's Trophic State Index (1977) was calculated for volunteer collected Secchi depth data and Ecology collected phosphorus data. Trophic state estimations - based on these calculations and an evaluation of other data - were assigned to each lake. For the 54 lakes sampled in 1998, 27 lakes (50%) were oligotrophic or oligomesotrophic, 21 lakes (40%) were mesotrophic or mesoeutrophic, and 3 lakes (5%) were eutrophic. Three lakes (5%) did not have enough Secchi data to calculate an index. For the 47 lakes sampled in 1999, 17 lakes (36%) were oligotrophic or oligomesotrophic, 21 lakes (45%) were mesotrophic or mesoeutrophic, and 4 lakes (9%) were eutrophic. Five lakes (10%) did not have enough Secchi data to calculate an index.

This report contains a lake assessment, a trophic state index, chemical data, a lake profile, and Secchi data for each volunteer monitored lake.

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Introduction

In 1989, the Washington State Department of Ecology (Ecology) began a grant funded statewide lake monitoring program. Volunteers collected bimonthly Secchi data (see Glossary, Appendix A) and Ecology staff collected water quality data in the spring and late summer. This program is described in Smith, et al., 2000. The primary technical goal was to assess the trophic state (see Glossary, Appendix A) of as many lakes in Washington as possible. In 2000, funding was reduced to minimum levels needed to maintain only the volunteer monitoring portion of the program. The current primary technical objective is to assess long term transparency trends in 40 to 50 lakes statewide.

The purpose of this report is to present the findings from the portion of the Lake Water Quality Assessment Program (LWQA) that deals with volunteer monitored lakes. In 1998, we studied 54 lakes and 47 lakes in 1999 . Lakes are reported and assessed on an individual basis (See Appendix B); a comparative analysis of statewide lake water quality is not within the scope of this report.

Program Objectives

The objectives of the volunteer monitoring portion of the program are as follows:

- Identify lakes that are exhibiting water quality problems.
- Assess publicly owned lakes by estimating trophic status.
- Promote public awareness of lake ecology.
- Pursue an integrated approach to lake assessment with Washington State Department of Fish and Wildlife (WDFW) officials, local government officials, and citizen volunteers.

Methods

Methods for lake selection, data collection, sample analysis, and data analysis are described below. Methods for quality assurance and quality control (QA/QC) of data collected for the program are discussed in the "Quality Assurance/Quality Control Evaluation" section.

Lake Selection

All Washington lakes that cover at least 20 acres and have a public access are eligible for inclusion in Ecology's volunteer monitoring program. Approximately 1,000 lakes in Washington meet these criteria, although the exact number is unknown (Rector and Hallock, 1995).

The main factor for selecting lakes was whether someone volunteered to monitor a lake for the program. Volunteers were recruited through press releases, or were referred to the program by Ecology staff, county offices, or from other volunteers. Potential volunteers were accepted into the program if they indicated that (1) they wanted to monitor an eligible lake, (2) they were willing and able to collect monitoring data for the six-month monitoring period, and (3) they had access to a boat to use while collecting data.

Ecology coordinated the lake selection with other volunteer lake monitoring programs in King County (implemented by King County Department of Natural Resources) and Snohomish County (implemented by Snohomish County Department of Public Works).

In summary, each year of monitoring includes a group of lakes which have been monitored by volunteers over a long period and potentially new lakes or volunteers who are added due to other lakes and/or volunteers leaving the program. We are fortunate to have a large core of volunteer monitors who have participated in our program for many years - some since the inception of the program in 1989. This long term monitoring data set could allow for trend analysis.

Field Methods

Many of the field methods implemented in 1998 and 1999 were adopted from methods used or developed outside of Washington State, which were then customized for the program's needs.

Sample Collection

Ecology staff visited volunteer monitored lakes twice between May and October. The purposes of these visits were to (1) collect Hydrolab® profile data (see Glossary, Appendix A) and sample for chemical parameters from the deep site of lakes; and (2) do Secchi depth quality assurance evaluations with the volunteer monitors.
During each field visit, the volunteer monitor escorted Ecology staff to their monitoring site. The boat was anchored if possible. The volunteer and Ecology staff each measured

Secchi depth. Temperature, pH, dissolved oxygen, and conductivity profiles were completed using a Hydrolab® Surveyor III or MiniSonde (see Glossary, Appendix A). Temperature profile data were used to determine whether the lake was stratified, and if so, to determine depths within the epilimnion (see Glossary, Appendix A) for collecting water samples. Weather conditions, water color, and general observations about the lake were recorded. If an obvious algal bloom was occurring at the surface or at depth (as indicated by a large change in dissolved oxygen with no concurrent decrease in temperature), a sample was collected for later identification. Macrophyte samples were either identified onsite or collected for later identification. Algae and macrophyte samples were collected for qualitative purposes only, and results may not include all species in the community. Complete aquatic plant surveys at selected lakes were conducted independently by other Ecology staff (see Parsons, 1999).

Chemical sampling of the lakes was not done in 1998. In 1999 during each Ecology site visit, water samples for total phosphorous (TP) were collected using a Kemmerer water sampler, and were composited from two to three equidistant depths within the epilimnotic strata (see Table 1). All samples were transported on ice to the lab and stored at 4°C.

Table 1. Analytical method used for samples collected for the LWQA Program.

Parameter	Strata Sampled[1]	Sample Preservation[2]	Analytical Method[3]	Method Detection Limit	Holding Time	Lab[4]
Total Phosphorus	epilimnion	H_2SO_4 to pH < 2	SM 4500-P D	3 µg/L	28 days	MEL

[1] All samples were composited.
[2] All samples kept on ice or stored at 4°C until delivery to the lab.
[3] Huntamer and Hyre, 1991
[4] Manchester Environmental Laboratory (MEL)

Sample Analysis Methods

Methods used for sample analyses are listed in Table 1. Sample preservation and analytical methods used by Manchester Environmental Laboratory (MEL) are described in Huntamer and Hyre (1991).

Keys used for algal identifications were Smith (1950), Edmondson (1959), Prescott (1962; 1978), and VanLandingham (1982). Keys used for macrophyte identifications were Tarver *et al.* (1978), Prescott (1980), and others (see Parsons, 1999).

Data Analysis Methods

Based on all data collected and best professional judgement, lakes were given an overall trophic state assessment. In addition, certain lakes were chosen to be part of a separate intensive lake study conducted by other Ecology staff (see Smith , K., D. Hallock, and S. O'Neal, 2000. *Water Quality Assessment of Selected Lakes Within Washington State:*

1998 and O'Neal, S., D. Hallock, and K. Smith, 2001. *Water Quality Assessment of Selected Lakes Within Washington State: 1999).* One of the results of these intensive lake studies was the proposal of a phosphorus criterion for each lake studied. These recommended phosphorus criteria are included as part of the overall lake assessment.

Estimating Trophic Status

Carlson's (1977) trophic state indices (TSI) for Secchi depth (TSI_{SD}) and total phosphorus (TSI_{TP}), tempered with professional judgment, were used to estimate the trophic status of the monitored lakes. Carlson's calculations for trophic state indices are as follows:

TSI_{SD} = 10*(6-(ln Secchi Depth in meters/ln 2))

TSI_{TP} = 10*(6-((ln(48/Total Phosphorus))/ln 2))

In general, TSIs of 40 or less indicate oligotrophy, TSIs between 40 and 50 indicate mesotrophy, and TSIs greater than 50 indicate eutrophy (Carlson, 1979). To describe lakes that appeared to be between trophic states, the terms "oligomesotrophic" and "mesoeutrophic" were used. Refer to the glossary in Appendix A for more detailed definitions of trophic state terms.

TSI_{SD} values were calculated from a time-weighted mean Secchi depth calculated from all Secchi data collected between mid-May and mid-October. A minimum of five Secchi depth measurements separated by at least two weeks were required to calculate an unqualified TSI_{SD} for each lake. TSI_{SD} values failing the five measurement minimum are qualified with the letter 'N.' TSI_{TP} values were similarly calculated from time-weighted mean total phosphorous values.

It is not valid to average TSI values from different trophic state parameters, and to use that average to summarize a lake's trophic status. According to Carlson (1977), "the best indicator of trophic status may vary from lake to lake and also seasonally, so the best index to use should be chosen on pragmatic grounds." A subjective assessment of all data collected during the monitoring season was used to determine an appropriate index for assigning trophic states. Other data collected during this study, data from other sources (short term lake surveys conducted by Ecology or universities, consultant reports from Ecology-funded lake restoration activities, etc.), and information from the volunteers (e.g. on aquatic herbicide use) were used to temper the trophic state assessment for most lakes. As a result, the final trophic state estimations were not based on TSI alone, and were not necessarily based on the same parameters for all lakes. The basis for each trophic state assessment is discussed in the "Summary" section of the individual lake assessments in Appendix B. Because chemical data was not collected from the lakes in 1998, all the TSIs for this year are qualified "J" to indicate the TSI is an estimate.

Setting Proposed Phosphorus Criteria

The Washington State Water Quality Standards (WAC 173-201A (6)) suggest total phosphorus criteria for lakes (also referred to as "action values," see Glossary) be based on ecoregion and trophic state. If measured concentrations are below the action value, a criterion may be proposed at or below the action value, or a lake specific study may be conducted. Measured concentrations above the action value or where no action value is provided require a lake specific study. The characteristics monitored in the lake specific studies portion of the LWQA Program (see Smith, et. al., 2000) are similar to examples included in the Water Quality Standards.

An evaluation of the primary uses on each lake is one of the purposes of the lake specific study. These were determined from user perception surveys, conversations with other natural resource biologists, observations during sampling, and discussions with volunteer monitors. Determining whether or not the water quality in the lake supports the primary uses required best professional judgment. The types of uses were considered and water quality was subsequently determined sufficient or insufficient to support those uses. The results of questionnaires were reviewed to determine how the users perceive water quality. Additionally, local governments, fish and wildlife officials, and other lake studies were consulted. Aquatic plant surveys as well as results from the habitat survey provided information on aquatic vegetation, which may impact the quality of swimming, fishing, and boating, as well as fish reproduction and wildlife habitat suitability.

If the lake's primary uses were supported, then the nutrient criterion recommended for the lake was generally the mean total phosphorus concentration plus an adjustment for inter-annual variation, described below, or the action value. In general, the more protective of either the action value or the mean total phosphorous value was recommended as a criterion. The final recommendation also depended on best professional judgment as to whether current nutrient concentrations were elevated due to anthropogenic sources.

If the lake's primary uses were not supported and were adversely impacted by artificially high nutrient concentrations, then further study may be necessary to determine what level of nutrient concentrations will support the primary uses. Alternatively, if uses were not supported because of habitat modifications, or other non-nutrient related attributes, then recommendations are made on how to improve conditions in order to support those uses. Recommendations can be based on the results from water quality, habitat, watershed, user perception, zooplankton, and Hydrolab® surveys. One benefit of this new approach to lake assessment is the potential to integrate information for management purposes.

The phosphorus criteria proposed in some of the lake assessments of this report were selected using information compiled through the seasonal sampling. As previously discussed, a criterion was usually recommended as either the action value listed in the Water Quality Standards, or the mean total phosphorus concentration plus an adjustment to allow for natural inter-annual variation. This adjustment was calculated as the median inter-annual standard deviation of all lakes monitored by the LWQA program for more than two years with similar phosphorus concentrations to the lake being evaluated (Table 2). For example, if the seasonal mean value for phosphorus in a given lake is 18.3 ug/L, a recommendation of a nutrient criterion of 18.3 + 4.1 = 22.4 ug/L total phosphorus was made. However, if that lake was in the Puget Lowlands and was assessed as lower mesotrophic, the action value of 20 ug/L may be recommended because the action value is more protective yet is still above the mean measured concentration.

Table 2. Median inter-annual standard deviations based on historical data as a function of mean total phosphorus concentrations.

Mean Phosphorus Concentration (µg/L)	Median Inter-annual Standard Deviation	Number of Lakes
Less than or equal to 10	3.0	19
>10 through 20	4.1	43
>20 through 30	5.1	17
>30 through 40	8.0	16
>40 through 60	15.0	7
>60 through 80	27.8	2
Greater than 100	70.6	8

The intent of the proposed phosphorus criteria are to be protective but not overly sensitive. The ideal criterion should be sensitive enough to have a reasonable probability of identifying lakes that may be degraded or degrading; yet not so sensitive as to falsely identify lakes as degrading that are merely undergoing interannual variation. Too insensitive a criterion would fail to identify degrading lakes; too sensitive a criterion would falsely report too many lakes as degrading and would be meaningless as a management tool. These criteria should be considered preliminary. Once a lake has exceeded a criterion, a more detailed study should be conducted, including in particular a nutrient loading analysis, the first objective of which should be an evaluation and refinement of the criterion.

Quality Assurance and Quality Control Evaluation

All data collected for the LWQA Program were evaluated to determine whether data quality objectives for the program (Table 3) were met. Methods used for data quality evaluations are described in *Lake Water Quality Assessment Program Quality Assurance Project Plan* (Hallock, 1995-draft). QA/QC analysis for all parameters is listed in Appendix C.

Table 3. Summary of data quality objectives for the LWQA Program.

Parameter	Detection Limit	Precision	Accuracy (Bias)
Secchi Depth	--	< 10% CV[a] (daily pairs)	< 10% CV[b] (volunteer/ Ecology)
Total Phosphorus	3 µg/L	< 7.5% CV (10 lab splits)	< 2.5% relative bias (lab check standards)
Profile parameters			
Temp.	--	--	± 1.0°C
pH	--	--	± 0.2 SU
D.O.	--	--	± 0.50 mg/L
Specific conductivity	--	--	± 5 µmhos/cm

[a] Coefficient of Variation
[b] In the case of Secchi depth, this isn't truly "accuracy" but rather a comparison between volunteer and Ecology staff collected readings. QC requirements for Secchi depth were only applied to volunteer collected data.

Profile Data

The Hydrolabs® were pre- and post-calibrated daily for pH and dissolved oxygen (See Appendix C). The manufacturer's instructions were followed for pH calibration, using pH 7 and pH 9.15 (low ionic strength) standard buffer solutions. Post-calibration readings within 0.2 pH units of the buffer values were considered acceptable. All Hydrolab® measurements failing quality assurance requirements are qualified accordingly, as denoted by the qualifier "J," indicating an estimate (See the Hydrolab® data table within each lake assessment).

The dissolved oxygen sensor was calibrated against theoretical water-saturated air, in accordance with manufacturer's instructions. Daily field samples were collected for Winkler titrations and check standards. Post-calibration results within 0.5 mg/L were considered acceptable. We have consistently had difficulties with oxygen check standards. Air calibration may be insufficiently accurate for our data quality objectives. All Hydrolab® measurements failing quality assurance requirements are qualified accordingly, as denoted by the qualifier "J," indicating an estimate (See the Hydrolab® data table within each lake assessment).

Specific conductance, a more stable parameter on the Hydrolab®, was checked periodically using the manufacturer's instructions. Potassium chloride standards used for conductivity calibration ranged from 101 to 147 µmhos/cm at 25°C (the molarity varied between individual solutions used). Post-calibration values within 5 µmhos/cm of the standard value were considered acceptable. All measurements failing quality assurance requirements are qualified accordingly, as denoted by the qualifier "J," indicating an estimate (See the Hydrolab® data table within each lake assessment).

Temperature was also checked periodically against a National Bureau of Standards (NBS) mercury thermometer. Values within 1.0°C were considered acceptable. All measurements failing quality assurance requirements are qualified accordingly, as denoted by the qualifier "J," indicating an estimate (See the Hydrolab® data table within each lake assessment).

Laboratory Quality Assurance

Laboratory quality control requirements include the use of check standards, reference materials, matrix spikes, blanks, and lab split samples (duplicates). Lab splits are discussed below. Data quality for this project met all lab quality assurance and quality control criteria as determined and evaluated by the Manchester Environmental Laboratory.

Field Quality Assurance

Total Phosphorous Data

Lab precision was calculated by pooling the coefficients for all pairs of lab splits. Not all of the results (See Appendix C) were all under the acceptable median CV% of 7.5 percent. Total phosphorous samples were collected at a second site from seven lakes during the course of the survey. These nonsequential samples were collected to evaluate the representativeness of collecting epilimnetic data from a single lake station. The Quality Assurance Project Plan (QAPP) for the LWQA Program (Hallock, 1995-draft) states that the total precision of these nonsequential duplicates should be evaluated by pooling the CV%s for each pair and, if the median CV% exceeds 21 percent, then collecting from a single lake station is generally not representative of lakewide epilimnetic phosphorous. Results (See Appendix C) show that the median CV% did exceed 21 percent in four of the seven lakes; therefore, sampling at one site did not appear to be is generally representative.

In addition to nonsequential duplicates, sequential duplicates were collected at three of these seven lakes by immediately repeating the sample collection at the original sampling site. Although no specific quality assurance standards were set for sequential duplicate total phosphorous data, both median CV%s of 0.1 and 1.5 indicate little variance.

Results

Data collected for each lake - individual lake assessments, chemistry data, Hydrolab® profile information and Secchi data - are tabulated and discussed in Appendix A. In some cases, where a lake specific study was done on the lake by other Ecology staff, a phosphorus criterion is recommended.

Table 4. Summary of Individual Lake Assessments

Lake Name	County	Assessed Trophic State 1998/ 1999$_a$		Mean Total Phosphorus (ug/L) - 1999 only	Mean Secchi Depth (meters) 1998	1999	Proposed Total Phosphorus Criteria (ug/L)
Alice	King	OM	OM	12.8	4.2	4.3	*b*
Big Meadow	Pend Oreille	M	ME	22	3.4	3.5	*b*
Black	Stevens	M	M	22.1	3.7	4.9	*b*
Black	Thurston	M	*c*	*c*	2.1	*c*	*b*
Bosworth	Snohomish	OM	OM	10.5	4.6	5.1	*b*
Chambers	Thurston	E	*c*	*c*	0.6	*c*	*b*
Clear	Spokane	M	M	18.5	3.3	3.9	*b*
Conconully	Okanogan	OM	*d*	17.2	4.8	3.4	*b*
Crawfish	Okanogan	O	M	21.4	4.4	3.9	*b*
Curlew	Ferry	M	M	19.3	3.5	5.1	20.0
Deep	Stevens	OM	M	20.4	4.1	4.2	*b*
Deer *	Stevens	*e*	OM	21.4	*e*	8.7	20.0
Duck	Grays Harbor	ME	E	43.8	2.4	0.9	47.2
Gillette *	Stevens	M	M	32.9	3.8	4.3	27.8
Haven	Mason	OM	OM	10.5	6.1	6.3	*b*
Hicks	Thurston	M	ME	14.2	2.6	2.1	*b*
Horseshoe	Kitsap	M	M	13.7	4.1	3.7	*b*
Isabella	Mason	M	ME	27.5	3.8	3.7	*b*
Island	Mason	OM	*c*	*c*	5.3	*c*	10.0
Kitsap	Kitsap	M	M	24.7	4.5	5.0	*b*
Lacamas	Clark	E	E	44.8	1.9	1.6	*b*
Lawrence	Thurston	M	ME	22.6	3.4	3.5	*b*
Leland *	Jefferson	ME	ME	34.1	2.3	2.5	20.0
Liberty *	Spokane	OM	ME	26.1	4.9	2.7	17.4
Limerick *	Mason	M	M	14.2	3.2	3.5	10.0
Loon	Stevens	OM	OM	10	7.7	6.4	*b*
Lake Martha	Snohomish	OM	M	12.5	4.0	3.4	15.8
Martha Lake	Snohomish	OM	*c*	*c*	4.9	*c*	*b*
Mason *	Mason	OM	OM	12.8	7.2	6.5	7.3

Table 4. Continued.

Lake Name	County	Assessed Trophic State 1998/ 1999[a]		Mean Total Phosphorus (ug/L) - 1999 only	Mean Secchi Depth (meters) 1998	1999	Proposed Total Phosphorus Criteria (ug/L)
McIntosh	Thurston	E	E	34.8	1.8	2.1	*b*
Munn	Thurston	E	*d*	18.5	1.3	1.7	*b*
Nahwatzel	Mason	O	O	6.7	5.0	6.0	*b*
Newman	Spokane	*d*	*d*	13.5	2.1	1.5	*b*
Offutt	Thurston	M	M	*c*	2.8	*c*	20.0
Osoyoos	Okanogan	M	M	16.8	2.9	3.1	*b*
Palmer	Okanogan	*c*	*d*	*c*	4.2	*c*	*b*
Pattison (North Arm)	Thurston	M	E	38.7	3.1	1.8	*b*
Phillips	Mason	O	OM	9.9	4.2	4.3	10.0
Roesiger (North Arm)	Snohomish	*d*	OM	4.9	5.0	5.4	*b*
Roesiger (South Arm)	Snohomish	OM	OM	11.3	5.2	5.7	*b*
Samish (East Arm)	Whatcom	OM	OM	6.9	4.7	6.0	*b*
Samish (West Arm)	Whatcom	OM	*d*	10.7	5.4	6.3	*b*
Sawyer	King	OM	M	14	4.6	4.6	*b*
Spanaway	Pierce	ME	M	18.1	3.2	3.6	20.0
Spencer	Mason	OM	*c*	*c*	4.6	*c*	*b*
St. Clair	Thurston	M	ME	51.5	3.1	3.1	*b*
Sullivan	Pend Oreille	*d*	*d*	13.6	10.0	7.8	*b*
Summit	Thurston	OM	OM	4.4	7.8	6.8	*b*
Tapps	Pierce	M	*d*	72.5	0.9	1.7	*b*
Thomas	Stevens	M	M	29.8	3.8	4.4	*b*
Tiger	Mason	OM	OM	8.7	5.1	5.2	*b*
Trails End	Mason	OM	O	10.4	4.3	5.4	*b*
Ward	Thurston	OM	OM	9.3	4.0	4.0	10.0
Wenatchee	Chelan	O	O	4.8	7.2	7.1	*b*
Wildcat *	Kitsap	OM	OM	16.8	5.2	5.4	10.0
Wooten	Mason	O	OM	5.5	7.2	6.6	*b*
Wye	Kitsap	OM	OM	6.6	4.1	4.0	*b*
MEAN				19.4	4.1	4.3	
MINIMUM				4.4	0.6	0.9	
MAXIMUM				72.5	10.0	8.7	

* 1999 mean total phosphorus level exceeds proposed total phosphorus criteria

a E= eutrophic; ME= mesoeutrophic; M=mesotrophic; OM= oligomesotrophic; O= oligotrophic

b no phophorus criteron determined

c only sampled in 1998

d not enough data for an assessment

e only sampled in 1999

The following is a summary of the percentage of lakes sampled each year by trophic state:

Trophic State	**Percentage of Lakes Sampled in 1998**	**1999**
Oligotrophic	9%	6%
Oligomesotrophic	42%	36%
Mesotrophic	35%	34%
Mesoeutrophic	6%	16%
Eutrophic	8%	8%

Compared to 1998, the trend in 1999 seems to be of a number of lakes becoming more productive. In order to determine whether this is a continuing trend, additional years of data for analysis are required.

Precision (the reproducibility of measurements) and accuracy (how close the measured value is to the "true" value) are always of concern in any monitoring program. Appendix C details the precision and accuracy of the data collected by the volunteer monitors in this program.

In 1998, seven out of 45 volunteers (15%) failed to meet the program's quality control level for Secchi depth accuracy as established in Ecology's *Lake Water Quality Assessment Project Quality Assurance Project Plan* (Hallock, 1995-draft). In 1999, this number dropped to 10% (five out of 48 volunteers). With good training and close supervision, volunteers are an extremely valuable resource in conducting a monitoring program.

Recommendations

- 1999 marked the final year of the volunteer monitoring program as outlined in the Quality Assurance Project Plan (QAPP) for the LWQA Program (Hallock, 1995). In 2000, a much reduced program was implemented. While technical monitoring and lake assessments have been eliminated, we have continued to provide resources to interested volunteer lake monitors to continue to collect Secchi data in 2001. These data will be used to assess transparency trends. Lakes are a vital ecosystem, providing critical habitat for salmonids and other organisms as well as recreation. This lake monitoring program was the only statewide program that assessed the health of these ecosystems, and the only program that developed protective water quality criteria for lakes. Funding for a statewide lake monitoring program should be restored.

- If the LWQA Program should obtain funding or be revived, several procedures need to be evaluated (see recommendations in Smith et al. 2000). Also, the accuracy of air calibrating the profiling instrument oxygen sensor should be investigated.

References

Carlson, R.E., 1977. "A Trophic State Index for Lakes." *Limnol. Oceanogr.* 22: 361-369.

-----, 1979. "A Review of the Philosophy and Construction of Trophic State Indices" *In* Maloney, T.E. *Lake and Reservoir Classification Systems*. U.S. Environmental Protection Agency Report No. EPA-600/3-79-074, pp. 1-52.

Edmondson, W.T. (ed.), 1959. *Fresh-Water Biology*, 2nd ed. John Wiley and Sons, Inc., NY, 1248 pp.

Hallock, D., 1995 (in draft). *Lake Water Quality Assessment Project Quality Assurance Project Plan*. Environmental Investigations and Laboratory Services Program, Washington Department of Ecology, Olympia, WA.

Huntamer, D., and J. Hyre, 1991. *Manchester Environmental Laboratory, Laboratory User's Manual*, Third Edition. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA, 342 pp.

Parsons, J., 1999. *Aquatic Plants Technical Assistance Program, 1998 Activity Report*. Washington State Department of Ecology, Olympia, WA, Publication No. 99-328.

Prescott, G.W., 1962. *Algae of the Western Great Lakes Area*. Wm. C. Brown, Co Publishers., Dubuque, IA, 977 pp.

-----, 1978. *How to Know the Freshwater Algae*. 3rd ed., Wm C. Brown Co., Dubuque, IA, 293 pp.

-----, 1980. *How to Know the Aquatic Plants*. Wm. C. Brown Co. Publishers. Dubuque, IA.

Rector, J. and D.Hallock, 1995. *1994 Statewide Water Quality Assessment Lakes Chapter, Companion Document to Washington State' 305(b) Report*. Washington State Department of Ecology, Environmental Investigations and Laboratory Services Program, Olympia, WA, Publication No. 95-311.

Smith, G.S., 1950. *The Freshwater Algae of the United States*. 2nd ed. McGraw-Hill Book Company, Inc., 719 pp.

Smith , K., D. Hallock, and S. O'Neal, 2000. *Water Quality Assessment of Selected Lakes Within Washington State: 1998*. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA, Publication No. 00-03-039.

Smith, K., J. Parsons, and D. Hallock, 2000. *Water Quality Assessment of Selected Lakes Within Washington State: 1997*. Washington State Department of Ecology, Environmental Assessment Program, Olympia, WA, Publication No. 00-03-009.

Tarver, D.P., J.A. Rodgers, M.J. Mahler, and R.L. Lazor, 1978. *Aquatic and Wetland Plants of Florida*. Florida Department of Natural Resources, 128 pp.

VanLandingham, S.L., 1982. *Guide to the Identification, Environmental Requirements and Pollution Tolerance of Freshwater Blue-Green Algae (Cyanophyta).* U.S. Environmental Protection Agency EPA-600/3-82-073. 341 pp.

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Appendix A
Individual Lake Assessments

Appendix B

Quality Assurance/Quality Control Results for 1998 and 1999

For details on procedures for evaluating QC data see Ecology's *Lake Water Quality Assessment Project Quality Assurance Project Plan* (Hallock, 1995-draft). This appendix is an evaluation of laboratory data and Secchi data in accordance with the quality assurance project plan.

Appendix C

Hydrolab® Quality Assurance/Quality Control Results for 1998 and 1999

For details on procedures for evaluating Hydrolab® QC data see Ecology's *Lake Water Quality Assessment Project Quality Assurance Project Plan* (in draft) (Hallock, 1995) or see the Hydrolab® post-calibration results of any prior Ecology lake water quality assessment program annual report.