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DEPARTMENT OF
ECOLOGY

Lake Ballinger
Total Phosphorus
Total Maximum Daily Load

Water Quality
Attainment Monitoring Report

April 2008

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by

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Abstract

The Washington State Department of Ecology (Ecology) is required, under Section 303(d) of the federal Clean Water Act, to (1) develop a list of impaired waters, (2) implement Total Maximum Daily Load (TMDL) studies for analysis of the pollutants, and (3) evaluate the effectiveness of the subsequent cleanup plans enacted to achieve the needed improvements in water quality.

Ecology listed Lake Ballinger (in Snohomish County) under Section 303(d) for non-attainment of beneficial uses based on a Phase III final lake restoration plan report. These beneficial uses included recreation, sport fishing, boating, and aesthetic enjoyment. The identified parameter of concern was total phosphorus.

Ecology submitted a TMDL (water cleanup plan) for Lake Ballinger, based on the Phase III report, to the U.S. Environmental Protection Agency (EPA). EPA approved the TMDL in 1993.

The objectives of this current study are to determine if (1) past restoration treatments have been effective in restoring Lake Ballinger to its designated uses, and (2) current phosphorus concentrations are consistent with the criterion set in the TMDL.

In November 2005, Ecology began a 12-month monitoring project to measure total phosphorus in Lake Ballinger. Evaluation of the data indicates the total phosphorus concentration was below the mean summer target limit of 30 µg/L set by the TMDL. The TMDL goal for total phosphorus at Lake Ballinger is currently being met. It appears restoration treatments have been effective in keeping phosphorus levels in Lake Ballinger from increasing over the TMDL target limit.

This report makes recommendations to help ensure phosphorus targets continue to be met. Recommendations include (1) lake and stormwater monitoring programs, (2) public education and outreach on fertilizer use and other activities that contribute nutrients to water, and (3) possible alum treatments as a short-term solution to internal lake phosphorus recycling.

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- In addition, the author would like to thank Mike Shaw from the City of Mountlake Terrace for reviewing this report and providing useful information about Lake Ballinger.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act Requirements

The Clean Water Act established a process to identify and clean up polluted waters. Under the Clean Water Act, every state has its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses for protection, such as cold water biota and drinking water supply, and criteria, usually numeric criteria, to achieve those uses.

Every two years, states are required to prepare a list of waterbodies – lakes, rivers, streams, and marine waters – that do not meet water quality standards. This list is called the 303(d) list or water quality assessment. To develop the list, Ecology compiles its own water quality data along with data submitted by local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data are reviewed to ensure that they were collected and analyzed using appropriate procedures and methods before the data are used to develop the 303(d) list. Data are evaluated using Ecology's Water Quality Program listing policy WQP 1-11.

TMDL Process Overview

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated in order for that waterbody to meet water quality standards. The local community then works with Ecology to develop a strategy to control the pollution and a monitoring plan to assess effectiveness of the water quality improvement activities.

Elements Required in a TMDL

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources.

If the pollutant comes from a discrete (point) source such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If it comes from a set of diffuse (nonpoint) sources such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation.*

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

Water Quality Assessment / Categories 1-5

The 303(d) list identifies polluted waters in Washington. The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. This list divides waterbodies into one of five categories:

- Category 1 – Meets tested standards for clean water.
- Category 2 – Waters of concern.
- Category 3 – No data available.
- Category 4 – Polluted waters that do not require a TMDL since the problems are being solved in one of three ways:
    - 4a – Already has an approved TMDL that is being implemented.
    - 4b – Has a pollution control plan in place that should solve the problem.
    - 4c – Is impaired by a non-pollutant (e.g., low water flow, non-native plant species).
- Category 5 – Polluted waters that require a TMDL – also known as the 303(d) list.

TMDL Analyses: Loading Capacity

Identification of the pollution loading capacity for a waterbody is an important step in developing a TMDL. The U.S. Environmental Protection Agency (EPA) defines the loading capacity as "the greatest amount of loading that a waterbody can receive without violating water quality standards" (EPA, 2001). The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with standards. The portion of the waterbody's loading capacity assigned to a particular source is a load or wasteload allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

Background

What is Effectiveness Monitoring?

An effectiveness monitoring evaluation determines if the TMDL interim targets and Washington State water quality standards have been met. The evaluation is an essential component of any restoration or implementation activity. It measures to what extent the elements of the Detailed Implementation Plan have influenced attainment of the waterbody restoration objectives or goals.

The benefits of effectiveness monitoring evaluation include:

- Efficient allocation of restoration efforts.
- Optimization in planning/decision-making (i.e., program benefits).
- Watershed recovery status (i.e., how much restoration has been achieved, how much more effort is required).
- Adaptive management or technical feedback to refine restoration treatment design and modification of TMDL implementation plans.

The effectiveness evaluation addresses four fundamental questions with respect to restoration or implementation activities:

1. Is the restoration or implementation work achieving the desired objectives or goals (significant improvement)?
2. How can restoration or implementation techniques be improved?
3. Is the improvement sustainable?
4. How can the cost-effectiveness of the work be improved?

Study Area

Lake Ballinger is in Snohomish County and within the cities of Mountlake Terrace and Edmonds between Interstate 5 and Highway 99 (Figure 1). The lake has a surface area of approximately 40.5 hectares (100 acres), a maximum depth of 11 meters (35 feet), and an average depth of 5 meters (15 feet).

Lake Ballinger is a monomictic lake, which means the water mixes throughout the fall, winter, and early spring. Thermal stratification is significant during the summer months in Lake Ballinger. The lake is productive and currently classified as a mesoeutrophic lake.

The Lake Ballinger watershed is divided into the following land uses: 60% medium density housing and multifamily dwellings, 30% commercial/industrial activities, 5% parks and community facilities, and 5% open space (Figure 2).

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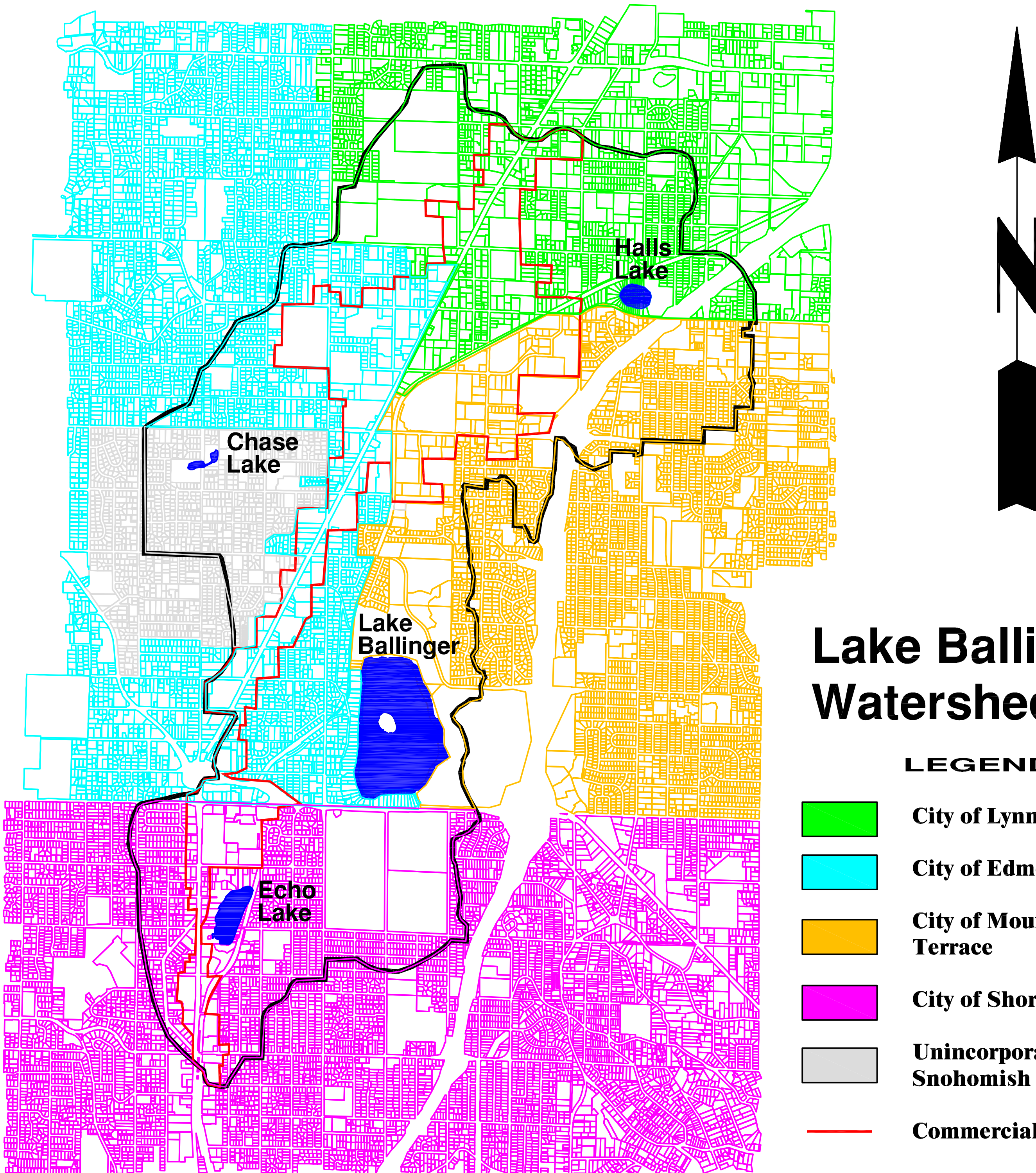
Figure 1. Aerial photo of Lake Ballinger.

Figure 2. Watershed map of Lake Ballinger (see next page):



Lake Ballinger Watershed

LEGEND

- City of Lynnwood - 22%
- City of Edmonds - 24%
- City of Mountlake Terrace - 24%
- City of Shoreline - 21%
- Unincorporated Snohomish County - 9%
- Commercial Properties
- Watershed Boundary

CITY OF EDMONDS Inc. 1890

MOUNTLAKE TERRACE

NOT TO SCALE

Snohomish County

CITY OF SHORELINE

CITY OF Lynnwood OFFICIAL WEB SITE

The shoreline is dominated by single family dwellings. Two golf courses are located on the north and east ends of the lake. There are three other lakes within the Lake Ballinger watershed: Echo Lake to the southwest, Chase Lake to the northwest, and Hall Lake to the northeast.

The major surface inlet to Lake Ballinger is Hall Creek with stormwater outfalls contributing the remaining inflow to the lake. The single outlet is McAleer Creek which drains to Lake Washington, approximately 3 ½ miles to the southwest.

The Lake Ballinger watershed is five square miles and highly urbanized, consisting of the cities of Lynnwood, Edmonds, Mountlake Terrace, and Shoreline, as well as unincorporated parts of south Snohomish County. Lake Ballinger receives considerable stormwater runoff during rain events.

Soils in the watershed are Alderwood-urban, McKenna gravelly silt loam, Mukilteo muck, Everett gravelly loam, and urban land complexes. Much of the watershed is underlain by glacial till with depositional products in the lowland area.

Lake Ballinger is very popular for recreational activities including fishing, swimming, boating, and wind surfing.

Pollutants Addressed by This TMDL

The 1993 TMDL study for Lake Ballinger (Butkus, 1993, unpublished) addressed total phosphorus as the parameter of concern. High levels of phosphorus in a lake can lead to excessive algal and macrophyte growth. Subsequent decomposition of this plant material could cause dissolved oxygen levels to decrease. Low dissolved oxygen levels can potentially cause fish kills as well as affect the beneficial uses (such as swimming, fishing, and aesthetic enjoyment) of the waterbody.

Watershed Implementation and Restoration Activities

Implementation Studies

In a 1972 study of 34 lakes in the Puget Sound area by METRO (1973), Lake Ballinger was rated as having the poorest water quality. The water quality problems listed for Lake Ballinger were excessive nutrient loading, algal blooms, sediment loading, and bacterial contamination. Subsequent sewering of the watershed removed most of the human-generated bacterial problems.

A 1977 joint study by METRO and the University of Washington (METRO, 1977) estimated 67% of the external nutrient loading to Lake Ballinger was via Hall Creek; this inflow also was low in dissolved oxygen and high in ammonia concentrations. The sediment loading to the creek was determined to be excessive due to erosion in the watershed. The extensive development of the watershed coincided with the decline in lake water quality.

The 1977 study recommended a two-phase project to improve Lake Ballinger water quality. Phase I, completed in 1980, consisted of the rehabilitation of Hall Creek and construction of two sedimentation basins to control phosphorus-rich sediments from reaching the lake. The Phase II project, started in 1982, constructed a hypolimnetic injection/withdrawal system which injected water with a higher dissolved oxygen content from Hall Creek into the lake. The project also removed nutrient-laden water from the lake hypolimnion into McAleer Creek. The establishment of stormwater control ordinances was also recommended as part of the restoration activities.

After the construction of the sedimentation ponds in Hall Creek and the installation of the hypolimnetic injection/withdrawal system, internal phosphorus loading was reduced from 227 kg in 1979 to 17 kg in 1984 (KCM, 1985).

In 1986, a report entitled *Restoration of Lake Ballinger, Phase III Final Report* (KCM, 1986) was published. The report evaluated restoration activities implemented at Lake Ballinger and Hall Creek. Many of the same conclusions reached in the KCM, 1985 report were reiterated (i.e., internal phosphorus loading was reduced, and the sediment ponds reduced external phosphorus loading). In addition, the 1986 report made the following recommendations:

- Improve the storm drainage system.
- Maintain and improve the sedimentation ponds and the hypolimnetic injection/withdrawal system. Additional suggestions were made for dealing with the waterfowl problems.
- Develop a Lake Ballinger Watershed Management Program.
- Conduct an alum treatment as a short-term improvement.

Restoration Activities

No significant retrofits to the existing storm drainage system have been made to date. Since a storm code was developed in 1988, new development in the watershed has implemented best management practices for water quality.

The sedimentation ponds were dredged in the mid-1980s; the south pond will be dredged again in 2008. No improvements for either the sedimentation ponds or the hypolimnetic injection/withdrawal system are planned at this time. The current Canada goose population ranges between 50 and 150 birds. This population has been controlled in the past by an interlocal agreement with the Washington State Department of Agriculture.

In June 1990, Lake Ballinger was treated with alum to control the severe algal blooms which were occurring. Within 48 hours of the treatment, the water clarity increased by 40% and the phosphorus concentrations were reduced by 70%. However, because of continued high watershed phosphorus loading, the alum treatment began to lose its effectiveness by the end of 1991. In addition, after the alum treatment, the total phosphorus concentrations in the hypolimnion remained high (156 µg/L) indicating the alum treatment was unable to prevent internal loading of phosphorus into the lake (Khan, 1993).

The cities in the Lake Ballinger watershed have recently begun discussions on developing a lake management program.

Water Quality Standards and Beneficial Uses

In the "Water Quality Standards for Surface Waters of the State of Washington" (Chapter 173-201A WAC), Lake Ballinger is listed as a lake class waterway. This classification assumes the waterbody will meet or exceed criteria for water supply, stock watering, fish migration and propagation, wildlife habitat, and recreation. The following are the water quality criteria for lakes:

- ***Temperature*** *– Human actions considered cumulatively may not increase the 7-day average of the daily maximum temperature more than 0.3°C (0.54°F) above natural conditions.*
- ***Dissolved Oxygen*** *– Human actions considered cumulatively may not decrease the dissolved oxygen concentration more than 0.2 mg/L below natural conditions.*
- ***Fecal Coliform*** *– Geometric mean less than 50 cfu/100 mL and no more than 10% of the samples obtained for determining the geometric mean exceeding 100 cfu/100 mL.*
- ***pH*** *– Within the range of 6.5 to 8.5, with human-caused variation within the above range of less than 0.2 units.*
- ***Turbidity*** *– (1) Not exceed 5 NTU over background when the background is 50 NTU or less or (2) a 10% increase in turbidity when the background turbidity is more than 50 NTU.*

Total Phosphorus – An Ecology recommendation of 30.0 µg/L for Lake Ballinger.

The main beneficial uses to be protected by the 1993 Lake Ballinger TMDL (Butkus, 1993, unpublished) were recreation (including primary contact recreation, sport fishing, and boating) and aesthetic enjoyment. Total phosphorus was identified as the parameter of concern. Table 1 identifies the waterbody listing:

Table 1. Study area waterbody on the 2004 303(d) list for total phosphorus.

Waterbody	Listing ID	Township	Range	Section
Lake Ballinger	6289	27N	04E	32

Goals and Objectives

Project Goals

The goals of this 2005-06 study were to determine if (1) past restoration treatments have been effective in restoring Lake Ballinger to its designated uses, and (2) current phosphorus concentrations are consistent with the criterion set in the 1993 TMDL study.

Study Objectives

The objectives of the study were:

- Review historic documentation regarding the TMDL.
- Compile data generated after implementation of the TMDL.
- Review data for representativeness, comparability, and quality.
- Perform monitoring using field and analytical procedures outlined in the study's Quality Assurance Project Plan (Bell-McKinnon, 2006) to obtain data.
- Analyze and interpret the data to determine the effectiveness of the TMDL.
- Make recommendations based on evidence gathered.
- Produce a final report (including a technical memorandum) to Ecology's Water Quality Program.

Methods

Sampling Design

Lake profiles and water samples for laboratory analysis were collected at the deepest spot of Lake Ballinger (latitude 47.7837°N, longitude 122.3273°W – NAD83). For quality control sampling, a second deep spot was located (latitude 47.7813°N, longitude 122.3301°W – NAD83). See Appendix B for a detailed map of the sampling locations. Sampling occurred monthly from November 2005 through October 2006.

Vertically, composites ensured the epilimnion lake samples were representative. Each composite resulted from three samples collected between 1 to 8 meters, depending on the size of the epilimnion.

The hypolimnion is not typically as well mixed as the epilimnion. Composite samples are a compromise and potentially could indicate whether significant internal nutrient release is occurring, but may not be adequate for internal nutrient load calculations. The internal loading calculations require discrete sampling at depth as well as accurate bathymetry of the lake to calculate a total phosphorus amount within a volume of lake water. In addition, Lake Ballinger has another variable in the form of the hypolimnetic injection/withdrawal system, which affects the internal loading.

Water samples for laboratory analysis were collected in Hall Creek, approximately 400 meters upstream from the mouth of the creek at Lake Ballinger (latitude 47.7893°N, 122.3300°W - NAD83). Water samples were also collected in McAleer Creek, approximately 250 meters downstream of the outlet from Lake Ballinger (latitude 47.7807°N, longitude 122.3214°W - NAD83).

Ecology's Manchester Environmental Laboratory (MEL) analyzed samples for total phosphorus, orthophosphorus, total persulfate nitrogen, and turbidity. In addition, chlorophyll-a samples were analyzed from water samples collected from the lake only. Bacteria samples collected from both Hall Creek and McAleer Creek were also analyzed. When the lake was stratified, nutrients (total phosphorus, orthophosphorus. and total persulfate nitrogen) were collected from both epilimnion and hypolimnion composite samples. All remaining parameters were analyzed in epilimnion composite samples only.

Using a HydroLab® MiniSonde 5 multiparameter probe, a monthly lake profile was completed. Field-measured parameters included temperature, conductivity, dissolved oxygen, and pH. Water clarity was measured using a Secchi disk. Secchi depth and chlorophyll measurements were used to assess algal growth.

Field Procedures

Standard Ecology protocols (Ward, 2001) were used to collect, preserve, and ship samples to MEL for analysis. In addition, other field protocols as described in Bell-McKinnon (2002) and Hallock (1995) were followed.

Field meters were maintained and calibrated according to the manufacturer's instructions.

Laboratory Procedures

MEL conducted the laboratory analyses following Standard Operating Procedures (SOPs) and other guidance documents (Ecology, 2001 and Ecology, 2005). Methods for parameters are listed in Table 2.

Table 2. Laboratory analytical methods.

Parameter	Sample Fraction	Sample Container (mL)	Method	Reference [a]	Reporting Limit	Holding Time (days)
Chlorophyll-a	Filtered	1000 brown	Fluorometric	SM10200H(3)	0.05 µg/L	1 to filtration, 28 after filtration
Turbidity	Total	500 clear	Nephelometric	SM2130	0.5 NTU	2
Orthophosphate	Dissolved	125 amber	Automated ascorbic acid	SM4500PG	0.003 mg/L	2
Total Nitrogen	Total	125 clear	Persulfate digestion, cadmium reduction	SM4500NB	0.025 mg/L	28
Total Phosphorus	Total	60 clear	ICPMS	EPA 200.8M	0.001 mg/L	28

[a] SM=Standard Methods (APHA, 1998).
EPA=Environmental Protection Agency (EPA, 1983).

TMDL Summary

When the 1993 Lake Ballinger TMDL was written, all phosphorus loading to the lake was attributed to nonpoint sources. Current potential nonpoint sources of pollution within the watershed include (1) at least 24 storm drain outfalls that flow into Hall Creek, (2) eight storm drain outfalls that go directly into Lake Ballinger, (3) sediment erosion from construction activity, (4) internal lake loading (5) waterfowl and (6) shoreline runoff from the commercial and residential use of fertilizers.

In 1975-76, a study of Lake Ballinger and its watershed (METRO, 1977) identified internal cycling as well as external loading of phosphorus as causing the poor water quality observed. The study recommended the loading of phosphorus into the lake be reduced as soon as possible to stop and reverse the effects of rapid urbanization of the watershed. The study also stated that the internal inputs of phosphorus from the lake sediments needed to be reduced.

The KCM, 1986 report calculated the following total phosphorus budget for Lake Ballinger:

- Hall Creek 44%
- Other Surface Water 34%
- Waterfowl 12%
- Internal Loading 10%

In the Lake Ballinger TMDL study (Butkus, 1993, unpublished), a loading capacity for total phosphorus of 0.95 kilograms (kg) per day (335 kg total phosphorus/year) was established. This loading rate is consistent with a mean summer total phosphorus concentration of 30.0 µg/L.

The TMDL phosphorus loading allocations for Lake Ballinger are as follows:

- Hall Creek 160 kg/year
- Other Surface Water 100 kg/year
- Waterfowl 55 kg/year
- Internal Loading 20 kg/year

The loading allocations for Lake Ballinger were set based on estimated loadings attained through implementation of various restoration activities done prior to 1993, which would produce levels of aesthetic enjoyment and support beneficial uses acceptable to the lake user community.

According to Ecology's Northwest Regional Office (NWRO), since the Municipal Stormwater General Permit became effective for Phase II municipalities such as Edmonds, Lynnwood, Shoreline, and Mountlake Terrace, some storm drain outfalls in the Lake Ballinger watershed are considered point sources. These point sources may be contributing to phosphorus loading. Construction sites (many of which are regulated by Ecology) may be considered another point source of phosphorus loading to the watershed.

As indicated in the 1993 TMDL, total phosphorus loading from Hall Creek to Lake Ballinger, including loading from construction activity and storm drain outfalls, should not exceed 160 kg/year. Total phosphorus loading to Lake Ballinger from surface water other than Hall Creek, including loading from construction activity and storm drain outfalls, should not exceed 100 kg/year.

Results and Discussion

Historic Data

The results of the 1977 METRO/ University of Washington study (METRO, 1977) established reasons for the decreasing water quality of Lake Ballinger and described the lake as eutrophic.

This 1977 study also concluded that the following characteristics suggested internal loading may be an important part of the phosphorus cycle:

- The fraction of the lake bottom under an aerobic hypolimnion.
- The length of the anaerobic period.
- The presence of high external iron loading (which may sediment incoming phosphorus only to release it under anaerobic conditions).
- The existence of large algal blooms in response to high post-overturn phosphorus concentrations.

The *Lake Ballinger Restoration Project, Interim Monitoring Study Report* (KCM, 1981) summarized two years of water quality data starting in 1979. The report found Lake Ballinger had an average annual total phosphorus concentration of 48 µg/L. Approximately 66% of the phosphorus was determined to be from external sources and 34% from phosphorus recycled from anaerobic sediments during lake stratification. A phosphorus concentration of 30.0 µg/L was suggested to control nuisance algal blooms.

The KCM 1981 report estimated 30% of the total phosphorus was removed from the lake's external sources by the Hall Creek sedimentation ponds. This result translated to a predicted lake total phosphorus concentration of 41.0 µg/L, higher than the goal of 30.0 µg/L. Therefore, the report recommended implementing the Phase II construction of the hypolimnetic injection/withdrawal system to further reduce the lake phosphorus concentration.

In 1985, a report entitled *Lake Ballinger Restoration Project, Interim Water Quality Report* (KCM, 1985) included an assessment of:

- Phosphorus loading to the lake.
- The need to further revise the 1984-85 monitoring program.
- The need for and possible effects of an alum treatment.
- Using an in-lake fountain as a hypolimnetic aerator.
- Water quality improvements due to restoration efforts.

In this 1985 study, the seasonal pattern of orthophosphate in Lake Ballinger was characterized by epilimnetic peaks (1) in the late fall as a result of water column mixing of the phosphorus rich hypolimnetic water following overturn, and (2) in the winter from nutrient-rich inflows, including the storm drain system. Epilimnetic orthophosphate concentration was typically lowest following the uptake of phosphorus by phytoplankton in the spring and summer. Hypolimnetic orthophosphate reached its maximum concentration during stratification as a result of decomposition of phytoplankton and allochthonous organics as well as release from the sediments under anoxic conditions. The pattern of total phosphorus was similar to orthophosphate with the magnitude of the peaks being much greater.

The 1985 report documented water quality improvements in Lake Ballinger after the restoration activities. Internal phosphorus loading appeared to have been reduced significantly as a result of these restoration activities. However, mean summer epilimnetic total phosphorus showed no improvement. This was most likely a function of excessive external loading related to watershed activities. Overall, any reduction in total phosphorus levels in the lake was being offset by an increase in watershed development leading to an increase in external loading of phosphorus.

The *Restoration of Lake Ballinger, Phase III Final Report* (KCM, 1986) summarized water quality data collected from January 1985 through May 1986. The report concluded that after the installation of the hypolimnetic injection/withdrawal system, internal phosphorus loading through the release from anoxic sediments was no longer significant. However, external loading increases replaced the internal sediment component of the phosphorus loading. External loading appeared to be directly and indirectly (through recycling of the increased productivity) driving the lake ecosystem. Even after all the Lake Ballinger watershed restoration activities to this point, the trend in improving water quality stopped in 1986. This was most likely due to the increase in external loading from nonpoint sources, primarily due to human activity within the watershed.

In the Phase III report, a restoration goal of 30.0 µg/L total phosphorus was again proposed for Lake Ballinger. This is also the report that was used as the basis for the Lake Ballinger Total Maximum Daily Load study completed by the Washington State Department of Ecology in 1993.

The Lake Ballinger Water Quality, 1987 Annual Report (Aldrich, 1988) summarized water quality data collected by the City of Mountlake Terrace. The report also outlined the projects completed by 1987 that were designed to improve the water quality of Lake Ballinger and made recommendations for future lake restoration activities.

In 1993, the City of Mountlake Terrace wrote a report (Khan, 1993) summarizing data the city collected in Lake Ballinger and Hall Creek during 1990-91. This water quality monitoring program was funded in part by an inter-local agreement between the cities of Mountlake Terrace, Edmonds, and Lynnwood.

The range of total phosphorus concentrations determined by earlier studies is shown in Table 3.

Water quality standards for total phosphorus were not developed for Washington lakes until 1997. A mean summer total phosphorus level of 30.0 µg/L for Lake Ballinger was set in the TMDL approved in April 1993.

Table 3. Epilimnion total phosphorus concentrations determined by previous studies.

Study	Data Year(s)	Range of Total Phosphorus (µg/L)	Mean (number of samples)
Water Quality Problems and Alternatives for the Restoration of Lake Ballinger (METRO, 1977)	1975-76	19 to 50	31 (33)
Lake Ballinger Restoration Project, Interim Monitoring Study Report (KCM, 1981)	1979-81	10 to 100	35 (26)
Lake Ballinger Restoration Project, Phase II, Interim Water Quality Report (KCM, 1985)	1982-84	5 to 160	42 (107)
Restoration of Lake Ballinger, Phase III Final Report (KCM, 1986)	1985-86	12 to 80	36 (27)
Lake Ballinger Water Quality, 1987 Annual Report (Aldrich, 1988)	1985-87	10 to 104	32 (30)
Water Quality Report (Khan, 1993)	1990-91	10 to 250	25 (32)

Results

In Lake Ballinger, the mean epilimnetic total phosphorus concentration over the sampling period of this current 2005-06 study was 19.9 µg/L, with a range from 8.2 µg/L in June 2006 to 45.6 µg/L in November 2005. For comparison with the TMDL criterion (30.0 µg/L), the mean summer (June through September) total phosphorus result was 11.7 µg/L.

The mean chlorophyll-a concentration over the sampling period was 7.7 µg/L with a range from 1.9 µg/L in November 2005 to 23.2 µg/L in October 2006.

See Appendix C-1 for all the chemistry data collected at Lake Ballinger.

Secchi depths for Lake Ballinger ranged from 1.9 meters in September 2005 to 4.6 meters in June 2005 with a mean of 2.0 meters.

Table 4 summarizes the total phosphorus, chlorophyll-a, and Secchi depth values for Lake Ballinger.

Table 4. Summary of epilimnetic total phosphorus, chlorophyll-a, and Secchi depth values for Lake Ballinger.

	Epilimnetic Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	Secchi Depth (meters)
TMDL Criterion	30.0 (summer)	N/A	N/A
Mean	19.9 (annual)	7.7	2.0
Minimum	8.2	1.9	1.9
Maximum	45.6	23.2	4.6
Standard Deviation	10.29	6.89	0.94
Number of Samples	12	12	12

The average total nitrogen:total phosphorus ratio at Lake Ballinger was 29, indicating phosphorus was likely the limiting nutrient.

The Trophic State Index (TSI) values were calculated as:

- Total Phosphorus = 47
- Chlorophyll-a = 51
- Secchi Transparency = 43

Considering all three parameters, the trophic state for Lake Ballinger was mesoeutrophic.

The current Washington State lake nutrient criteria for Puget Lowland ecoregion lakes are as follows:

Table 5. Guidelines for establishing lake nutrient criteria.

Trophic State	Measured Epilimnetic Total Phosphorus (µg/L)	Nutrient Criteria (µg/L)
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Mesoeutrophic	>10-20	20 or less
	>20	A lake specific study may be initiated

These criteria were established in 1997, after the Lake Ballinger TMDL was approved. However, the mean summer epilimnetic total phosphorus result from this 2005-06 current study (11.7 µg/L) shows Lake Ballinger below the criteria for a mesoeutrophic lake as well as below the TMDL criteria of 30.0 µg/L.

Figure 3 shows the monthly total phosphorus concentrations for Lake Ballinger.

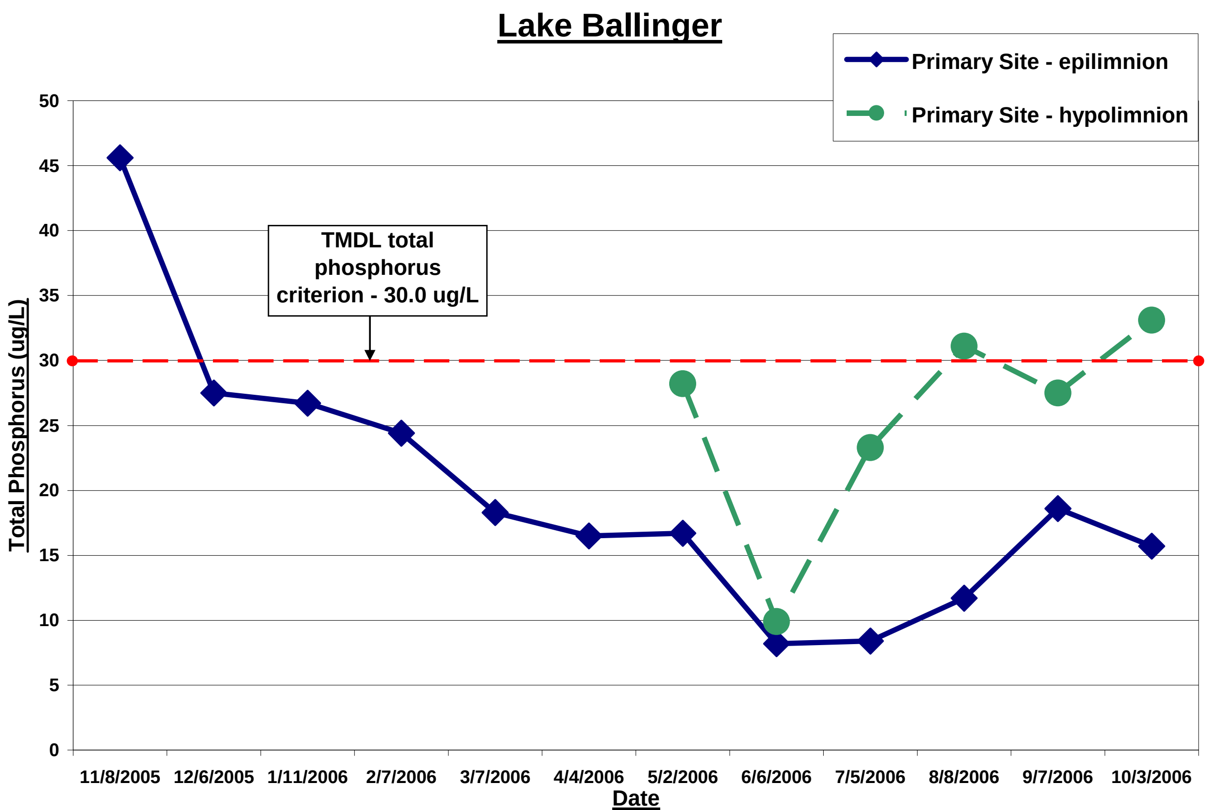


Figure 3. Monthly total phosphorus concentrations at the primary sampling location for Lake Ballinger.

HydroLab® profiles were taken monthly at Lake Ballinger (Appendix D, Table D-1). Stratification occurred beginning in May 2006 and lasting through October 2006. Anoxic conditions in the hypolimnion existed in March 2006 and June 2006 through October 2006.

HydroLab® readings were also taken at both Hall and McAleer Creeks (Appendix D, Tables D-2 and D-3).

In addition to the chemistry samples collected at Lake Ballinger, chemistry samples were collected at Hall Creek (the inlet to Lake Ballinger) and McAleer Creek (the outlet from Lake Ballinger).

As mentioned earlier in this report, a hypolimnetic injection/withdrawal system was installed in Lake Ballinger as part of the lake restoration. The system takes oxygen-rich water from Hall Creek and pipes it into the hypolimnion of the lake. The purpose is to prevent anoxia from taking place in the hypolimnion. Anoxic conditions allow phosphorus to be released from the sediment and potentially become available for algal uptake. In addition, the hypolimnetic injection/withdrawal system takes nutrient-rich water from the lake's hypolimnion and discharges it into McAleer Creek.

Appendix C, Tables C-2 and C-3, show the chemistry results for Hall and McAleer Creeks. In Hall Creek, total phosphorus concentrations ranged from 36.1 µg/L on 2/7/2006 to 76.0 µg/L on 3/7/2006. The orthophosphate levels ranged from 13.0 µg/L on 2/7/2006 to 35.0 µg/L on 3/7/2006.

In McAleer Creek, total phosphorus concentrations got much higher. They ranged from 12.9 µg/L on 4/4/2006 to 228.0 µg/L on 8/8/2006. The minimum and maximum orthophosphate concentrations also occurred on these same dates and were 4.7 µg/L and 30.0 µg/L, respectively.

Comparisons of monthly total phosphorus concentrations in Hall Creek, Lake Ballinger, and McAleer Creek are shown in Figure 4.

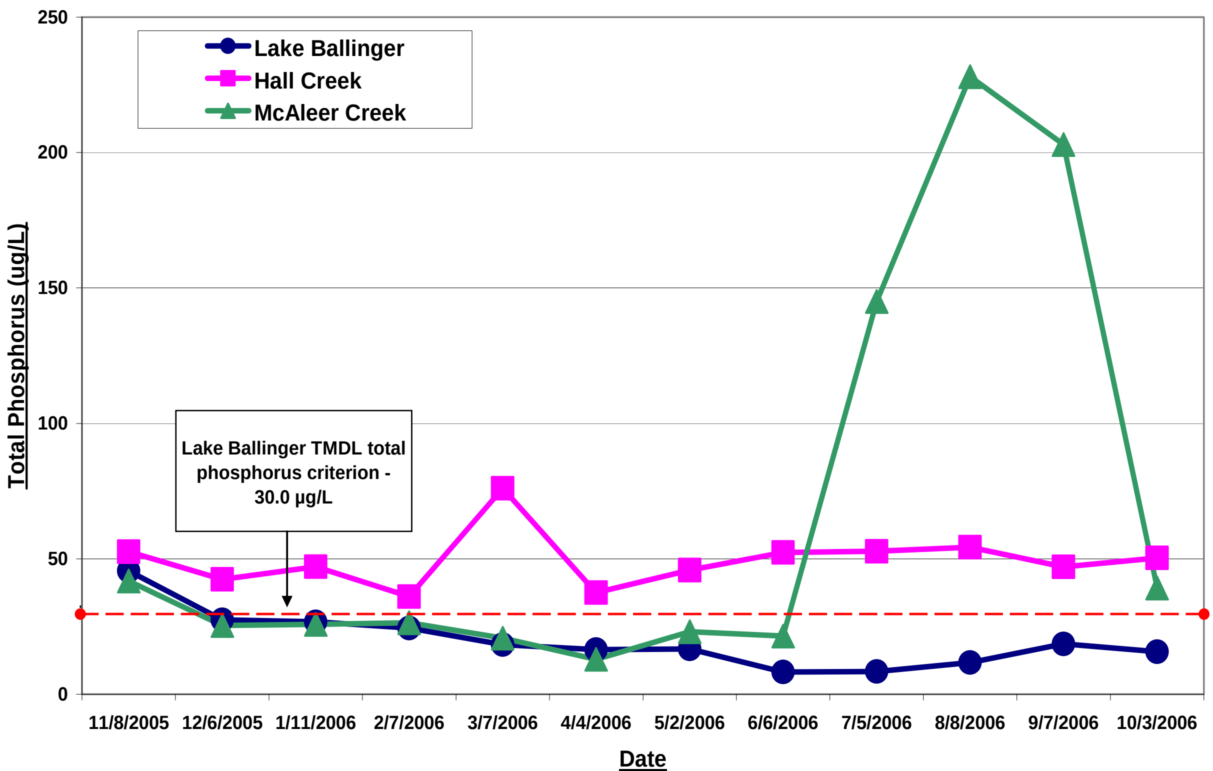


Figure 4. Total phosphorus levels for Hall Creek and McAleer Creek as compared to Lake Ballinger.

Monthly total phosphorus concentrations in Hall Creek were consistently higher than those measured in Lake Ballinger. Total phosphorus concentrations in McAleer Creek correlated closely to Lake Ballinger concentrations until July 2006. Increased total phosphorus levels in McAleer Creek appeared to coincide with the release of hypolimnetic water from Lake Ballinger into McAleer Creek. At this same time, anoxic conditions existed in Lake Ballinger allowing for the release of phosphorus from the lake sediments.

Data from this study of Lake Ballinger have been entered into Ecology's Environmental Information Management (EIM) database.

Quality Control (QC) Analysis

The performance of the HydroLab® MiniSonde 5 profiling instrument resulted in no problems for temperature measurements. The instrument was not checked for temperature calibration prior to each sampling event because the temperature probe is inherently more stable than the other parameters. Periodic checks during the course of the sampling season comparing the instrument to a NIST thermometer were within criteria (Appendix E; Bell-McKinnon, 2006).

The pH probe failed calibration on three occasions and the dissolved oxygen probe failed on two occasions; those data were coded as estimates ("J"). In the case of the pH probe, the calibration failures were between 0.01 to 0.04 standard units above the criterion of 0.20. For dissolved oxygen, the failure was between 0.05 to 0.07 mg/L above the criterion of 0.40 mg/L.

The conductivity probe passed all calibration checks.

The 95th percent confidence intervals on the average difference between the original results and the duplicate (or quality control) results included "0" for all four HydroLab® parameters (Table 6).

Table 6. Difference between the original and duplicate (QC) profile results.

Parameter	Maximum Difference	Average Difference	Number of Pairs	Standard Deviation	Lower 95th Percent Confidence Interval	Upper 95th Percent Confidence Interval
Conductivity (µS/cm)	7.00	-0.24	37	1.52	-0.75	0.26
Dissolved Oxygen (mg/L)	1.58	0.02	37	0.34	-0.09	0.14
pH (standard units)	0.23	0.02	37	0.11	-0.01	0.06
Temperature (°C)	-0.50	-0.02	37	0.13	-0.06	0.03

Calculations were also performed for the 95th percent confidence intervals for comparing the profile results from the Lake Ballinger primary sampling location to the secondary sampling location (Table 7). The confidence intervals on the average difference between the primary sampling location and the secondary sampling location included "0" for all the HydroLab® parameters except pH.

This indicates, with a 95% confidence level, when comparing the primary sampling site to the secondary sampling site, the average difference for each HydroLab® parameter, except pH, will lie within the confidence interval.

Table 7. Difference between the profile results at the Lake Ballinger primary and secondary sampling locations.

Parameter	Maximum Difference	Average Difference	Number of Pairs	Standard Deviation	Lower 95th Percent Confidence Interval	Upper 95th Percent Confidence Interval
Conductivity (µS/cm)	14.00	0.32	31	2.99	-0.78	1.42
Dissolved Oxygen (mg/L)	5.28	0.21	31	1.12	-0.20	0.62
pH (standard units)	1.36	0.14	31	0.30	0.03	0.25
Temperature (°C)	0.90	-0.07	31	0.27	-0.17	0.03

Laboratory samples were processed according to procedures specified in Manchester Environmental Laboratory User's Manual and quality control guidance (Ecology, 2001 and Ecology, 2005). Laboratory quality control requirements were met except in the following cases, all of which were qualified as estimates ("J"):

Table 8. Sample dates not meeting laboratory requirements.

Date	Reason
March 7, 2006	Chlorophyll-a sample was filtered past its holding time.
May 2, 2006	Orthophosphate sample was analyzed past its holding time; the duplicate relative percent difference for chlorophyll-a was greater than the acceptance limit.
August 8, 2006	Chlorophyll-a sample leaked; result was qualified as an estimate.
September 7, 2006	Chlorophyll-a sample was analyzed past its holding time.
October 3, 2006	Chlorophyll-a sample was analyzed past its holding time.

Quality control evaluations of discrete samples used the pooled standard deviation of sequentially collected samples, converted to a relative standard deviation by dividing by the mean of all the results and expressed as a percent (%RSDp).

The Quality Assurance Project Plan (Bell-McKinnon, 2006) established criteria based on lab split samples. Comparing sequential samples (i.e., the QC sample was collected immediately after the primary sample) is more stringent than comparing lab split samples. This is because sequential samples include environmental and sampling variability in addition to variability due to field processing and laboratory analyses.

All the sampled duplicates, except for the fecal coliform samples, met the quality control criteria (Tables 9-13). Fecal coliform samples, especially in levels below 50 cfu, typically are more variable than other parameters (Table 13).

Table 9. Quality control results for discrete composited samples collected sequentially in the epilimnion at the primary sampling location.

Parameter	No. of Sequential Sample Pairs	Average Result	%RSDp of Difference [a]	QC Precision Criteria
Nitrogen, total (mg/L)	4	0.48	5.5%	20%
Phosphorus, total (µg/L)	4	17.60	5.5%	20%
Phosphorus, orthophosphate (µg/L)	3	7.00	2.6%	20%
Chlorophyll-a (µg/L)	2	4.10	3.7%	20%
Turbidity (NTU)	4	2.30	19.1%	20%
Secchi depth (meters)	4	3.31	0.27 M	± 0.50 M

Table 10. Quality control results for discrete composited samples collected sequentially in the epilimnion at the primary sampling location versus the secondary sampling location.

Parameter	No. of Sequential Sample Pairs	Average Result	%RSDp of Difference [a]	QC Precision Criteria
Nitrogen, total (mg/L)	4	0.48	3.9%	20%
Phosphorus, total (µg/L)	4	19.00	9.9%	20%
Phosphorus, orthophosphate (µg/L)	3	6.40	2.5%	20%
Chlorophyll-a (µg/L)	3	4.00	12.5%	20%
Turbidity (NTU)	4	1.50	14.1%	20%
Secchi depth (meters)	4	3.27	0.30 M	± 0.50 M

Table 11. Quality control results for discrete composited samples collected sequentially in the hypolimnion at the primary sampling location.

Parameter	No. of Sequential Sample Pairs	Average Result	%RSDp of Difference [a]	QC Precision Criteria
Nitrogen, total (mg/L)	3	0.43	8.5%	20%
Phosphorus, total (µg/L)	3	28.70	12.3%	20%
Phosphorus, orthophosphate (µg/L)	2	11.30	14.9%	20%

Table 12. Quality control results for discrete composited samples collected sequentially in the hypolimnion at the primary sampling location versus the secondary sampling location.

Parameter	No. of Sequential Sample Pairs	Average Result	%RSDp of Difference [a]	QC Precision Criteria
Nitrogen, total (mg/L)	3	0.43	3.1%	20%
Phosphorus, total (µg/L)	3	30.00	13.2%	20%
Phosphorus, orthophosphate (µg/L)	2	13.00	16.1%	20%

Table 13. Quality control results for laboratory splits, including both lake and creek data.

Parameter	No. of Sequential Sample Pairs	Average Result	%RSDp of Difference [a]	QC Precision Criteria
Nitrogen, total (mg/L)	15	0.94	4.7%	20%
Phosphorus, total (µg/L)	13	69.50	0.6%	20%
Phosphorus, orthophosphate (µg/L)	10	9.50	2.7%	20%
Chlorophyll-a (µg/L)	9	3.80	8.3%	20%
Turbidity (NTU)	6	1.60	6.0%	20%
Fecal Coliform (cfu)	12	128.50	***48.5%***	***40%***

[a] %RSDp is the pooled relative standard deviation (pooled standard deviation divided by the mean of all samples) expressed as a percent. For Secchi depth, the test value is the mean difference between duplicates.

Table 10 and Table 12 quality control results are all below the QC Precision Criteria. This indicates the primary sampling site in Lake Ballinger is representative of conditions throughout the entire lake.

These results also show the person collecting the samples did not introduce a significant amount of variability into the results (e.g., through improper sampling technique or mishandling of the samples).

All laboratory blank results were less than reporting limits.

Conclusions

The current total phosphorus results for Lake Ballinger indicate compliance with the TMDL goal. Even with an increase in the development of the Lake Ballinger watershed since the TMDL was written in 1993, the sedimentation ponds and the hypolimnetic injection/withdrawal system appear to help keep phosphorus concentrations in Lake Ballinger below the TMDL criterion of 30.0 µg/L.

As mentioned earlier in this report, TMDL effectiveness evaluation addresses four fundamental questions with respect to restoration or implementation activity:

1. Is the restoration or implementation work achieving the desired objectives or goals (significant improvement)?

Data collected during this November 2005–October 2006 study indicate that the proposed TMDL total phosphorus goal is being met in Lake Ballinger.

Anoxic conditions occurred in the hypolimnion of the lake 6 out of the 12 months of this study; with anoxia taking place consistently from June 2006 through October 2006. It does not appear the hypolimnetic injection/withdrawal system is preventing anoxia from taking place during the summer months. In addition, water from the lake inlet, Hall Creek, consistently had total phosphorus concentrations above 30.0 µg/L, yet the total phosphorus concentration of the hypolimnion water in Lake Ballinger was below or very near 30.0 µg/L. Beginning in June 2006, the total phosphorus concentrations of the lake outlet, McAleer Creek, became very high. This is probably due to nutrient-rich water leaving the lake and entering McAleer Creek.

2. How can restoration or implementation techniques be improved?

The hypolimnetic injection/withdrawal system appears to be removing nutrient-rich water from the Lake Ballinger hypolimnion, keeping the lake epilimnion total phosphorus concentrations below 30.0 µg/L. Persistent and frequent algal blooms did not occur during this study. Chlorophyll-a concentrations were low except in September 2006 and October 2006.

If the general consensus of the lake managers and residents is that the boating and aesthetic values of Lake Ballinger are not being met because of algal growth in the lake, an alum treatment could address those issues as a short-term solution.

3. Is the improvement sustainable?

The Lake Ballinger watershed is very urbanized and completely developed. The levels of stormwater input do not appear to have the ability to increase dramatically. However, future stormwater inputs will continually add more nutrients to Lake Ballinger and the internal cycling process. This could result in future algal problems.

4. How can the cost effectiveness of the work be improved?

Results from water quality monitoring of Lake Ballinger by volunteers could add to the existing baseline information collected in this study. Additionally, environmental outreach to the watershed community could be done by volunteers with assistance by city staff in Edmonds, Lynnwood, Mountlake Terrace, and Shoreline. Improvements to water quality could be made by educating the residents and businesses about nutrient loading to the lake and the surrounding watershed as well as other stormwater-related issues.

Recommendations

The following recommendations are made as a result of this 2005-06 attainment monitoring study:

- Implement a surface water and stormwater monitoring program in the Lake Ballinger watershed. This should provide information as to the quantity and quality of phosphorus entering Lake Ballinger from stormwater and other sources. These data will allow managers to determine what activities should be implemented to reduce nutrient input to the lake.

- Continue the local lake water quality monitoring program. Only long-term trend information will indicate whether the lake is improving, staying the same, or deteriorating.

- Educate lake residents about the importance and means to control excessive waterfowl access to the lake from residential lawns and boat docks.

- Investigate the prevalence of on-site septic tanks. The Snohomish Health District and Snohomish County are currently developing new tools for identifying the location and potential for pollution from failing on-site septic systems.

- While transport of phosphorus out of Lake Ballinger may be good for the lake, impacts of downstream phosphorus loading to McAleer Creek and Lake Washington should be evaluated. Ecology's Northwest Regional Office will examine the Lake Ballinger hypolimnetic discharge to McAleer Creek and will issue a Water Quality Modification or other appropriate authorization in 2008.

- If there is agreement that algal blooms are a problem at the lake, an alum treatment should be considered. This will provide a short-term solution to the internal recycling of phosphorus in the lake.

- Reduce nutrient input to the lake by educating the watershed residents and businesses about the proper use of fertilizers and other activities which contribute nutrients to the watershed waters. Citizens educating other citizens is often a powerful way to get the message across.

Ecology's Northwest Regional Office Water Quality Program has proposed the following actions to help control potential phosphorus pollution from stormwater runoff. Many of these actions could be implemented in conjunction with local stormwater management activities required by the Phase I and Phase II permits.

- Require use of Ecology's Phosphorus Treatment Menu (or equivalent) as established in Ecology's *2005 Western Washington Stormwater Manual* (Ecology, 2001, revised 2005) for all new development, redevelopment, or stormwater facility retrofits.

- Affected cities can use any education and outreach activities undertaken to implement Special Condition S5.C.1 (a) in the Phase II Western Washington Municipal Stormwater Permit.

- Consider use of techniques outlined in the *Low Impact Development Technical Manual for Puget Sound, January 2005* (PSAT, 2005) for new development and redevelopment to encourage on-site management of stormwater and prevent erosion of soils during construction. Also consider stormwater treatment retrofits in areas where high phosphorus inputs are detected that cannot be reduced or eliminated using source control best management practices (BMPs). Soil augmentation retrofits should be considered where this technique could significantly reduce stormwater runoff volumes.

- Encourage affected cities to require that all new high-density residential complexes include car wash facilities to minimize future discharges of detergent phosphorus to Municipal Separate Storm Sewer Systems (MS4s).

- Consider prioritizing outfall reconnaissance inventories under Illicit Discharge Detection and Elimination efforts in the Lake Ballinger watershed. All inventories should include screening for sewage/septic sources and surfactants/soaps in the Lake Ballinger watershed.

- Establish and implement policies and procedures to reduce pollutants in discharges from municipally owned and operated lands (currently in S.5.C.5 (g) of the Western Washington Phase II Municipal Stormwater Permit) within the Lake Ballinger watershed. This includes parks and municipally-owned golf courses.

- Discuss phosphorus pollution control as part of interjurisdictional coordination activities for physically connected and shared MS4s and waterbodies (per S.5.A.5 of the Western Washington Phase II Municipal Stormwater Permit).

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Appendices

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Appendix A. Glossary and Acronyms

303(d) List: Section 303(d) of the federal Clean Water Act requires Washington State periodically to prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Aerobic: A biological process which occurs in the presence of oxygen.

Anaerobic: A biological process which occurs in the absence of oxygen.

Anoxic: Depleted of oxygen.

Bathymetry: Measure of depth of a waterbody.

Clean Water Act: Federal Act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Designated Uses: Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each waterbody or segment, regardless of whether or not the uses are currently attained.

Ecology: Washington State Department of Ecology.

Epilimnion: The uppermost layer of water in a lake where water temperature changes less than 1° C per one meter of depth.

Eutrophic: Nutrient rich and high in productivity.

Hypolimnion: The deepest layer of water in a lake where water temperature changes less than 1° C per one meter of depth.

Load Allocation: The portion of a receiving waters' loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

Loading Capacity: The greatest amount of a substance that a waterbody can receive and still meet water quality standards.

Margin of safety: Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving waterbody.

Municipal Separate Storm Sewer Systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, storm water, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

Nonpoint Source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities. This includes, but is not limited to, atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System Program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Oligotrophic: Nutrient poor and low in productivity.

Point Source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or is likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Primary Contact Recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface Waters of the State: Lakes, rivers, ponds, streams, inland waters, saltwaters, wetlands and all other surface waters and water courses within the jurisdiction of the state of Washington.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Wasteload Allocation: The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Appendix B. Study Site and Sampling Locations

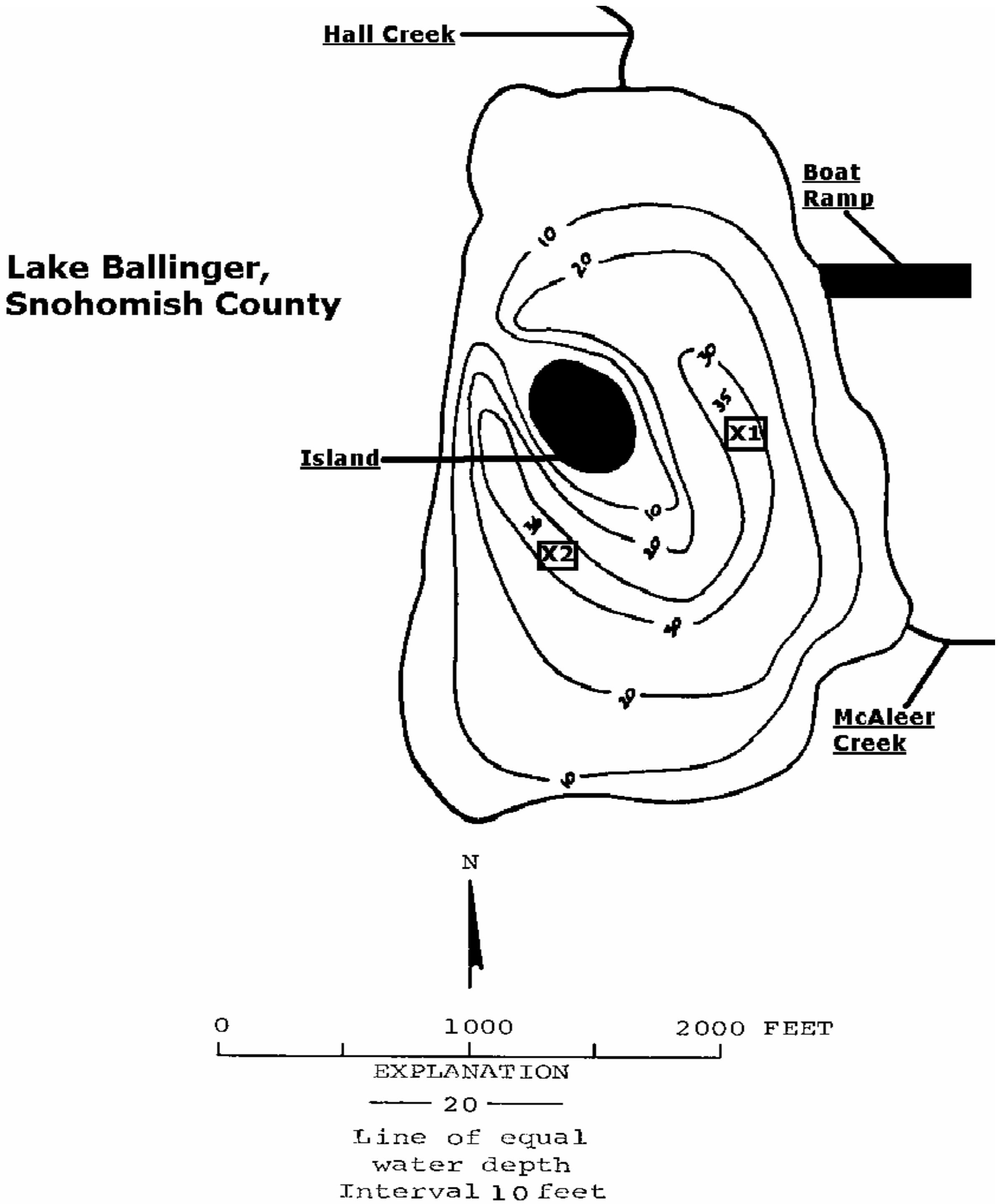

Figure B-1. Lake Ballinger Monitoring Locations (X1 is the primary sampling site; X2 is the secondary sampling site).

Appendix C. Discrete/Composite Results

Table C-1. Lake Ballinger Discrete/Composite Results.

Site	Date	Strata [a]	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Orthophos-phate (µg/L)	Chlorophyll-a (µg/L)	Turbidity (NTU)	Secchi Depth (feet)
Primary	11/8/2005	E	0.488	45.6	8.0	1.88	2.0	10.0
Primary	12/6/2005	E	0.529	27.5	9.0	6.10	1.5	11.4
Primary	1/11/2006	E	0.786	26.7	11.0	4.50	2.5	8.2
Secondary	1/11/2006	E	0.814	25.2	11.0	3.90	2.0	8.8
Primary	2/7/2006	E	0.841	24.4	12.0	2.68	1.6	8.7
Primary	3/7/2006	E	0.700	18.3	5.3	6.26 J	1.6	11.0
Primary	4/4/2006	E	0.521	16.5	5.3	10.20	1.5	12.0
Primary	5/2/2006	E	0.619	16.7	3.8 J	3.50	0.8	15.0
Secondary	5/2/2006	E	0.600	21.4	3.5 J	4.30 J	0.8	16.5
Primary	5/2/2006	H	0.631	28.2	7.9 J	**	**	**
Secondary	5/2/2006	H	0.625	27.0	6.7 J	**	**	**
Primary	6/6/2006	E	0.471	8.2	4.1	4.36	1.0	15.1
Primary	6/6/2006	H	0.486	9.9	5.6	**	**	**
Primary	7/5/2006	E	0.313	8.4	3.0 U	6.50	1.4	13.9
Primary	7/5/2006	H	0.301	23.3	3.1	**	**	**
Primary	8/8/2006	E	0.280	11.7	4.2	3.40	1.2	13.0
Secondary	8/8/2006	E	0.240	11.8	4.6	4.40	1.5	12.1
Primary	8/8/2006	H	0.259	31.1	7.9	**	**	**
Secondary	8/8/2006	H	0.240	23.2	6.7	**	**	**
Primary	9/7/2006	E	0.282	18.6	3.4	20.10 J	2.6	6.2
Primary	9/7/2006	H	0.268	27.5	7.0	**	**	**
Primary	10/3/2006	E	0.240	15.7	3.7	23.20 J	5.1	6.5
Secondary	10/3/2006	E	0.250	14.7	3.9	30.20	8.0 J	5.6
Primary	10/3/2006	H	0.430	33.1	17.0	**	**	**
Secondary	10/3/2006	H	0.404	27.6	13.0	**	**	**

[a] E = epilimnion; H = hypolimnion   ** parameter not sampled

Table C-2. Hall Creek Discrete Results.

Date	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Orthophos-phate (µg/L)	Turbidity (NTU)	Fecal Coliform (cfu)
11/8/2005	1.23	52.6	16.0	2.1	84
12/6/2005	1.36	42.4	16.0	2.7	57
1/11/2006	1.81	47.1	15.0	6.9	88
2/7/2006	1.43	36.1	13.0	4.1	88
3/7/2006	1.26	76.0	35.0	6.1	73
4/4/2006	1.15	37.5	14.0	2.8	250
5/2/2006	1.26	45.8	15.0 J	2.6	41
6/6/2006	1.24	52.4	25.0	2.3	150
7/5/2006	1.53	52.8	28.0	2.5	230
8/8/2006	1.79	54.3	33.8	2.0	520
9/7/2006	0.76	47.0	30.0	1.5	530
10/3/2006	1.39	50.3	29.0	7.6	320

Table C-3. McAleer Creek Discrete Results.

Date	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Orthophos-phate (µg/L)	Turbidity (NTU)	Fecal Coliform (cfu)
11/8/2005	0.428	41.8	7.7	1.7	17
12/6/2005	0.463	25.4	9.1	1.3	8
1/11/2006	0.757	25.8	12.0	2.3	35
2/7/2006	0.842	26.4	12.0	2.9	7
3/7/2006	0.722	20.7	5.5	2.7	15
4/4/2006	0.732	12.9	4.7	1.2	14
5/2/2006	0.658	23.1	6.3 J	1.2	21
6/6/2006	0.472	21.5	6.5	2.1	12
7/5/2006	0.571	145.0	24.0	5.0	310 J
8/8/2006	0.734	228.0	30.0	11.0	200
9/7/2006	0.931	203.0	29.0	7.3	410
10/3/2006	0.326	39.2	16.0	5.2	62

Appendix D. Profile Results

Table D-1. Lake Ballinger Hydrolab ® Profile.

Date	Depth (M)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Std. Units)	Conductivity (µS/cm)
11/8/2005	0.0	10.50	6.98	7.24 J	134
	1.0	10.49	6.95	7.48 J	134
	2.0	10.46	6.88	7.51 J	134
	4.0	10.46	6.84	7.57 J	134
	6.0	10.39	6.72	7.57 J	134
	8.0	10.35	6.70	7.51 J	135
	9.7	10.32	5.97	7.38 J	135
	9.8 - bottom				
12/6/2005	0.0	6.49	7.28J	6.84 J	121
	1.0	6.39	7.12J	6.87 J	122
	2.0	6.35	7.04J	6.79 J	122
	3.0	6.34	6.92J	6.79 J	122
	4.0	6.33	6.89J	6.83 J	122
	5.0	6.33	6.88J	6.81 J	122
	6.0	6.33	6.85J	6.81 J	122
	8.0	6.32	6.85J	6.87 J	122
	9.0	6.32	6.76J	6.83 J	122
	9.2 - bottom				
1/11/2006	0.0	6.88	10.31	6.70	108
	1.0	6.87	10.26	6.86	107
	2.0	6.86	10.25	6.91	107
	3.0	6.86	10.25	6.93	107
	4.0	6.86	10.22	6.96	107
	5.0	6.85	10.18	6.97	107
	6.0	6.85	10.18	6.98	107
	8.0	6.84	10.12	7.00	107
	9.5 - bottom	6.85	10.09	7.00	108
1/11/2006 Secondary Site	0.0	6.83	10.19	6.93	109
	1.0	6.83	10.18	6.99	109
	2.0	6.81	10.13	7.05	109
	3.0	6.81	10.09	7.05	110
	4.0	6.79	10.09	7.05	110
	5.0	6.79	10.05	7.05	110
	6.0	6.78	10.05	7.05	110
	7.2 - bottom	6.79	9.94	7.05	110
2/7/2006	0.0	6.38	11.37	6.91 J	101
	1.0	6.36	11.36	6.95 J	101
	2.0	6.31	11.32	7.21 J	101
	3.0	6.24	11.26	7.31 J	101
	4.0	6.13	11.26	7.28 J	101
	5.0	6.13	11.21	7.19 J	101
	6.0	6.11	11.18	7.16 J	101
	8.0	6.13	11.06	7.10 J	104

Date	Depth (M)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Std. Units)	Conductivity (µS/cm)
	9.5	6.09	10.84	7.04 J	110
	9.6 - bottom				
3/7/2006	0.0	6.31	10.90	7.38	89
	1.0	6.30	10.87	7.62	89
	2.0	6.30	10.87	7.73	89
	3.0	6.29	10.86	7.69	91
	4.0	6.29	10.83	7.76	92
	5.0	6.30	10.79	7.83	90
	6.0	6.30	10.79	7.85	95 J
	8.0	6.29	10.74	7.89	90
	9.0	6.30	0.95	7.46	127
	9.1 - bottom				
4/4/2006	0.0	10.10	10.94 J	7.78	113
	1.0	10.0	10.91 J	8.02	113
	2.0	9.77	10.86 J	8.02	113
	3.0	9.76	10.79 J	7.86	113
	4.0	9.70	10.44 J	7.78	113
	5.0	8.95	8.27 J	7.42	113
	6.0	8.66	8.26 J	7.29	113
	8.0	8.49	7.05 J	7.15	113
	8.4 - bottom				
5/2/2006	0.0	13.80	10.65	7.83	114
	1.0	13.80	10.61	8.05	114
	2.0	13.70	10.58	8.03	114
	3.0	13.70	10.56	7.95	115
	4.0	13.70	10.50	8.00	115
	5.0	12.30	7.88	7.49	114
	6.0	10.40	4.99	7.25	115
	7.0	9.90	4.07	7.18	116
	8.0 - bottom	9.70	3.51	7.11	116
5/2/2006 Secondary Site	0.0	14.0	10.69	7.82	114
	1.0	14.0	10.69	7.89	114
	2.0	13.80	10.63	7.83	114
	3.0	13.70	10.59	7.88	114
	4.0	13.40	10.15	7.83	115
	5.0	12.60	8.46	7.46	114
	6.0	10.60	5.99	7.23	114
	7.0	9.70	4.20	7.11	116
	7.4 - bottom				
6/6/2006	0.0	19.50	9.40	7.78	118
	1.0	19.10	9.41	7.90	118
	2.0	18.80	9.33	7.91	118
	3.0	18.50	8.92	7.86	117
	4.0	17.50	8.19	7.55	115
	5.0	15.7	5.13	7.32	117
	6.0	13.6	1.21	7.05	122
	7.0	11.6	0.32	6.87	128
	7.5 - bottom	11.1	0.28	6.94	130

Date	Depth (M)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Std. Units)	Conductivity (µS/cm)
7/5/2006	0.0	23.1	9.51	8.42	125
	1.0	23.1	9.50	8.51	125
	2.0	23.1	9.44	8.51	125
	3.0	23.1	9.38	8.46	126
	4.0	20.8	8.18	7.97	123
	5.0	17.7	4.83	7.57	122
	6.0	14.3	1.70	7.20	127
	7.0	12.5	0.33	7.08	135
	8.0	11.1	0.30	6.96	151
	8.5 - bottom				
8/8/2006	0.0	22.6	8.08	7.94	137
	1.0	22.6	8.08	7.95	137
	2.0	22.6	8.07	8.11	137
	3.0	22.6	8.07	8.08	137
	4.0	22.4	6.86	7.84	138
	5.0	19.7	1.50	7.26	134
	6.0	15.6	2.36	7.21	137
	7.0	12.6	0.27	7.07	163
	8.0	12.2	0.25	7.04	167
	9.0	11.4	0.23	7.11	174
	9.2 - bottom				
8/8/2006 Secondary Site	0.0	22.9	8.21	7.91	137
	1.0	22.8	8.25	7.93	137
	2.0	22.8	8.23	7.98	137
	3.0	22.7	8.16	7.97	137
	4.0	21.5	4.62	7.42	136
	5.0	19.8	2.53	7.24	133
	6.0	16.1	0.87	7.09	135
	7.0	13.3	0.35	7.00	149
	7.8 - bottom				
9/6/2006	0.0	22.2	10.66	8.84	138
	1.0	21.6	10.75	9.03	137
	2.0	21.2	10.31	9.00	137
	3.0	21.1	9.44	8.82	137
	4.0	20.5	5.91	7.94	138
	5.0	19.6	2.43	7.85	138
	6.0	15.8	0.40	7.65	138
	7.0	14.1	0.33	7.66	165
	7.4 - bottom				
10/3/2006	0.0	17.3	10.90	8.75	141
	1.0	17.3	10.90	8.88	141
	2.0	17.3	10.91	8.97	141
	3.0	17.3	10.90	9.07	141
	4.0	17.3	10.70	9.06	141
	5.0	17.2	4.39	8.00	143
	6.0	16.6	1.57	7.75	145
	7.0	14.4	0.34	7.70	180
	8.0 - bottom	13.0	0.32	7.74	192

Date	Depth (M)	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Std. Units)	Conductivity (µS/cm)
10/3/2006 Secondary Site	0.0	17.5	10.96	8.73	141
	1.0	17.5	10.99	8.74	141
	2.0	17.4	10.88	8.77	141
	3.0	17.4	10.11	8.59	141
	4.0	17.3	5.42	7.70	141
	5.0	17.2	5.16	7.53	141
	6.0	16.6	1.50	7.31	145
	7.0	14.7	0.36	7.21	176
	7.4 - bottom				

Table D-2. Hall Creek HydroLab® Results.

Date	Dissolved Oxygen (mg/L)	Temperature (°C)	pH (Std. Units)	Conductivity (µS/cm)
11/8/2005	9.60	9.05	6.74	198
12/6/2005	9.73	7.56	7.04	202
1/11/2006	10.57	8.0	6.74	139
2/7/2006	11.74	6.18	6.94	177
3/7/2006	10.82	7.80	7.44	177
4/4/2006	11.16	9.66	7.75	183
5/2/2006	11.61	11.40	7.68	233
6/6/2006	8.54	14.78	7.48	202
7/5/2006	8.83	15.10	7.67	255
8/8/2006	9.53	16.50	7.83	242
9/6/2006	8.67	15.0	7.81	244
10/3/2006	10.07	12.85	7.82	249

Table D-3. McAleer Creek HydroLab® Results.

Date	Dissolved Oxygen (mg/L)	Temperature (°C)	pH (Std. Units)	Conductivity (µS/cm)
11/8/2005	6.84	10.54	7.06	134
12/6/2005	7.24	6.45	6.45	123
1/11/2006	10.23	6.99	6.97	109
2/7/2006	11.09	6.41	6.87	102
3/7/2006	11.39	6.65	7.33	92
4/4/2006	11.06	10.75	7.56	117
5/2/2006	10.51	14.30	7.50	117
6/6/2006	8.74	19.78	7.61	119
7/5/2006	8.39	15.30	7.17	161
8/8/2006	4.46	18.0	6.87	172
9/6/2006	1.11	13.50	7.11	188
10/3/2006	8.61	17.05	7.84	146

Appendix E. Profiling Instrument Post-Calibration Results

Results rejected or qualified for failing quality control requirements (Bell-McKinnon, 2004) are shown in bold italics. The difference between expected and reported results is given in parentheses (for pH this is the difference for either the pH 7 or pH 9 buffer).

Table E-1. HydroLab ® MiniSonde 5 Post-Calibration Results.

Calibration Date	pH (criteria ± 0.20 std. units)	Dissolved Oxygen (criteria ± 0.40 mg/L)	Conductivity (criteria ± 10 µS/cm)	Temperature (criteria ± 1.0 °C)	Comments
11/8/2005	***Fail (0.24)***	Pass	Pass		
12/6/2005	***Fail (0.21)***	***Fail (0.47)***	Pass	Pass	DO failed calibration but the Winkler check standard was within QC
1/11/2006	Pass	Pass	Pass		
2/7/2006	***Fail (0.21)***	Pass	Pass		
3/7/2006	Pass	Pass	Pass		
4/4/2006	Pass	***Fail (0.45)***	Pass		DO failed calibration; one Winkler check standard was within QC (0.34) and one was outside of QC (0.69)
5/2/2006	Pass	Pass	Pass		DO passed calibration but both Winkler check standards were outside of QC (0.45 and 0.54)
6/6/2006	Pass	Pass	Pass	Pass	
7/5/2006	Pass	Pass	Pass		Lots of debris and stagnant water in McAleer Creek – variability may be naturally high
8/8/2006	Pass	Pass	Pass		
9/6/2006	Pass	Pass	Pass		
10/3/2006	Pass	Pass	Pass		DO passed calibration but the Winkler check standard was outside of QC (0.43)

DO – dissolved oxygen
QC – quality control

Appendix F. Field Notes

Table F-1. Field Notes.

Sampling Date	Lake Ballinger	Hall Creek	McAleer Creek [a]
11/8/2005	Established lake height reference point from top of dock at first piling to lake surface - first lake height reading = 3.54 feet; algae obvious - clumping in downwind sheltered areas (probably *Aphanizomenon sp.*); two fishermen and six ducks at park.	Established initial staff gage reading = 0.29; city cleaning out brush upstream of culvert, left bank.	Stage height = 1.48; established stage height reference point from top of culvert (downstream side).
12/6/2005	Lake height = 4.00 feet; approximately 30 cormorants and misc. ducks; *Aphanizomenon sp.* Filaments moderately thick; two cars at launch - one person fishing.	Staff gage reading = 0.31; 10 inch rainbow trout (?) upstream of culvert - looks like they could be wild.	Stage height = 1.91
1/11/2006	Lake height = 2.79 feet (± 0.02, windy); 23 straight days of rain - about 1/2 inch per day in Seattle; dragging anchor slightly; about 25 geese near island.	Staff gage reading = 1.12	Stage height = 1.91
2/7/2006	Lake height = 3.60 feet; a few algal clumps but not many; a few geese around the island.	Staff gage reading = 0.64	Stage height = 2.43; no rain last couple of days but lots of rain before that; sunny - about 40°F.
3/7/2006	Lake height = 4.24 feet; a dozen geese at the island; fewer algae clumps than last month - quite clear in fact.	Staff gage reading = 0.33; five ducks just upstream.	Stage height = 3.14
4/4/2006	Lake height = 4.15 feet; about 8 anglers at the pier and beach; about 8 geese and a few ducks; more algae visible in the upper water column than last month.	Staff gage reading = 0.30; sunny day; some light rain yesterday.	Stage height[a] = 3.05; algae in stream from lake.
5/2/2006	Lake height = 4.12 feet; 30 minutes of heavy rain yesterday; 15 geese on lake.	Staff gage reading = 0.21; couple of ducks upstream.	Stage height = 5.11

Sampling Date	Lake Ballinger	Hall Creek	McAleer Creek [a]
6/6/2006	Lake height = 4.02 feet; about 10 people at park - some fishing; some faded algae clumps in water (photo taken) but not *Aphanizomenon sp.;* 1 or 2 big *Daphnia sp.* In each sample cast; no H_2S smell.	Staff gage reading = 0.28	Stage height = 2.76
7/5/2006	Lake height = 4.41 feet*; Nymphaea odorata* in bloom; algae (tiny balls - *Anabaena sp.*?) visible at boat launch but not so much in the open water; note water color is greenish rather than the usual brown.	Staff gage reading = 0.17; water is slightly milky.	Stage height = 3.53; very slight flow if any.
8/8/2006	Lake height = 4.41 feet; 12 geese and 25 ducks at beach area; 5 anglers on pier fishing; water is the clearest I've seen with only a few obvious algal colonies; weather has been in the 80-90°F range but cooler today (low 70's); green tinge to water color at 8 meters but not at 6 meters; no H_2S smell.	Staff gage reading = 0.20; streambank has been weed-whacked, access is much easier.	Stage height = 3.56; flow is nearly stagnant - hard to find an open spot for sampling.
9/6/2006	Lake height = 4.23 feet; about 6 people at beach; no H_2S smell at 6 meter sample cast; water a bit hazy with *Aphanizomenon sp.* Flakes as well as smaller species.	Staff gage reading = 0.20; flow is several times greater than McAleer Creek.	Stage height = 3.50; no flow visible at culvert, some flow where channel is constricted - only flow in creek is due to discharge; sampled creek at hypolimnetic discharge point - took a total phosphorus sample; slight H_2S smell.
10/3/2006	Lake height = 4.36 feet; waterfowl at beach and near Hall Creek outlet; very quiet on lake - no other activity; decomposing cyanobacteria bloom in water and on *Nymphaea odorata;* algae present at all three sample casts (1, 2, and 3 meters deep); no algae or *Daphnia sp. a*t 6 meter sample cast; H_2S smell and clumps of decomposing algae at 7 meter sample cast.	Staff gage reading = 0.25; milky haze in water.	Stage height = 2.84; same algae in creek as in lake.

[a] Stage height is determined by establishing a reference point on a hard surface above the stream surface and then using a measuring tape to measure down from that reference point to the stream surface. This means the larger the number, the lower the stream height. This is just the opposite of reading a staff gage (such as in Hall Creek). There the larger the number, the higher the stream height.