Draft Lake Cyanobacteria Management Plan

Echo Lake, Shoreline, Washington

Prepared for
City of Shoreline

Prepared by
Herrera Environmental Consultants, Inc.

Funded by
Washington State Department of Ecology Freshwater Algae Program
Grant Number WQALG-2023-Shorel-00030

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Echo Lake, Shoreline, Washington

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Executive Summary

About This Report

Echo Lake is a small and valuable urban lake that suffers from harmful algal blooms (HABs). These HABs are comprised of a group of algae called cyanobacteria, which occasionally produces toxic substances capable of causing illness or death to humans and animals when consumed. Toxic cyanobacteria blooms not only impair beneficial uses of the lake by threatening human, pet, and wildlife health, but also restrict uses of the lake for user protection, form unsightly and odorous scums on the lake surface, and are transported downstream to potentially impact uses of Lake Ballinger. In 2022, the City of Shoreline (City) received a grant from the Washington State Department of Ecology (Ecology) and contracted with Herrera Environmental Consultants (Herrera) to develop this Lake Cyanobacteria Management Plan (LCMP) to reduce cyanobacteria blooms and improve water quality in Echo Lake. The City initiated and funded this LCMP in support of partnerships with the lake community. The lake water and bottom are owned by the state; the City is not obliged to manage the lake and has no near-term plans, budget, or staff resources to implement large-scale improvements at the lake.

Herrera developed and implemented an Ecology-approved monitoring plan to collect data, in order to evaluate what is causing the HABs and how best to control them. This draft LCMP presents the study findings and recommendations for the City and other stakeholders to consider. A final LCMP will be prepared, addressing comments on the draft LCMP.

What are Cyanobacteria and Why are They a Problem?

Cyanobacteria (also called “blue-green algae”) are a diverse group of bacteria found in freshwater, saltwater, moist soils, and even within plants and lichen. Algae are microscopic organisms that need light and nutrients to grow. Cyanobacteria are a normal part of the algae community in lakes, but under certain conditions they can form unsightly scums. Some cyanobacteria also produce toxins (“cyanotoxins”), such as anatoxin-a or microcystin, that are harmful to humans and animals when consumed or upon contact with skin. Cyanobacteria may have several competitive advantages over other algae, including the ability to obtain nitrogen from air and store high quantities of phosphorus (two crucial nutrients for growth). Other advantages include being able to regulate their buoyancy in the lake water (i.e., move up to get light energy near the lake surface and down to get more nutrients near the lake bottom) and being too big or unpalatable to microscopic animals (i.e., zooplankton) that eat algae.

Cyanobacteria bloom on Echo Lake, September 21, 2021.

Why and When Does Echo Lake Have Toxic Algae Blooms?

Cyanobacteria bloom in Echo Lake because there is an abundance of nutrients to fuel their growth. Lake and watershed monitoring for the LCMP occurred between October 2022 and September 2023. We found the amount of algae growth is controlled by the amounts of both phosphorus and nitrogen, but phosphorus is generally in lowest supply; phosphorus inputs should be controlled to reduce cyanobacteria blooms. Cyanobacteria were the dominant type of algae in the summer and were responsible for an algae bloom in early August 2023.

Historical cyanotoxin monitoring data show that cyanobacteria blooms in Echo Lake have occurred anytime between April and October, with the greatest levels of microcystin (a liver toxin) and exceedances of the state guideline most often occurring in September and October. Since cyanotoxin monitoring began in 2009, approximately 109 samples have been tested for cyanotoxins and microcystin concentrations exceeded the state recreational guideline of 8 micrograms per liter (µg/L) in 11 samples. However, only two of those 11 samples have been collected since 2016 (in 2021 and 2023). Anatoxin-a was detected above the state criterion (1 µg/L) in four of the 109 samples; all of all four of those samples occurred in April and May 2021 (1.85–114 µg/L). Thus, both microcystin and anatoxin-a have been observed in the lake at levels that threaten human and animal health.

WARNING

TOXIC ALGAE PRESENT

Lake unsafe for people and pets

ADVERTENCIA - HAY ALGAS TÓXICAS EN EL LAGO - El lago es peligroso para personas y mascotas

- Do not swim or water ski. *No nade ni practique esquí acuático.*
- Do not drink lake water. *No beba agua del lago.*
- Keep pets and livestock away. *Mantenga a las mascotas y al ganado alejados.*
- Clean fish well, discard guts. *Limpie bien el pescado y deseche las tripas.*
- Avoid areas of scum when boating. *Evite las zonas con verdín al navegar.*

警告
湖泊里发现有毒藻类
湖泊对人和宠物不安全

경고
호수에는 독성 조류가 자라고 있습니다
이 호수는 사람과 반려동물에게 안전하지 않습니다

ВНИМАНИЕ
ТОКСИЧЕСКИЕ ВОДОРОСЛИ В ОЗЕРЕ
Озеро небезопасно для людей и домашних животных

УВАГА
ТОКСИЧНІ ВОДОРОСТІ В ОЗЕРІ
Озеро небезпечне для людей та домашніх тварин

CẢNH BÁO
TRONG HỒ CÓ TẢO ĐỘC
Hồ không an toàn cho người và thú nuôi

Call your doctor or veterinarian if you or your animals have sudden or unexplained sickness or signs of poisoning.

For more information or to report a bloom:
nwtoxicalgae.org | 360-407-6000

Health
DOH 333-273 May 2021

The City of Shoreline posts warning signs at Echo Lake Park for about 2 weeks after every cyanotoxin test that has exceeded the State guideline, cautioning visitors not to swim in the lake. Also posted are year-round, educational signs that encourage visitors to use caution whenever they observe algae scums that look like cyanobacteria: "when in doubt stay out!"

Where is the Excess Phosphorus Coming From?

There are two major pathways of phosphorus to Echo Lake: stormwater runoff into the lake and internal release from lake sediments. Figure ES-1 presents a diagram of a lake phosphorus cycle, with inputs, outputs, and transformations of phosphorus in a lake. The annual and summer phosphorus budgets of inputs and outputs to Echo Lake for water year 2023 are presented in Table ES-1.

Most of the stormwater phosphorus enters the lake during the winter months and settles to the lake sediments when the water is too cold and sunlight is too low for much uptake by algae. As the weather and lake surface warms in the spring, the lake becomes thermally stratified (layered) into a warm surface layer (epilimnion) and a cold bottom layer (hypolimnion). As spring and summer progress, algae produce oxygen in the epilimnion while bacteria consume oxygen in the hypolimnion (where there is not enough light for algae to grow). We found that oxygen in Echo Lake is rapidly consumed in the deep waters of the hypolimnion, which were anoxic (without oxygen) between May and October when the epilimnion cooled enough for wind to mix with the hypolimnion.

Figure ES-1. Example Diagram of a Lake Phosphorus Cycle.

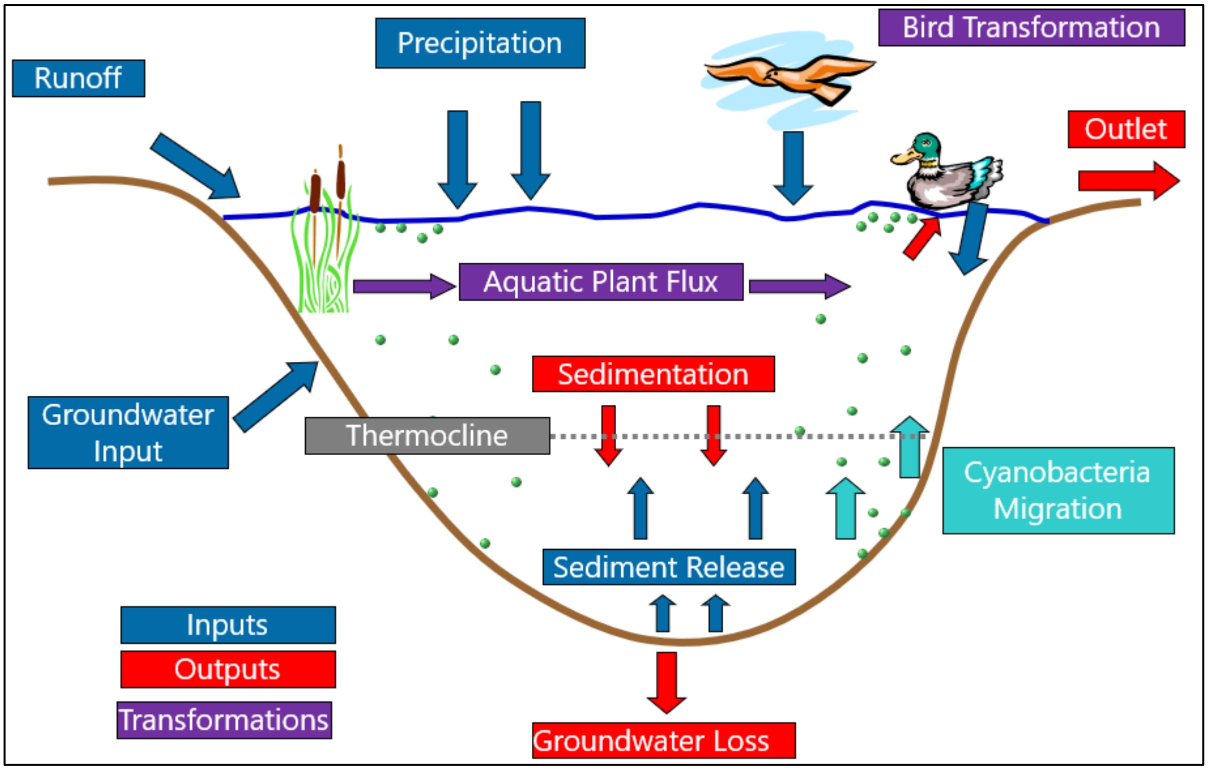


Table ES-1. Annual and Summer Total Phosphorus Budget for Echo Lake.

Pathway	Annual (Oct. 2022 to Sept. 2023)		Summer (May to October 2023)	
	Mass (kg)	% of Total	Mass (kg)	% of Total
Inputs				
Surface Inflow (Stormwater)	62.5	55%	18.7	29%
Direct Precipitation to Lake	1.2	1%	0.3	<1%
Groundwater Inflow	6.3	5%	0.2	<1%
Internal Sediment Release	44.5	39%	44.5	70%
Residual Input (unaccounted mass balance)	12.8	-	0	-
Outputs				
Lake Export from Outlet (to Lake Ballinger)	48.6	31%	0.2	2%
Groundwater Outflow	2.4	1%	2.4	4%
Sedimentation to Lake Bottom	108.1	68%	54.1	93%
Loss in Lake Storage Amount	31.8	-	4.6	-
Residual Output (unaccounted mass balance)	0	-	10.4	-

kg = kilograms

Internal sediment release estimates ranged from 30.1 to 58.0 kg per year, based on various estimation methods.

Loss in lake storage is the difference in mass present in the lake at the beginning and end of the budget period.

Residual Input/Output is the net mass balance remaining when the calculated total output is subtracted from the total input. It represents error or unaccounted sources (e.g., birds and aquatic plant flux).

The sediments of Echo Lake are rich in phosphorus bound to organic matter (e.g., decomposing algae, waterfowl feces, and plant debris) and metals (e.g., iron, calcium, and aluminum). The loss of oxygen in the hypolimnion and underlying deep sediments changes the chemical structure of iron, which then releases iron-bound phosphorus. In the hypolimnion, the released phosphorus builds up to high concentrations that are available to migrating cyanobacteria and diffuses up into the epilimnion where light and temperatures support rapid algae growth. Furthermore, warmer temperatures in both water layers increase microbial decay of sediment organic matter, which releases bound phosphorus up into the water column for algae uptake.

The primary sources of accumulated sediment phosphorus are phosphorus particles in stormwater and algae that settle to the lake bottom and together represent the loss of phosphorus from the lake as sedimentation. Controlling external watershed loading of phosphorus, along with internal sediment release, will be important in the long term for reducing algae blooms and curbing the replenishment of internal sediment loads.

What are the Management Objectives for Echo Lake?

The goal for Echo Lake management is to improve and protect lake uses by decreasing cyanobacteria blooms and the conditions that support them. The recommended water quality objectives for Echo Lake are adapted from Ecology (2023) criteria for determining lake impairment due to harmful algae blooms. These objectives include the following:

- Within a 5-year period, there is no more than one year with two or more events with cyanotoxins exceeding state recommended guidelines.
- Within a 5-year period, there is no more than one year with a public health advisory lasting three weeks or longer.

To prevent harmful algae blooms, it is recommended to reduce the trophic state (amount of algae and nutrients) of Echo Lake from eutrophic (high algae and nutrients) to mesotrophic (moderate algae and nutrients) by not exceeding the following upper-mesotrophic thresholds, based on average summer (June through September) values in the epilimnion (1 meter depth) (Carlson 1977):

- Chlorophyll-a concentration not exceeding 7.2 µg/L
- Total phosphorus not exceeding 24 µg/L
- Secchi depth exceeding 2.0 meters.

What Do We Do Next?

We recommend an adaptive management approach that provides long-term prevention through internal load reduction and watershed phosphorus control. We recommend oxygen saturation technology (OST) for internal phosphorus control and a combination of education and stormwater treatment for watershed phosphorus control. Ongoing monitoring should be used to monitor achievement of water quality objectives and to inform adjustments to management techniques.

In-Lake Management

Sediment release is the primary source of phosphorus to cyanobacteria in the lake. While controlling watershed inputs is critical to the prevention of additional phosphorus accumulation in the sediments, we recommend managing the lake's existing reservoir of phosphorus, in order to manage phosphorus and algae abundance. For long-term management, we identified three feasible alternatives:

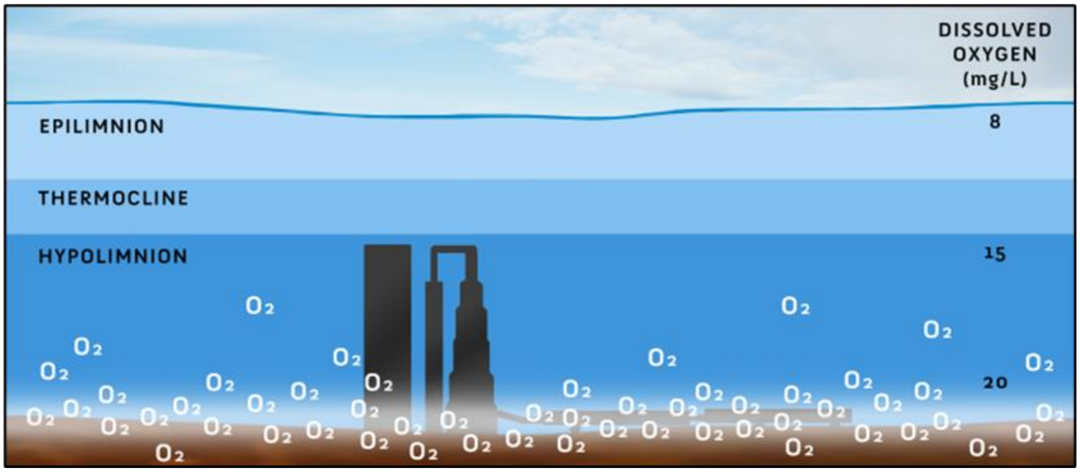
1. Installation of a hypolimnetic oxygenation system, specifically an oxygen saturation technology (OST) system, to oxygenate the deep waters of the lake, reduce internal phosphorus loading, and improve fish habitat
2. Annual phosphorus water column stripping with a low dose of either alum or EutroSorb G (lanthanum)
3. Phosphorus sediment inactivation with high doses of either alum or EutroSorb G (lanthanum)

For long-term management, we recommend installation of a hypolimnetic oxygenation system, specifically an oxygen saturation technology (OST) system, to oxygenate the deep waters of the lake, reduce internal phosphorus loading, and improve fish habitat. The near- and long-term costs for sediment inactivation are dependent on the longevity of each treatment and the selected inactivation chemical. Overall, for a 23-year period from 2025 to 2047, OST is the lowest cost option at $0.6 million, followed by sediment inactivation at $1.1 to $3.6 million, and water column stripping at $3.0 million. Due to the lower costs, greater sustainability, and potential ecological benefit of improving fish and benthic invertebrate habitat, OST is the preferred option. In addition, OST is likely a better candidate than sediment inactivation for funding by another algae management grant, because of its innovation, sustainability, and habitat improvement.

Hypolimnetic (deep water) oxygenation or aeration techniques have been implemented in many lakes, to combat low oxygen by maintaining or increasing oxygen levels in deep waters without causing whole-lake mixing. Hypolimnetic oxygenation systems have been successfully employed in many lakes, including Newman Lake in Spokane County, Washington, and this type of system is currently sought for Spanaway Lake in Pierce County, Washington. A hypolimnetic aeration system (injecting air rather than oxygen) was installed in 1994 and recently (in 2022) upgraded in Lake Fenwick in Kent, Washington. Maintaining oxygenated conditions in the upper sediments suppresses the release of phosphorus (as well as nitrogen). Preventing lake destratification (mixing of epilimnion and hypolimnion, or top and bottom layers) is important, to avoid introducing relatively nutrient-rich deep waters into the surface.

Oxygen Saturation Technology (OST) is a relatively new, patent-pending innovation used to administer precise concentrations of oxygen at strategic depths in a waterbody (Figure ES-2). The OST's design eliminates bubbles, which eliminates turbulence, sediment resuspension, and undesirable mixing. These systems can maintain dissolved oxygen (DO) levels as high as 20 milligrams per liter (mg/L) directly over and into the sediments, where oxygen is needed most. They may also help to prevent oxygen-related fish mortality. In order to overcome the high oxygen demand of organic-rich sediments in Echo Lake, these high dissolved oxygen levels (exceeding those from simple saturation with the air) are important. Traditional hypolimnetic aeration systems can fail, because they do not meet the sediment oxygen demand (i.e., the rate at which dissolved oxygen is removed from the water column during the decomposition of organic matter in lake sediments). OST will not fail, because (1) it uses pure oxygen, (2) it uses mechanical mixing to dissolve more oxygen than is normally diffused by traditional systems, and (3) it includes continuous monitoring of dissolved oxygen, which allows adjustments in the oxygenation rate, as needed, to meet sediment oxygen demand.

Figure ES-2. Oxygen Saturation Technology.



An OST system functions by transporting approximately 95 percent pure oxygen from an onshore facility to an in-lake device where the water is supersaturated with oxygen. The water is then injected back into deep areas of the lake where it disperses over the sediment surface. The oxygenated water can coat and penetrate the sediments, preventing the release of phosphorus from iron-phosphate complexes and allowing the oxidized iron to bind to phosphate released by microbial decay of organic matter. The onshore facility consists of a compressor and an oxygen generator. There is no storage of oxygen on premises.

It is anticipated that further evaluation, securing funding, and obtaining permits for the OST will take several years. We recommend that the City consider the long timeframe for evaluation, funding, and permitting when making any decisions to potentially take further steps in lake management. Further evaluation of OST is needed to select it as the internal loading management alternative. Then, funding sources can be sought and may include a variety of City, State, and citizen sources, as described below. Environmental permits should then be pursued through submittal of a Joint Aquatic Resources Permit Application, as required by the State Environmental Policy Act (SEPA) and Shoreline Management Act (SMA). This will include obtaining Hydraulic Project Approval from the Washington Department of Wildlife for protection of fish and their aquatic habitat, and Aquatic Use Authorization from the Washington Department of Natural Resources for use of the state-owned lakebed and waters. In addition, a Critical Areas Special Use Permit and Building Permit (for the oxygenation system on shore) will be needed from the City.

An OST system is expected to cost approximately $377,000 in the first 3 years for the oxygenation system installation, pump building, electrical hookup, permitting, engineering oversight, taxes, and contingency. Ongoing operation and maintenance are estimated to cost approximately $260,000 for the next 20 years based on $9,000 per year and 3.5 percent annual inflation. This yields an average annual cost $28,000 per year for the first 23 years, or less if the system lasts for more than 20 years.

The OST alone is not expected to reduce lake phosphorus concentrations enough to meet the lake management objectives. Assuming the OST provides a 75 percent reduction in internal loading, an additional 75 percent reduction in stormwater phosphorus loading is likely needed to achieve the total phosphorus management objective of 24 µg/L (Table ES-2). However, the total phosphorus management objective is based on a summer mean value in the epilimnion (surface layer), and the phosphorus budget prediction is based on a summer mean value in the entire lake, which would include higher concentrations in the hypolimnion. It is possible that the lake management objectives for reduced toxic cyanobacteria blooms may be achieved with OST alone, without substantial stormwater management. Because OST is most cost effective when reducing phosphorus loads, it is recommended to operate the OST system before implementing costly watershed management actions.

Table ES-2. Observed and Predicted Total Phosphorus Concentrations in Echo Lake Following Load Reduction Actions.

Scenario	Total Phosphorus (summer volume-weighted mean concentration in entire lake in micrograms per liter)
Current Conditions	82.3
Predicted TP (current load)	82.5
75% Internal Load Reduction ONLY	58.4
75% Internal Load Reduction + 25% Stormwater Load Reduction	47.2
75% Internal Load Reduction + 75% Stormwater Load Reduction	**24.7**
75% Stormwater Load Reduction ONLY	48.7

Predicted TP using Brett and Benjamin (2008). $TP_{Lake} = TP_{In} / (1+1.12 * T_w^{0.47})$

Watershed Management

A key long-term pathway to preventing cyanobacteria blooms is to decrease the loading of nutrients to the lake. This involves both source control and treatment. Source control is the removal or mitigation of a source, such as reducing phosphorus fertilizer use, managing erosion due to construction, and conducting business investigations and enforcement actions. Treatment is the reduction of a nutrient through built and natural infrastructure, such as infiltrating stormwater using LID techniques, filtering stormwater with phosphorus-adsorbing media, or installing vegetative buffers along waterways.

Source Control

The City has implemented stormwater education and outreach programs focused on waterfowl management, natural yard care, rain gardens, other low impact development retrofits, pet waste management, and pollution prevention for businesses and construction. These existing programs should be continued within the Echo Lake watershed to reduce nutrient loads to the lake.

Stormwater Management

Stormwater runoff is an important pathway of nutrients collected from paved and unpaved surfaces to surface water and groundwater. The Echo Lake watershed is highly impervious (58 percent), and most stormwater runoff flows into the City's stormwater drainage system. The rest of rainfall on the watershed infiltrates and enters subsurface groundwater flow. Approximately 50 percent of the annual rainfall reaches the lake through the stormwater drainage system. Even with an extensive education and source control program, nutrients still contaminate stormwater runoff with phosphorus from construction sites, fertilized areas, domestic animals, and wildlife.

The City recognizes the sensitivity of Echo Lake to phosphorus pollution and currently requires phosphorus treatment of stormwater for new and redevelopment in the Echo Lake watershed. In order to track the implementation of this phosphorus treatment requirement through the plan review process and the contribution towards the overall watershed reduction goal, additional training and documentation would be useful. The City should provide additional training for plan review staff and educate developers and drainage system designers on proper treatment system design, operation, and maintenance to reduce stormwater phosphorus loading to Echo Lake.

The City's Surface Water Utility inspects and maintains the stormwater system, constructs new facilities to address drainage issues and reduce pollution, works with businesses and residents to reduce pollution, monitors the health of the City's streams and lake, and responds to flooding from storm events. Maintenance of the stormwater system includes activities such as cleaning and repairing catch basins, clearing ditches, cleaning stormwater pipes, and maintaining stormwater treatment facilities. Regular maintenance reduces nutrient transport to the lake.

In addition, two stormwater retrofit projects are recommended for the basin. These two projects, in order of increasing cost, include the following:

- Bioretention Soil Mix Replacement ($841,000), because they were constructed with compost and shown by King County to be exporting phosphorus to the stormwater drainage system
- Detention Tank System (DTS) Phosphorus-Optimized Stormwater Treatment (POST) Retrofit ($3.5 million), because the DTS is the major source of stormwater phosphorus to the lake, it does not provide phosphorus treatment, and the POST system is a highly-effective, Ecology-approved system for treating high flow rates from the DTS

Monitoring

Regardless of the management strategy ultimately employed, ongoing monitoring is recommended and considered essential to evaluating success and allowing adaptive management. The adaptive management approach for Echo Lake includes short-term and long-term monitoring. Short-term monitoring is focused on key data gaps and will provide the information needed to confirm and refine the selected measures and develop more accurate cost estimates. Long-term monitoring will provide the information needed to evaluate progress toward achieving management goals and to adjust or augment the lake management measures.

As outlined in Table ES-2, we recommend developing a monitoring plan that builds on current water quality and lake level monitoring programs. The recommended plan would include the following:

- Additional routine lake monitoring
- Cyanobacteria bloom and fecal bacteria surveillance
- Stormwater treatment performance and inlet monitoring
- Sediment phosphorus monitoring

Costs are estimated for each monitoring element, with a 20 percent contingency included and a total annual cost of $33,660.

Adaptive Management

To further the long-term water quality and lake use goals for Echo Lake, this plan includes the following adaptive lake management framework. This framework will regularly reassess and amend LCMP strategies or goals, as part of ongoing, adaptive lake management, pursuant to future lake needs, stakeholder values, and funding. This LCMP includes an adaptive management section describing: 1) the decision-making process and adaptation framework by which the LCMP shall be modified, 2) current knowledge gaps and the recommended monitoring plan for continued effectiveness evaluation, and 3) potential future LCMP adaptations to begin considering.

Table ES-3. Recommended Monitoring Plan.

Monitoring	Description	Parameters
Lake Monitoring	Monthly water quality sampling (1 m below surface and 1 m above lake bottom) May through October Twice monthly vertical profiling (1-m intervals) with water transparency measurements	Nutrients (nitrogen and phosphorus) Chlorophyll-a and some phytoplankton Secchi depth Temperature, dissolved oxygen, pH Lake level
Recreational Safety	Weekly monitoring (Memorial Day to Labor Day) at Echo Lake Park for algae bloom observation and fecal bacteria testing.	Cyanotoxins *E. coli*
Surveillance for Cyanobacteria Blooms	Expand existing surveillance program for identifying and sampling cyanobacteria blooms to year-round to encompass reported wintertime algae blooms.	Algal scums Cyanotoxins
Sediment Monitoring	Collect two sediment cores every 5 years	Phosphorus fractions Iron
Stormwater/Inlet Monitoring	Monitor performance of stormwater treatment facilities (6 storm events at 1 site) and 2 lake inlets each year	Total phosphorus
Data QA and Management	Input laboratory and field data into database, perform data QA/QC.	All
Annual Reporting and Project Management	Summary of Monitoring Data, Management Effectiveness (if applicable), and Adaptive Management Recommendations	All

OST will reduce internal phosphorus loading, but it alone will not sufficiently reduce in-lake total phosphorus concentrations enough to meet the management objective for total phosphorus. Watershed source control efforts are necessary to reduce phosphorus to 24 µg/L or less. This total phosphorus objective is the boundary between mesotrophic (moderate productivity) and eutrophic (high productivity) classifications that is also expected to meet the other established objectives for water clarity (Secchi depth), algae biomass (chlorophyll-a) and toxic cyanobacteria blooms (cyanotoxins) (see Lake Management Objectives).

If the OST alone does not appear to be adequately reducing the hypolimnetic phosphorus, then modification of the management strategies is needed. Modifications may include in order of priority:

1. Increase the oxygen input amount and/or extend the duration of oxygen input to the hypolimnion (cold bottom layer of the lake separated by a thermocline from the warm top layer of the lake during summer months) from the OST system.
2. Increase the amount of iron in the lake sediments to bind phosphate under oxygenated conditions by applying zero valent iron to either the entire lake or just the hypolimnion area.
3. Plan and initiate a phosphorus inactivation treatment of the lake using alum or lanthanum.

Plan Cost and Funding

The recommended set of management strategies is estimated to cost approximately $777 thousand for the first 3 years (in 2024 dollars) and $3.2 to 5.8 million for the following 20 years (including 3.5 percent/year inflation) (Table ES-3). Additional funding sources will be necessary to implement the recommend elements of this plan. A combination of budget allocations, grants, and/or loans should be sought to fund and implement this management plan. We recommend considering the following sources:

- Special Use District Dues (e.g., Flood Control District, or Lake Management District)
- City of Shoreline Public Works Fund
- King County Department of Natural Resources and Parks Management Funds
- King County Flood Grants
- State Legislative Budget Allocations
- Freshwater Algae Control Grants
- Clean Water State Revolving Fund Loans
- Centennial Clean Water Grants
- Section 319(h) Clean Water Grants

Table ES-4. Recommended Cyanobacteria Plan Implementation Cost Summary.

	First 3 years		Next 20 years	
Plan Element	**Description**	**Cost (2024$)**	**Description**	**Cost ($)**
Oxygen Saturation Technology (OST)	Permit and install an OST	$377K	Ongoing maintenance and electricity costs (base cost: $7K/year)	$0.26M[a]

Watershed Source Control Education/Outreach (Waterfowl, Septic, Shoreline, and Land Stewardship)	Leverage existing Lake Stewardship program from King County to encourage and install best management practices.	$0	Ongoing	$0
New Development and Redevelopment	Improve training, tracking, and education of phosphorus treatment for new and redevelopment.	$0	Ongoing	$0
Stormwater Retrofit Evaluation	Evaluate potential stormwater retrofit locations.	$100K	Implement high-value, multi-benefit stormwater retrofits	$0.8–3.5M
Monitoring and Reporting	Routine/supplemental lake monitoring, bloom and fecal surveillance, stormwater monitoring, sediment monitoring, and reporting (base cost: $34K/year)	$110K	Routine/supplemental lake monitoring, bloom and fecal surveillance, stormwater monitoring, sediment monitoring, and reporting (base cost: $34K/year)	$1.1M[a]
Lake Management Administration	Finance and grant tracking. Adaptive management. Coordination with consultants and contractors. Implementation of management plan (base cost: $60K/year)	$190K	Finance and grant tracking. Adaptive management. Coordination with consultants and contractors. Implementation of management plan. (base cost: $60K/year)	$1.0M[a]
Total (first three years)		$777K	**Total (next 20 years)**	$3.2-5.8M

[a] 20-year cost assumes cost escalation of 3.5 percent each year in consideration of wage, utility, and material cost increases.

Introduction

Echo Lake is an urban lake in the City of Shoreline, in King County, Washington. The City of Shoreline ("the City") is contracted with King County ("the County") for lab and technical support and is assisted by volunteers from the Friends of Echo Lake (FOEL) nonprofit group to conduct bimonthly water quality monitoring of Echo Lake as part of King County's Lake Stewardship Program. Water quality assessments have revealed lake conditions commonly associated with cyanobacteria blooms. Echo Lake's Trophic State Index, an indicator of a lake's overall biological productivity, shows that the algae community is much more productive than would be predicted by the amount of phosphorous in the lake. Toxins produced by these blooms both inhibit recreational use of the lake and impact wildlife. Based on observed trends in nutrients and their relationship to cyanobacteria, toxic blooms may continue to increase unless actions are taken to reduce nutrient sources and change lake conditions.

The City applied for and received a grant from the Washington State Department of Ecology (Ecology) Freshwater Algae Program (Grant Number WQALG 2023-Shorel-00030) to prepare a Lake Cyanobacteria Management Plan (LCMP) that describes a strategy to reduce the frequency and duration of toxigenic algae blooms and to restore recreational use. The City contracted with Herrera Environmental Consultants (Herrera) to prepare the Echo Lake LCMP based on a Quality Assurance Project Plan (QAPP), which guided all study design, sample collection, field and laboratory analyses, data analyses, quality assurance, and reporting activities for data collected from the lake and its watershed (Herrera 2022a). Herrera developed the QAPP according to Ecology's Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies (Lombard and Kirchmer 2004), Guidance for Quality Assurance Project Plans (EPA 2002), and the Freshwater Algae Grant Funding Guidelines, State Fiscal Year 2024 (Ecology 2022a).

Using the scientific data collected following the QAPP, along with input from the City, the County, and the public, this LCMP identifies community concerns, defines priorities, outlines goals and objectives, characterizes the lake and watershed, and describes an adaptive lake management strategy. This LCMP will be used as a guideline and tool for allocating resources to implement the recommended management activities, with a framework and decision steps for future management needs.

Study Area Background

Watershed Characteristics

Echo Lake is located within the City of Shoreline in northern King County, about 12 miles north of downtown Seattle (Figure 1). The lake receives most of its water from stormwater runoff from its approximately 207-acre urban watershed (King County 2017), as well as from direct rainfall and underground springs. Echo Lake drains from an outlet on the north shore of the lake in Echo Lake Park. Water leaving the lake flows northeast through a piped stream and storm drain system into Lake Ballinger, which drains east into McAleer Creek and ultimately flows into the Puget Sound via Lake Washington (Figure 1).

Land Use, Land Cover, and Nutrient Sources

Echo Lake's watershed drains approximately 190 acres of primarily developed Puget lowlands (Figure 2). The lake's watershed is characterized by predominantly urban residential (40 percent) and commercial (30 percent) uses. Land in the watershed is highly developed, with approximately 58 percent impervious land cover. The Aurora Avenue North (Highway 99) Corridor (Aurora Corridor) is the developed area of highest intensity; it extends north-south within 350 feet of the western edge of the lake (Figure 2). Table 1 presents land use cover in each drainage basin identified for this project.

Table 1. Land Cover in Monitored Echo Lake Drainage Basins.

	NLCD (2021) Land Cover (Acres)							NLCD (2021) Imperviousness			
Drainage Basin	**Total Area**	**Agriculture**	**Forest**	**Wetlands**	**Grass/ Shrub/ Bare**	**Water**	**Developed**	**Total Acres**	**Impervious Acres**	**Percent Impervious**	**Runoff Coeff. Rv**
RES_FIRLANDS	41	0	0	0	0	0	41	41	19	45%	0.45
AURORA_NORTH	61	0	0	0	0	0	61	61	33	55%	0.55
SE_SKY	20	0	0	0	0	0	20	20	17	85%	0.82
AURORA_SOUTH	63	0	0	0	<1	0	63	63	45	71%	0.69
DTS_LEVEL	131	0	0	0	<1	0	131	131	82	63%	0.61
ECHO_IN	143	0	0	0	<1	0	143	143	89	62%	0.61
ECHO_X	47	0	3	0	0	0	44	47	27	56%	0.56
Lake	13	0	0	0	0	6	0	13	2	14%	--
Total Watershed	**190**	**0**	**3**	**0**	**<1**	**0**	**187**	**190**	**116**	**58%**	**--**

RES_FIRLANDS = Residential Firlands basin, which drains to. AURORA_NORTH, DTS_LEVEL, and ECHO_IN basins.

AURORA_NORTH = Aurora North basin, which drains to DTS_LEVEL, and ECHO_IN basins, and includes RES_FIRLANDS basin.

SE_SKY – Southeast Sky basin, which drains to AURORA_SOUTH, DTS_LEVEL, and ECHO_IN basins.

AURORA_SOUTH = Aurora South basin, which drains to DTS_LEVEL and ECHO_IN basins and includes SE_SKY basin.

DTS_LEVEL = Detention Tank System Level basin, which drains to ECHO_IN, and includes AURORA_NORTH and AURORA_SOUTH basins and 7 acres in the immediate vicinity.

ECHO_IN = Echo Lake Inlet, which drains to the south shore of Echo Lake, and includes DTS_LEVEL basin and 12 acres south of the DTS and west of the AURORA_SOUTH basin.

ECHO_X = Echo Lake Unmonitored Inflow, which includes 47 acres around lake east of Aurora and north of N 192nd.

Lake = Lake area not included in the total watershed area

National Land Cover Database (NLCD 2021) used for land cover and imperviousness.

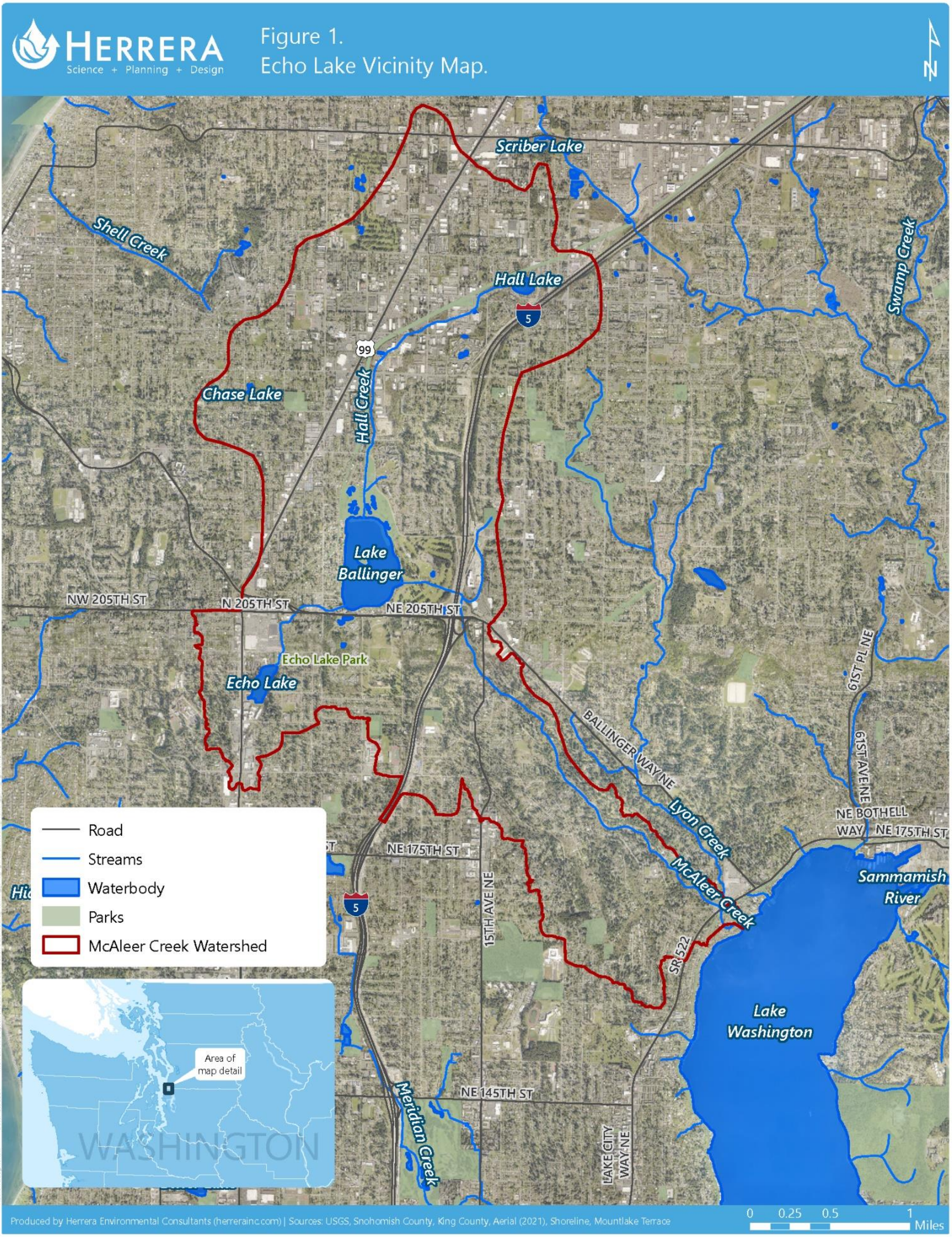
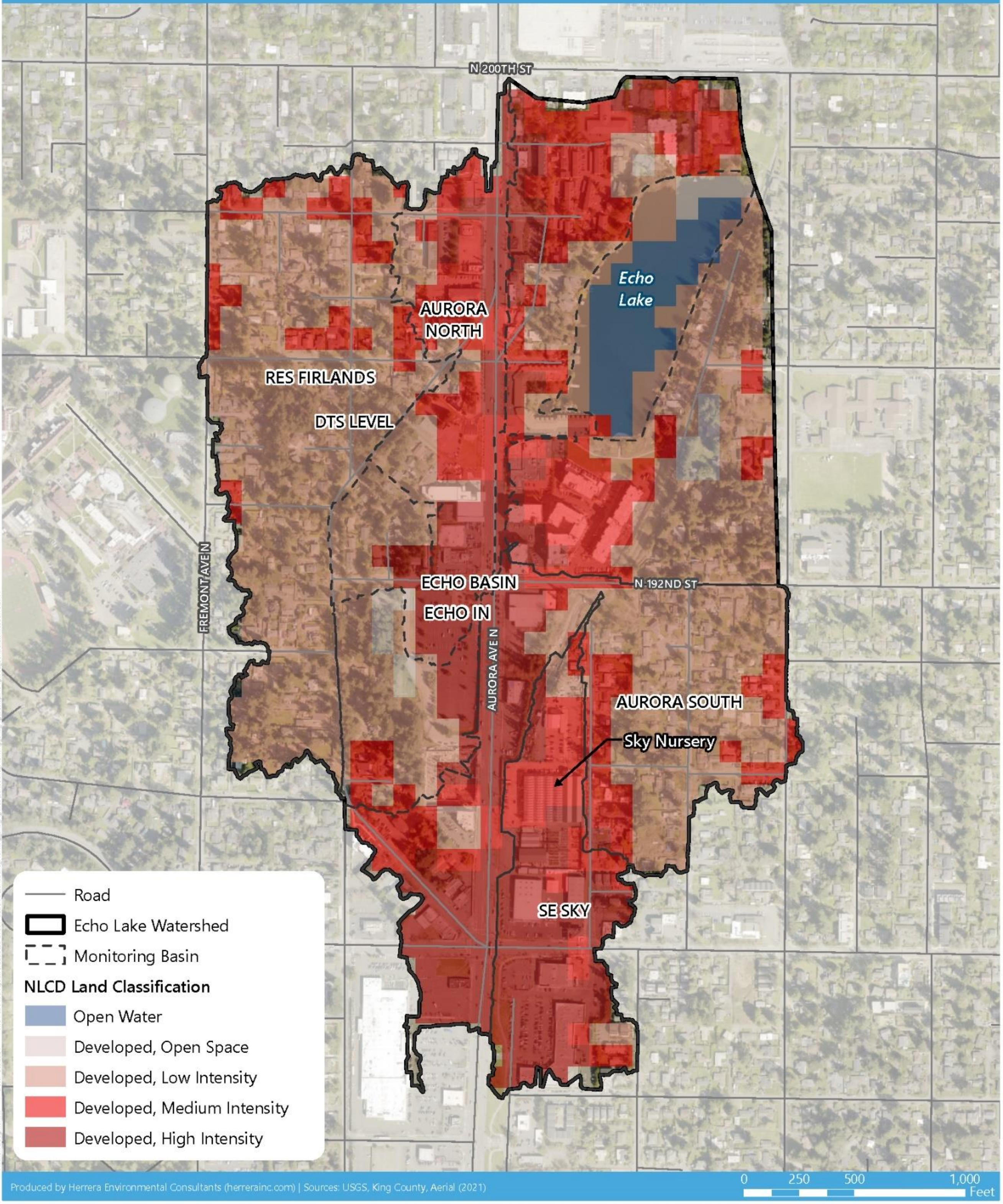


Figure 1.
Echo Lake Vicinity Map.

Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: USGS, Snohomish County, King County, Aerial (2021), Shoreline, Mountlake Terrace

Figure 2. Land Classification and Potential Phosphorus Sources in the Echo Lake Watershed.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: USGS, King County, Aerial (2021)

Potential major sources of nutrients in the watershed include roads (especially the Aurora Corridor) and uncovered piles of soil and compost. There is recent, ongoing, and anticipated future construction along the section of the Aurora Corridor within the watershed. Construction has the potential to be a large source of nutrients to the lake if not appropriately managed and contained. Other potential nutrient sources include residential lawns throughout the watershed.

Stormwater Conveyance and Monitoring

Echo Lake is stormwater-fed. A network of stormwater pipes in seven conveyance basins carries water to the lake (King County 2017) (Figure 3). Surface water runoff drains to the lake via approximately 10 stormwater outfalls located along the lake shoreline. By far, most of that runoff drains to a large outfall at the south end of the lake. Stormwater conveyance basins draining to Echo Lake were monitored for this LCMP from October 2022 through October 2023). Figure 3 shows the basins that were monitored and associated monitoring station locations. The monitoring station basins include the following:

- Echo Lake Inlet basin (ECHO_IN) is the largest basin. It drains 143 acres and was sampled where it discharges to the south shore of Echo Lake from the DTS (and an additional 12 acres near the DTS). ECHO_IN includes:
  - Detention Tank System (DTS) Level basin (DTS_LEVEL) represents most of the Echo Lake Inlet basin, draining 131 acres where the DTS outflow was monitored but not sampled. DTS_LEVEL includes:
    - Aurora North basin (AURORA_NORTH) drains 61 acres west of the lake and was sampled where it flows into the DTS. AURORA_NORTH includes:
      - Residential Firlands basin (RES_FIRLANDS) drains 41 acres of residential development in the western portion of the Aurora North basin and was sampled upstream of the Aurora North sampling station.
    - Aurora South basin (AURORA_SOUTH) drains 63 acres south of the lake and was sampled where it flows into the DTS. AURORA_SOUTH includes:
      - Southeast Sky basin (SE_SKY) drains 20 acres to the south-central portion of Aurora South basin and was sampled upstream of the Aurora South sampling station.
- Echo Lake Unmonitored Inflow (ECHO_X) drains 47 acres around a lake east of Aurora and north of N 192nd that was not monitored.

Stormwater Treatment

No targeted water quality treatment existed within the basin until retrofits of the stormwater conveyance infrastructure along the Aurora Corridor began in 2011. The Aurora Corridor retrofits were completed in 2017. Completion of the retrofits included installing bioretention planter boxes (BPBs) and Filterra® (FLT) systems (Figure 4). Table 2 lists a total of 48 stormwater treatment facilities in the watershed.

A detention tank system (DTS) was also installed at the park and ride facility at North 192nd Street and Aurora Avenue North to provide stormwater flow control before the main inlet drain discharges to Echo

Lake (also shown on Figure 4). The DTS is a system of 8-foot-diameter corrugated metal pipes, with a total length of 350 feet (and a total capacity of 17,600 cubic feet). The DTS is followed by a multiple orifice restrictor flow control structure and is designed to manage all of the flows for the 125-acre drainage basin (King County 2017).

Table 2. Stormwater Treatment Facilities in the Echo Lake Watershed.

Asset ID in GIS	Installation Date	Location	Owner	Name/Type
BR-9	2011	19022 Aurora Ave N	City	
BR-10 & BR-11		18820 Aurora Ave N Ste 103		
BR-12		18821 Aurora Ave N		
BR-13		18811 Aurora Ave N		
BR-20		Aurora Ave N & N 192nd St		
BR-21		Aurora Ave N & N 192nd St		Plaza Rain Garden
BR-104	2015	19906 Aurora Ave N	City	
BR-105		19806 Aurora Ave N		
BR-107		19425 Aurora Ave N		
BR-108		19522 Aurora Ave N		
BR-120	2017	19425 Aurora Ave N	Private	Public Storage Bioretention
BR-121		19237 Aurora Ave N		
FA-1	2011	18421 Aurora Ave N	City	
FA-2		18427 Aurora Ave N		
FA-3		18528 Aurora Ave N		
FA-4, FA-8, & FA-9		Midvale Ave N & N 185th St		
FA-5 & FA-6		18420 Aurora Ave N		
FA-7		1130 N 185th St Ste 101		
FA-10 & FA-11	2012	18551 Aurora Ave N Ste 201	City	
FA-12		1121 N 188th St		
FA-13		18811 Aurora Ave N		
FA-14		18821 Aurora Ave N		
FA-15		18820 Aurora Ave N Ste 101		
FA-16		18820 Aurora Ave N Ste 103		
FA-17		19022 Aurora Ave N		

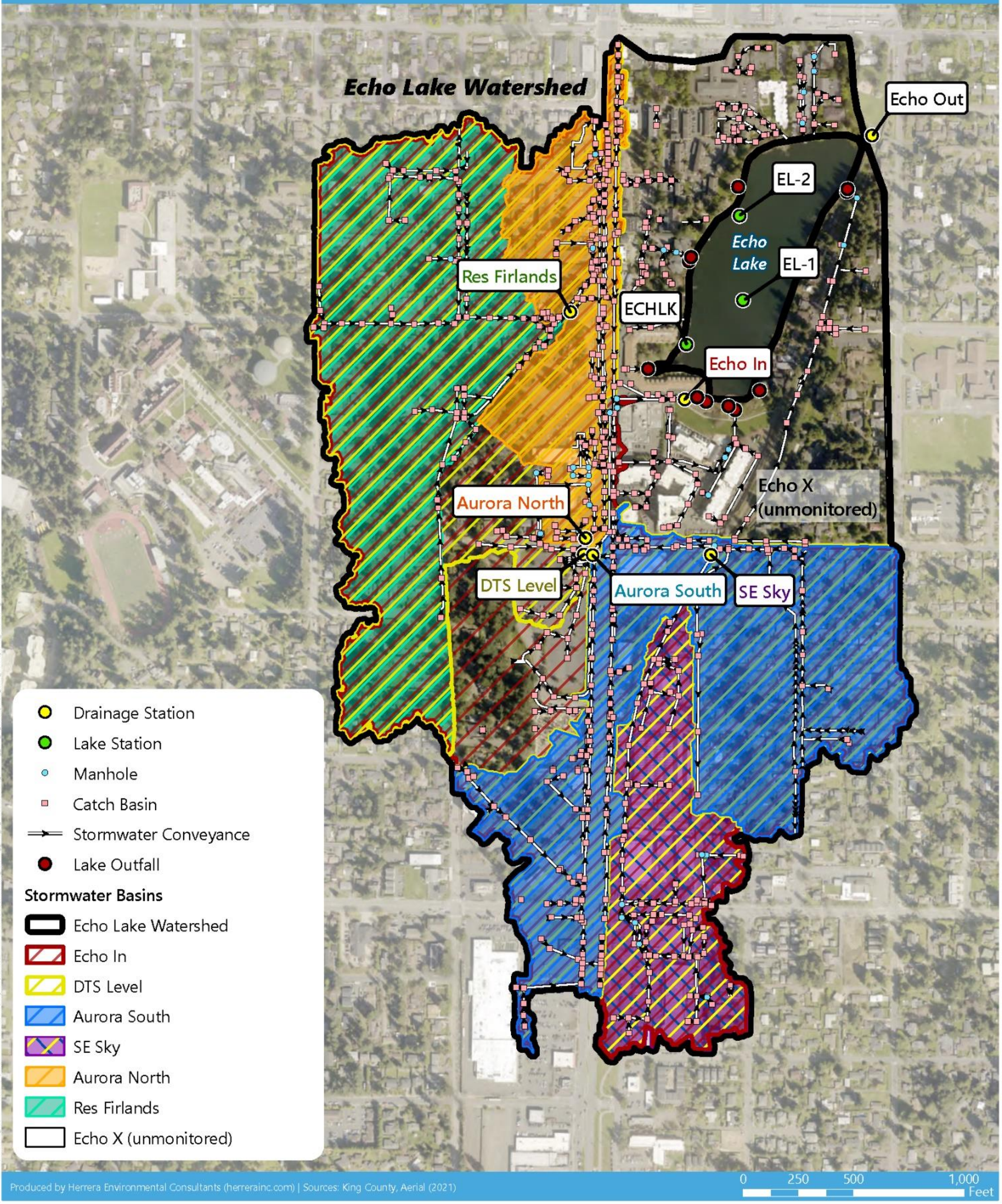
Table 3 (continued). Stormwater Treatment Facilities in the Echo Lake Watershed.

Asset ID in GIS	Installation Date	Location	Owner	Name/Type
FA-18 & FA-19	2015	19290 Aurora Ave N	City	
FA-20		19414 Aurora Ave N Unit 101		
FA-21		19428 Aurora Ave N Unit 223		
FA-22		19508 Aurora Ave N		
FA-23		19522 Aurora Ave N Unit 14		
FA-24		19805 Aurora Ave N		
FA-25		19550 Aurora Ave N		
MC12	2012	18821 Aurora Ave N	City	192nd St Detention System
MC10	2019	18557 Firlands Way N	City	Bayfilter Water Quality Vault
21015	2021	19230 Ashworth Ave N	Private	Echo Lake Elementary Ball Field
21017	2021	19425 Aurora Ave N	Private	New Hope Seattle Church
00002	Unknown	19527 Aurora Ave N	Private	Days Inn
03110	Unknown	18821 Aurora Ave N	Private	Shoreline Park & Ride
11001	Unknown	18530 Aurora Ave N	Private	Sky Nursery StormFilter Vault
14001	Unknown	19222 Aurora Ave N	Private	Echo Lake Mixed Use Village
16011	Unknown	1162-1196 N 198th St	Private	Echo Lake Village Townhomes
24001	Unknown	19806 Aurora Ave N	Private	St Margaret's Place

Sanitary Wastewater

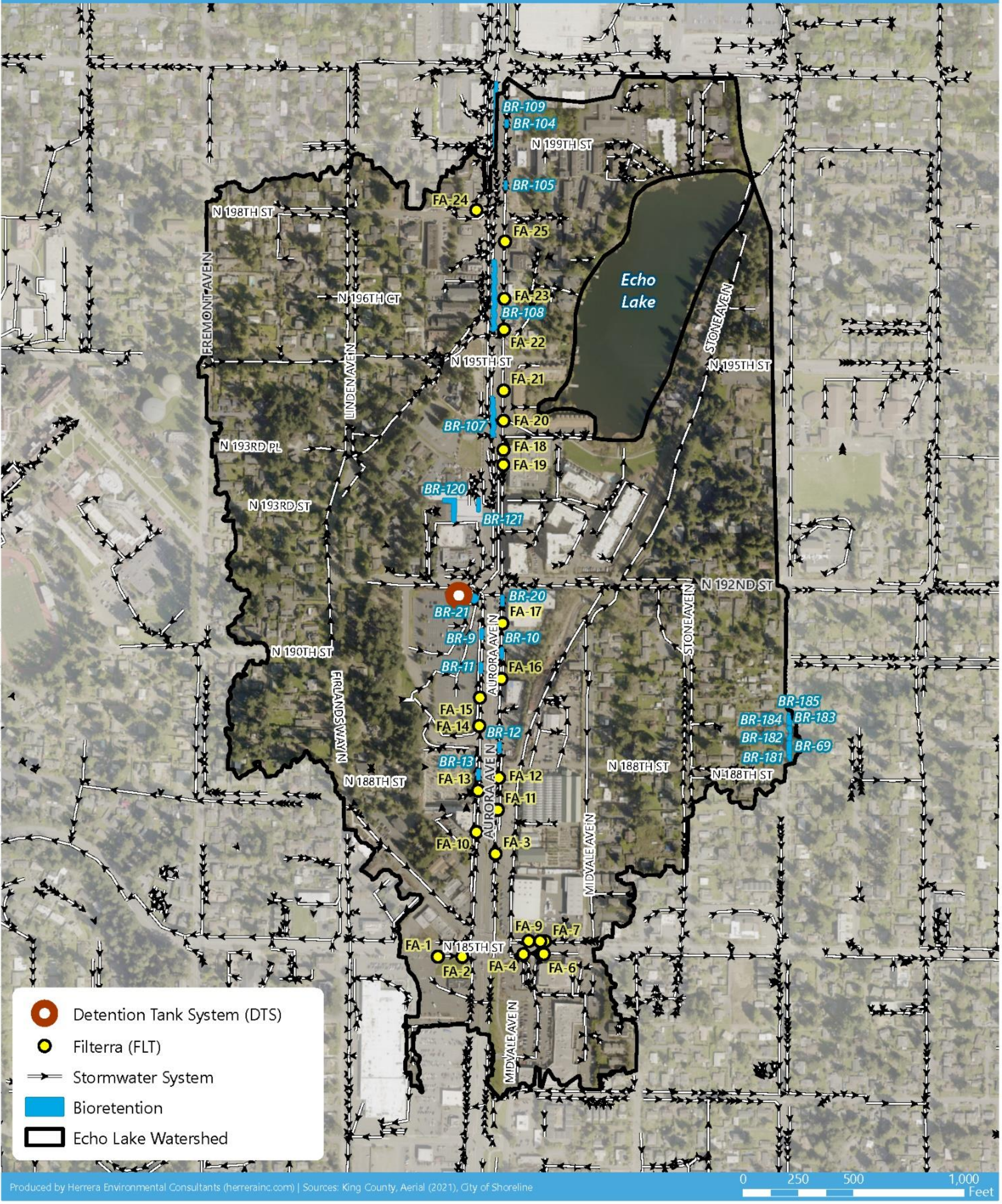
Echo Lake and its watershed are located within the service area for the City's Wastewater Utility (formerly Ronald Wastewater District until 2021). All sanitary wastewater in the Echo Lake watershed is conveyed via a separated sanitary sewer system for treatment outside the watershed (Figure 5). There are no onsite sewer systems (OSS) in the watershed. Sanitary sewer overflows (SSOs) and cross connections are not a known issue in the watershed. There was one report of illegal dumping of sewage in the lake reported in 2021, but there have been no other reports of SSOs or sewage discharges in the past 5 years (S. Grozev, personal communication, April 23, 2024). Other reported illicit discharges in the watershed in the past 5 years have included fuel and/or vehicle related fluids, sediment/soil from construction activities, paint, and food-related oil/grease.

Figure 3. Stormwater Conveyance and Monitoring Stations in the Echo Lake Watershed.



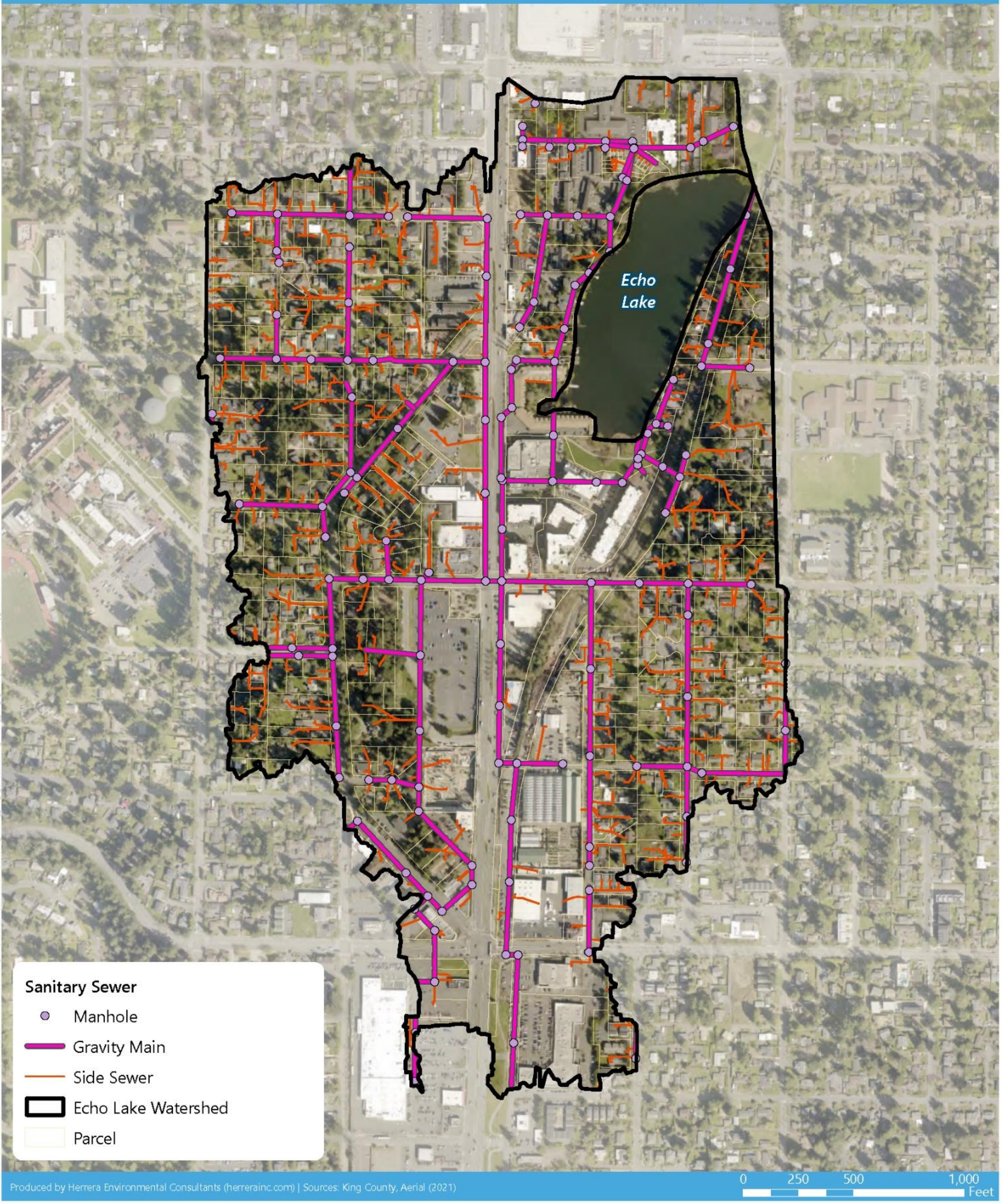
Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: King County, Aerial (2021)

Figure 4.
Stormwater Treatment in the Echo Lake Watershed.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: King County, Aerial (2021), City of Shoreline

Figure 5.
Sanitary Sewer System in the Echo Lake Watershed.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: King County, Aerial (2021)

Lake Characteristics and Uses

Echo Lake is a small lake, 13.0 acres in size, and has a maximum depth of 9.1 meters (30 feet) just south of the lake center (Figure 6, Table 4) (King County 2022). The shallow portions of the lake are the south and north ends, with lake depth increasing rapidly along the east and west sides. The mean depth is 5.2 meters (17.2 feet), which means that 50 percent of the lake area is shallower than 5.2 meters (17.2 feet). Table 5 presents the lake area and volume associated with each 5-foot contour interval shown in Figure 6.

Table 4. Morphometric Characteristics of Echo Lake.

Characteristic	English	Metric
Surface Area	13.0 acres	5.3 hectares
Maximum Depth	30 feet	9.1 meters
Mean Depth	17.2 feet	5.2 meters
Volume	223.9 acre-feet	276,189 cubic meters
Osgood ratio (mean depth [m]/ lake area [km^2](1/2)	22.8	
Lake Altitude (NAVD88)	395 feet	120 meters
Watershed Drainage Area	190 acres	77 hectares

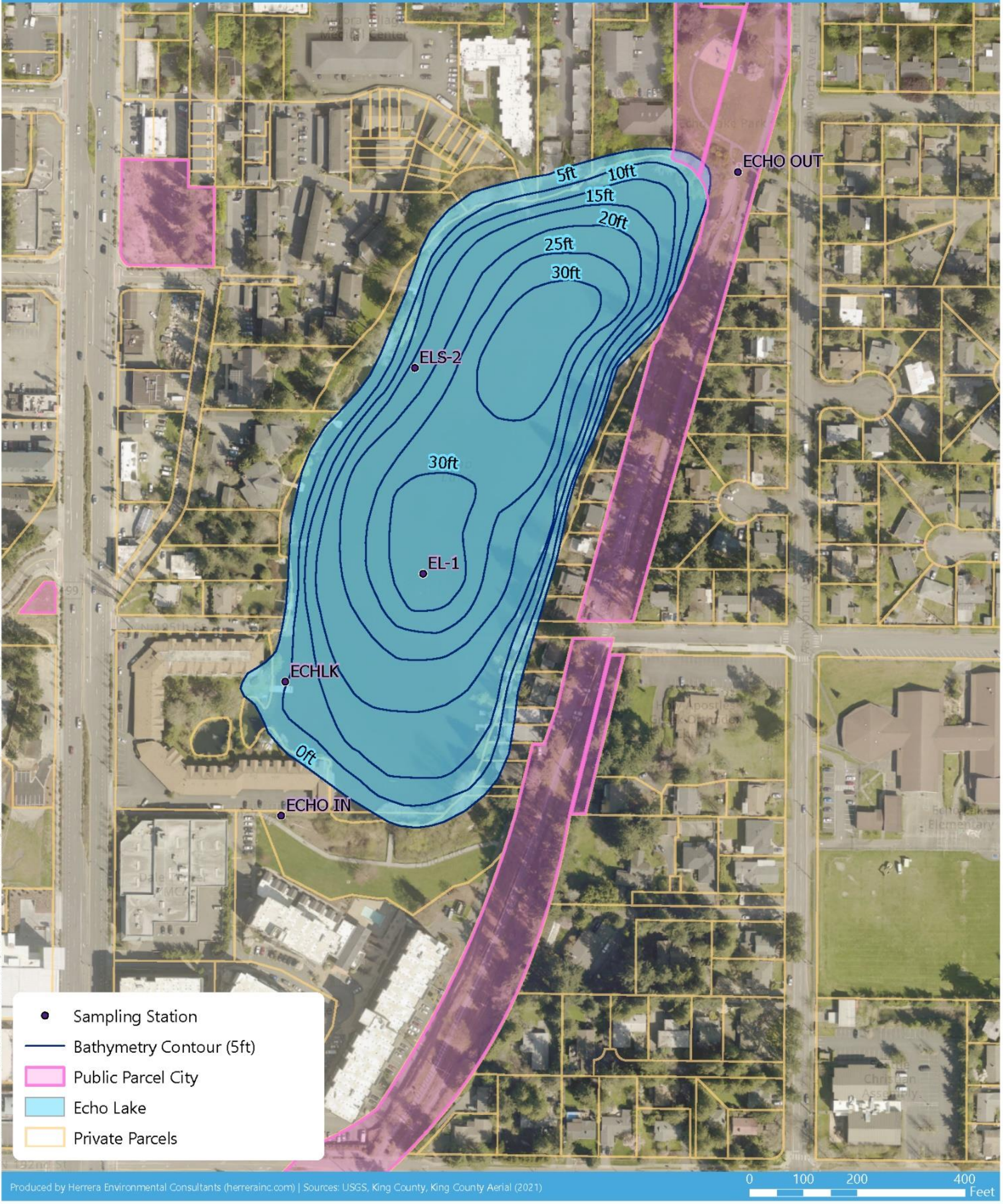
Table 5. Echo Lake Depth-Area-Volume.

Depth		Area		Volume Below	
Meters	Feet	Hectares	Acres	Cubic Meters	Acre-feet
0.0	0	5.3	13.0	276,189	223.9
1.5	5	4.5	11.2	201,489	163.4
3.0	10	3.9	9.6	137,269	111.3
4.6	15	3.1	7.7	83,940	68.1
6.1	20	2.2	5.4	43,630	35.4
7.6	25	1.5	3.7	15,742	12.8
9.1	30	0.6	1.6	–	–

In 2019, King County installed a continuous water level and temperature gauge at a dock on the southwest shoreline of Echo Lake (site code “ECHLK”; 47.77027, -122.34447). Prior to 2019, volunteers had measured lake levels weekly at the same station since 2003.

Precipitation and air temperature is measured at a continuous gauge operated by King County. The continuous gauge is located about 2.5 miles southwest of Echo Lake, at Shoreline Community College (site code “04u” – Boeing Creek; 47.75005, -122.360077).

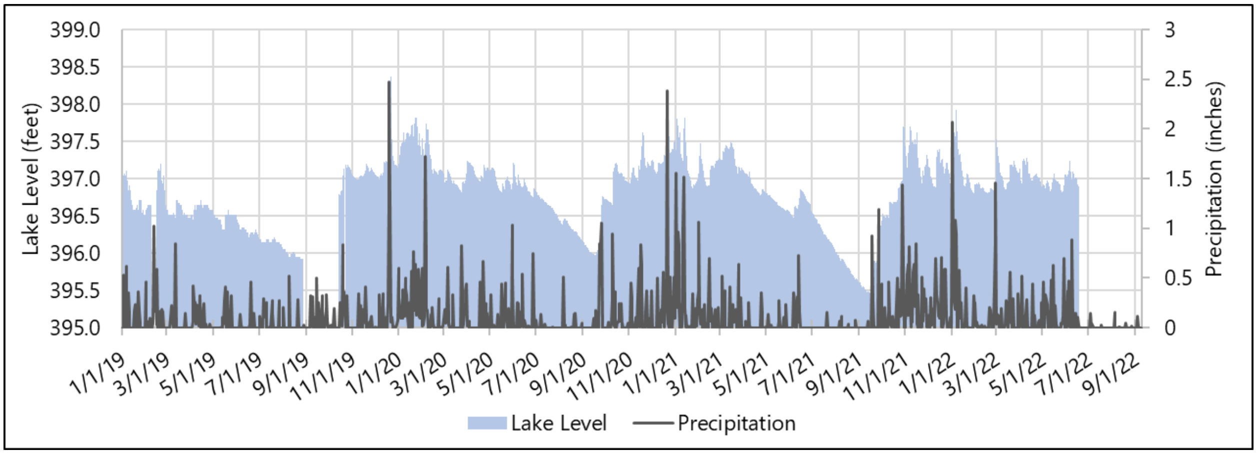
Figure 6.
Echo Lake Bathymetric Map.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: USGS, King County, King County Aerial (2021)

Figure 7 shows lake level and precipitation data from 2019 to 2022.

Figure 7. Echo Lake Level and Precipitation.



The lake surface elevation ranges between approximately 395.5 and 398.5 feet above sea level; it exhibits summertime fluctuations of about 1.6 feet on average and winter fluctuations of about 1.2 feet on average. Minimum annual stages typically occur August–September. Maximum annual stages typically occur October–February, varying relatively consistently with season and precipitation.

Beneficial Lake Uses

Echo Lake Park is a public park located at the north end of the lake, which is owned and operated by the City of Shoreline. Park amenities include a swimming beach, a playground, picnic areas, a restroom, and connection to the Interurban Trail. Shoreline fishing is available at the public park, from which anglers may catch largemouth bass and annually stocked rainbow trout. In 2010, Echo Lake Park was certified by the Washington State Department of Fish and Wildlife (WDFW) as a Backyard Wildlife Sanctuary. In the same year, Echo Lake Park was also certified by the National Wildlife Federation as a Certified Wildlife Habitat. The lake supports a range of wildlife, including ducks, geese, songbirds, herons, eagles, a variety of small mammals, freshwater otters, and many turtles. Although beavers are present in the nearby Ronald Bog, Twin Ponds, and downstream McAleer Creek, they have not been observed in Echo Lake (ELNA 2022).

Much of the Echo Lake shoreline is occupied by year-round residential housing, with an apartment complex, several townhomes and condominiums, and approximately 16 single-family homes (from which there are approximately 20 docks or other in-water structures). There are also some private commercial buildings along the shoreline. These private commercial buildings and Echo Lake Park represent a small portion of the shoreline.

Water from Echo Lake is designated for domestic, industrial, agricultural, and stock water supply uses. This does not include drinking water. Water Quality Standards for Surface Waters of the State of Washington provides use designations for freshwater bodies in Washington State (WAC 173-201A-600). Echo Lake has the following designated uses:

- Core summer salmonid habitat
- Primary contact recreation
- Water supply (domestic, industrial, agricultural)
- Stock watering
- Wildlife habitat
- Harvesting
- Commerce/navigation
- Boating
- Aesthetic value

Current and Historical Lake Uses

The land that is now the City of Shoreline was originally inhabited by the Suquamish, Snohomish, and Snoqualmie Tribes (Native Land 2024). Additionally, Puget Sound Salish groups, including the ha-ah-chu-ahbsh “small lake people” (from Lake Union), utilized resources in Shoreline to gather cranberries growing in nearby peat bogs (like the Echo Lake Peat bog located just southwest of Echo Lake (Copass 1996)). The first European settlers arrived in the 1830s. In 1855, Suquamish, Snohomish, and Snoqualmie leaders signed the Treaty of Point Elliott (Cession 347), in which the tribes surrendered millions of acres of land in return for a small sum and permanent protection from the United States government. The tribes also retained their hunting and fishing rights as a result of this treaty (Native Land 2024).

In 1891, a portion of the Great Northern railroad was completed, connecting the growing City of Shoreline to downtown Seattle. This attracted city residents seeking hunting or vacationing opportunities or those desiring to live in the country while working in the city (Stein 1999). Mowatt’s Mill at the north end of Echo Lake (Copass 1996, ELNA 2024) processed cedar, Douglas fir, and hemlock trees until it burned in 1912 (ELNA 2024). Other mills in Shoreline continued through at least the 1930s. When the land was cleared in the 1930s, it gave way to Seattle commuters and farmers (e.g., berries and chickens). They became Shoreline’s primary residents through 1940. By 1910, the Interurban electric train system had also connected Shoreline to Everett and Tacoma (Figure 8), with a station located at Echo Lake. This eased commutes and promoted the growth of small farms and subdivisions in Shoreline (Copass 1996, Stein 1999).

Figure 8. Mowatt Sawmill and Interurban Tracks at Echo Lake, circa 1910 Looking Northwest.

Photo courtesy of Shoreline Historical Museum, donated by Florence Butzke.

From 1916 to 1966, the Echo Lake Bathing Beach was a popular destination located at the south end of Echo Lake (Figure 9, Figure 10). Initially, the beach was informally used by nurses from the Firland Tuberculosis Sanatorium as a place to swim. In 1916, the Butzke family developed it as a public beach complete with dressing rooms, an admission stand where entry was permitted at the cost of five cents, boat rental facilities, and a concession stand (Copass 1996, UW Libraries 2024). In the winter, the lake was also used for ice-skating (Stein 1999, ELNA 2024). In 1947, the Holiday Resort was built on Echo Lake but did not prosper; it was replaced by a trailer park in 1960 (Copass 1996). In 1966, the bathing beach closed; in 1968, it was replaced by the Echo Lake Condominiums, which continue to operate today (ELNA 2024).

The lake today features Echo Lake Park, which is open to the public and owned by the City of Shoreline. The park features a beach, paved trails, a playground, and public art. Echo Lake is also home to many private residents (including single family homes, condominiums, and apartment communities) who keep private docks that allow abundant access for recreation. Waterfront vegetation along the shoreline varies, consisting of modified shoreline with bulkheads or fill, landscaped shoreline, and more natural shoreline with mixes of native and weedy vegetation. A thorough shoreline assessment to track changes and opportunities for restoration could be performed. There are no known significant water withdrawals for any water supply uses.

Figure 9. Echo Lake Bathing Beach-Goers, 1935.

Photo courtesy of Shoreline Historical Museum, donated by Florence Butzke.

Figure 10. Echo Lake Bathing Beach and parking lot, Echo Lake, 1952

Photo courtesy of Shoreline Historical Museum, donated by Florence Butzke.

Fisheries

Historically, as shown in photos and reports of caught trout, Echo Lake was a popular recreational fishing lake (ELNA 2024). Today, it is still popular for fishing for stocked trout. WDFW has stocked the lake with rainbow trout since at least 1995, with up to 795 pounds of fish stocked annually. Historical annual trout stocking data are presented in Table 5. In April 2023, 350 pounds of legal-size rainbow trout were stocked in Echo Lake (WDFW 2024a), approximating the 29-year annual average of 390 pounds. No other estimates of fishery conditions or population sizes are available.

Table 6. Echo Lake Annual Rainbow Trout Stocking (WDFW 2024a).

Year	Number	Pounds
1995	1433	515
1996	1000	244
1997	1000	333
1998	800	216
1999	–	–
2000	1050	300
2001	1000	250
2002	–	–
2003	1200	300
2004	1200	444
2005	1200	300
2006	1500	455
2007	1500	455
2008	1500	375
2009	1000	313
2010	1000	286
2011	1200	353
2012	1100	543
2013	1590	795
2014	1213	485
2015	1500	600
2016	1200	500
2017	1200	480
2018	1208	525
2019	1248	520
2020	1000	476
2021	1000	435
2022	1000	476
2023	1050	350
Mean	**1,100**	**390**

– no data available, assumed no stocking

Aquatic Plants

The aquatic plant community in Echo Lake is comprised by abundant native plants and a few nonnative noxious weeds.

In June 2016, the City conducted a survey, in partnership with Ecology, to identify native and nonnative aquatic and submerged vegetation in response to community concerns regarding the extensive abundance of lily pads. The survey was conducted by boat using visual inspection and rake collection. The survey identified nine native species and three nonnative species (Table 7). The three nonnative species are classified as non-regulated noxious weeds by the King County Noxious Weed Control Board (i.e., state-listed Class B and C noxious weeds, which negatively impact people and the environment but are not designated for mandatory control in King County).

Table 7. Echo Lake Aquatic Vegetation (2016).

Scientific Name	Common Name	Type	Status
Ceratophullim demersum	Coontail; hornwort	Submerged	Native
Comarum palustre	purple (marsh) cinquefoil	Emergent	Native
Eleocharis sp.	spike-rush	Emergent	Native
Elodea nuttallii	Nuttall's waterweed	Submerged	Native
Juncus sp.	rush	Emergent	Native
Nuphar polysepala	yellow water-lily	Floating	Native
Potamogeton amplifolius	large-leaf pondweed	Submerged	Native
Potamogeton sp. (thin leaved)	thin leaved pondweed	Submerged	Native
Schoenoplectus sp.	naked-stemmed bulrush	Emergent	Native
Iris pseudacorus	yellow flag iris	Emergent	Class C Noxious Weed
Nymphaea odorata	fragrant waterlily	Floating	Class C Noxious Weed
Typha angustifolia	lesser cattail	Emergent	Class C Noxious Weed

According to the survey report (COS 2016), both yellow flag iris and fragrant water lily were observed mostly along the western shoreline in scattered patches mixed with native yellow water lily. Patches of the nonnative cattail were observed along the northeast shoreline near Echo Lake Park.

The report recommends residents may control these non-regulated noxious weeds within the fish window (July 16–September 30), utilizing the WDFW Aquatic Plants and Fish pamphlet as a permit. Additionally, Ecology (pers. comm., H. Maiefski, City of Shoreline, April 1, 2022) confirmed that noxious weed removal in Echo Lake, which is regulated as a wetland, is an allowed activity per SMC 20.80.324(B)(4) if performed in accordance with WDFW's pamphlet and is exempt from the following activities and regulations:

- Critical area provisions per SMC 20.80.030(E)
- Permitting per SMC 20.50.310(A)(6)
- SEPA per WAC 197-11-800(24)(h).

Endangered/Rare Species Present

According to WDFW's Priority Habitats and Species (PHS) in Washington State tool (WDFW 2024b), there are no sensitive habitats within the Echo Lake watershed. The only identified natural habitat in the watershed is wetland. Habitat notes by WDFW biologists indicate these wetlands are associated directly with the lake or smaller tributary streams (i.e., stormwater conveyance) and that most of this area is heavily developed as urban housing and industrial land uses.

The only endangered, sensitive, or rare species identified for the Echo Lake watershed is the little brown bat (*Myotis lucifugus*; sensitive status). WDFW cautions PHS users that these data are for informational purposes only and do not represent an exhaustive list of all fish and wildlife presence. WDFW strongly recommends users to schedule a field visit by a fish and wildlife biologist or habitat expert to make determinations about species presence, absence, or exact location before making any final decisions about a project.

Lake and Watershed Quality Summary

Echo Lake is a eutrophic lake with high algal productivity based on historical trophic state index (TSI) values for chlorophyll-a (algae biomass) and total phosphorus. Water clarity based on the TSI for Secchi depth has typically been in the mesotrophic range, representing moderate algal production. TSI values in 2023 agreed with contemporary TSI values, suggesting gradual, long-term eutrophication. Eutrophic conditions in Echo Lake are characterized by high phosphorus concentrations, high algae growth, and low water clarity. Blooms in Echo Lake are often toxic and occasionally occur at levels that risk the health of humans or wildlife. Existing blooms are driven by an abundance of bioavailable nutrients, which fuel algae growth and are typically limited by the amount of phosphorus, particularly during the summer months.

Water quality characteristics of the lake and drainage to the lake are presented in the Lake and Watershed Monitoring Report (Appendix A) and summarized as follows:

- Echo Lake undergoes summer thermal stratification from mid-May through early-mid September. Particularly elevated surface temperatures occurred in July and August but never exceeded the EPA recommended maximum temperature for survival of juvenile trout (24°C).
- High dissolved oxygen (DO) in April, May, and August from the lake surface to depths between 2.5 and 4.5 meters indicates abundant phytoplankton growth in the surface layer (epilimnion) and near the thermocline.
- Anoxic conditions (DO <1 mg/L) in the hypolimnion (bottom layer >5 meters) strongly follow the thermal stratification period, beginning in early May near the lake bottom at 8 meters, rising up to 4 meters by August, and persisting near the lake bottom through late October.
- The greatest surface water clarity occurred in May and June when chlorophyll-a at the surface was low.

- Summertime chlorophyll-a concentrations peaked at the lake surface in April, August, and October, coinciding with reduced water clarity and/or elevated dissolved oxygen conditions indicative of algae blooms. Chlorophyll-a near the lake bottom was substantially greater than respective surface chlorophyll-a concentrations.
- Prompted by observations of algae blooms and scums, cyanotoxin samples collected in September and October contained detectable concentrations of microcystin, barely exceeding state criteria (8 µg/L) once on October 2, 2023, at 10 µg/L, coinciding with a chlorophyll-a peak.
- All cyanobacteria species identified in Echo Lake are toxin-producers. *Aphanizomenon* at the lake surface and *Oscillatoria* at the lake bottom comprised a significant portion of the phytoplankton community in July. This dominance likely extended to early August, as indicated by the peak in chlorophyll-a, before subsiding to low levels of both chlorophyll-a and cyanobacteria in late August.
- Phytoplankton were not analyzed in October, but cyanobacteria abundance and biomass results indicate Oscillatoria, a producer of microcystin, is a likely culprit behind Echo Lake's toxic algae blooms.
- Generally, crustacean zooplankton (copepods and cladocerans like Daphnia) accounted for most of the community abundance when the lake surface algae community wasn't dominated by cyanobacteria. Small rotifers dominated by numbers in July when cyanobacteria dominated the algae community.
- Phosphorus at the surface of Echo Lake frequently exceeded thresholds for undesirable algae growth in 2023 and during previously monitored summers; it exhibited a statistically significant ($p<0.05$) increasing long-term trend (King County 2023).
- Elevated summertime total phosphorus, orthophosphate, and total nitrogen concentrations were observed in the hypolimnion (bottom layer), facilitated by anoxic conditions.
- Low nitrate + nitrite in the lake suggests nitrogen is largely comprised of, or produced by, the existing algae stock at the lake surface and comprised of ammonia at the lake bottom, released from anoxic lake sediments.
- The proportion of orthophosphate relative to total phosphorus indicates a greater amount of phosphorus was available for algae growth at the lake surface in early summer, but in late summer the most phosphorus available for algae growth was at the lake bottom.
- Total nitrogen to phosphorus (TN:TP) ratios between 9 and 22 in the epilimnion indicate algae growth is limited by both phosphorus and nitrogen at least May through October, with the relative strength of limitation by phosphorus greatest in mid-summer. Though limited by both nutrients, which is common in other Puget Sound lowland lakes, phosphorus control in Echo Lake, particularly during the summer months, is key to reducing algae and cyanobacteria blooms.
- Echo Lake may become increasingly nitrogen limited over time ($p<0.05$; King County 2023), which can favor growth of nitrogen-fixing cyanobacteria over other types of algae. Phosphorus controls will also reduce nitrogen inputs, and lower phosphorus favors other types of algae.

- Lake sediments contain moderate levels (10 to 40 percent) of active phosphorus (i.e., able to be released) in the biologically active zone (0 to 10 cm), and total iron to phosphorus ratios (Fe:TP) indicate that iron in the lake sediments is generally sufficient to regulate phosphorus; its release can be prevented when the sediment surface has oxygen.
- Stormwater runoff is a major contributor to the lake's phosphorus load, with minor contributions from groundwater and direct precipitation to the lake. The AURORA_SOUTH basin more consistently contributes the most phosphorus and water to the lake, compared to other basins, but sources in more residential basins (e.g., RES_FIRLANDS) also intermittently contribute high phosphorus loads.

Contaminants of Concern

The contaminants of concern in Echo Lake are the cyanotoxins microcystin and anatoxin-a, total phosphorus, and fecal coliform bacteria. According to the 2018 Integrated Report for Sections 303(d) and 305(b) of the Clean Water Act, Echo Lake is listed as impaired (Category 5) due to elevated levels of total phosphorus (per an average of 38.9 µg/L in 2017).

Ecology recently revised Water Quality Program Policy 1-11 to develop Narrative Water Quality Standards for the basis of impairment for Harmful Algae Blooms (Ecology 2023). Ecology will utilize a combination of public health advisory information, cyanotoxin data from the Northwest Toxic Algae database, public health assessment information, and Washington Department of Health (DOH) recreational guidance as the basis for evaluating the health of contact recreation in the Water Quality Assessment (WQA).

Fish in Echo Lake are impaired during the summer months by high water temperatures in surface waters and low dissolved oxygen levels in the bottom waters.

Community Involvement & Public Support

Public stakeholders include lakeshore homeowners and other Echo Lake community members who recreate in the lake and at Echo Lake Park. This community is highly engaged in protective activities for the lake, which are often orchestrated through the FOEL nonprofit group and/or the Echo Lake Neighborhood Association (ELNA) as the primary organizations for community engagement and homeowner membership. Since 1996, ELNA's mission as part of the City of Shoreline Council of Neighborhoods has been to build community by providing a forum for sharing information, connecting neighbors, promoting activities, and fostering civic involvement (ELNA 2024). ELNA publishes regular online newsletters, and members meet once monthly except in August and December.

Additional stakeholders include (1) King County, which provides lake monitoring program leadership and coordination, and (2) the City of Shoreline, which owns a public park located on the lake's northeast shore and provides regulatory oversight, guidance, and lake monitoring assistance as well as some program funding. State agencies with an interest in Echo Lake include (1) Ecology as managers of the state-owned waters and project funder, (2) WDFW for managing fish and issuing permits for sediment-disturbing actions in the lake, and (3) the Washington Department of Natural Resources (DNR) as managers of state-owned aquatic lands and lake bottom.

Improvement Efforts

General lake and water quality improvement efforts undertaken at Echo Lake have included but are not limited to:

- Prohibiting feeding geese and duck populations within Echo Lake Park
- Permitting redevelopment of commercial centers that include regulatory-required installation of stormwater treatments systems to remove pollutants from run-off before entering the lake, particularly along the Aurora Corridor
- Education and outreach to property owners in the watershed and around the shoreline regarding use of pesticides, fertilizers, pet waste, and soaps
- Removal of noxious aquatic weeds (by volunteers and lakeshore residents)
- Requirement for phosphorus treatment for development/redevelopment within the drainage basin

Project Description

Project Goals and Objectives

The overall goal of the project is the development of a cyanobacteria management plan that identifies sources of phosphorous fueling the toxic algae blooms that occasionally occur during the summer in Echo Lake. Monitoring of Echo Lake water quality and other parameters will be performed with the primary goal of evaluating the effects of environmental conditions and past lake management practices on algae growth and toxin production. Toxic algae blooms are stimulated by several factors, which may include but are not limited to:

- Stormwater runoff or other surface pollutant sources, washing nutrients into the lake
- Less oxygen in bottom waters or sediments from oxygen consumption by microbial respiration and decomposition, increasing the release of sediment phosphorus (internal loading)
- Warmer weather, extending the period of low oxygen in bottom waters or sediments
- Wind mixing up nutrient-rich bottom waters
- Increased nutrients from the increased aquatic plant decay or waterfowl activity
- Trout stocking, reducing zooplankton grazing of algae

The resulting cyanobacteria management plan will build on past management actions, provide recommendations for water quality improvements to enhance recreational and wildlife use of the lake, and primarily focus on developing a management strategy to reduce the frequency and duration of toxic algae blooms. To meet this goal, the following objectives have been defined for this project:

- Fill data gaps in water quality, watershed, and biological information for Echo Lake.
- Evaluate effects of environmental conditions and past lake management practices on algae growth and toxin production.
- Develop a phosphorous loading model and budget using data from the project and historical datasets.
- Identify the sources of phosphorous that stimulate cyanobacteria blooms.
- Determine predictors of chlorophyll-a concentration and algae production for modelling of treatment efficacies.
- Develop recommendations for watershed phosphorus loading reduction treatments and in-lake restoration techniques.
- Develop a cyanobacteria management plan, which, when implemented, reduces the frequency and duration of cyanobacteria blooms.

- Inform and guide future aquatic plant and waterfowl management actions and ongoing monitoring strategies with respect to cyanobacteria blooms.
- Provide high quality data for the City of Shoreline, FOEL, and other users.

Lake Management Objectives

The goal for Echo Lake management is to improve and protect lake uses by decreasing cyanobacteria blooms and the conditions that support them. The recommended water quality objectives for Echo Lake are adapted from Ecology (2023) criteria for determining lake impairment due to harmful algae blooms. These objectives include the following:

- Within a 5-year period, there is no more than 1 year with two or more events with cyanotoxins exceeding state recommended guidelines.
- Within a 5-year period, there is no more than 1 year with a public health advisory lasting 3 weeks or longer.

To prevent harmful algae blooms, it is recommended to reduce the trophic state of Echo Lake from eutrophic to mesotrophic by not exceeding the following upper-mesotrophic thresholds based on average summer (June through September) values in the epilimnion (1 meter depth) (Carlson 1977):

- Chlorophyll-a concentration not exceeding 7.2 µg/L
- Total phosphorus not exceeding 24 µg/L
- Secchi depth exceeding 2.0 meters

Schedule

For this project, City of Shoreline, King County, Herrera, and FOEL may share certain responsibilities and project actions. The lead entity and schedule for each project action are thus provided below in Table 8.

Data Used for Plan Development

This plan was developed using data collected as part of this LCMP project. A summary of the types of data gathered, methodology used, data quality assurance results, and sources of additional datasets are presented in Appendix A. Field data and laboratory data reports are compiled in Appendix B and Appendix C, respectively.

Table 8. Project Organization, Responsibilities, and Schedule.

Task	Item	Responsible Entity				Begin Date	End Date
		HEC	COS	KC	FOEL		
1.0	Project management	**X**	x			9/1/22	6/30/24
2.1	Stormwater monitoring		**X**		x	10/14/22	10/30/23
	Lake water quality monitoring		x	x	**X**	10/14/22	10/30/23
	Lake sediment P monitoring	**X**			x	8/1/23	8/30/23
2.2	Water/Phosphorus Budgets	**X**	x			11/1/23	5/1/24
2.3	Pre-draft LCMP	**X**	x			11/1/23	5/1/24
	Draft LCMP	**X**	x	x	x	5/1/24	5/24/24
	Final LCMP	**X**	x	x	x	5/24/24	6/26/24
2.4	Project Kickoff Meeting	x	**X**	x	x	9/1/22	10/16/22
	Pre-Summer Monitoring Meeting	x	**X**	x	x	5/1/23	5/30/23
	Draft LCMP meeting/presentation	**X**	x	x	x	4/1/24	5/16/24
	Final project meeting/presentation	**X**	x	x	x	6/1/24	6/30/24
3.1	Background Review	**X**	x			9/1/22	9/22/22
3.2	Draft QAPP	**X**	x	x		9/1/22	9/22/22
	Final QAPP	**X**	x	x	x	9/30/22	9/30/22
3.3	Laboratory Analyses	x	**X**	x		10/16/22	11/30/23
4.1	Stormwater Sampling Contingency	**X**				10/14/22	10/30/23
4.2	Stormwater Management Contingency	**X**	x			11/1/23	4/14/24

X = lead entity x = participating entity

HEC = Herrera Environmental Consultants COS = City of Shoreline KC= King County

FOEL = Friends of Echo Lake volunteers

Echo Lake Hydrologic Budget

Development

A lake's hydrologic budget refers to the quantification and analysis of the various inflows, outflows, and storage changes that contribute to the overall water balance of the lake over a defined period, typically annually. This concept is vital for understanding the hydrological dynamics and sustainability of a lake ecosystem. A comprehensive description of a lake's water budget involves the following components:

- Precipitation (*P*): Precipitation represents the input of water onto the lake surface in the form of direct rain and snowfall.
- Evaporation (*E*): Evaporation refers to the loss of water from the lake surface due to the conversion of liquid water to water vapor, which is driven by solar radiation and atmospheric conditions. Evaporation rates vary based on factors such as air temperature, humidity, wind speed, and lake surface area.
- Runoff (*R*): Runoff includes all surface water inflows to the lake from its watershed. Runoff can result from rainwater and snowmelt onto watershed lands beyond the limits of the lake, and it carries nutrients, sediments, and pollutants into the lake. In Echo Lake, Runoff consists of inputs from the Detention Tank System to the main lake inflow (Q_{Echo_In}) and direct stormwater discharges from outfalls and other areas around the lake (Q_{Storm}).
- Groundwater Inflow (GW_{In}): Groundwater inflow represents the subsurface flow of water from aquifers into the lake. This contribution can significantly influence the lake's water budget, particularly in regions with permeable soils and high groundwater recharge.
- Groundwater Outflow (GW_{Out}): Groundwater outflow represents the subsurface flow of water from lake into aquifers.
- Outflow (*O*): Outflow consists of water leaving the lake via surface water. Echo Lake's outflow is a 24-inch corrugated metal pipe to a stormwater conveyance network that ultimately discharges to Lake Ballinger.
- Change in Storage (ΔS): This component accounts for the change in the lake's water volume stored over the defined time period. Positive values indicate an increase in storage (lake level rise), while negative values signify a decrease (lake level decline).

The water budget equation can be expressed as the difference between inflows and outflows:

$$\Delta S = P + Q_{Echo\_in} + Q_{Storm} + GW_{IN} - (O + E + GW_{Out})$$

Because of the difficultly in measuring groundwater flows, the groundwater component is often expressed as the net (GW_{Net}), calculated as the difference between inflows and outflows plus the change in storage:

$$GW_{Net} = GW_{In} - GW_{OUt} = (Ouflows + \Delta S) - Inflow$$

Change in Lake Storage

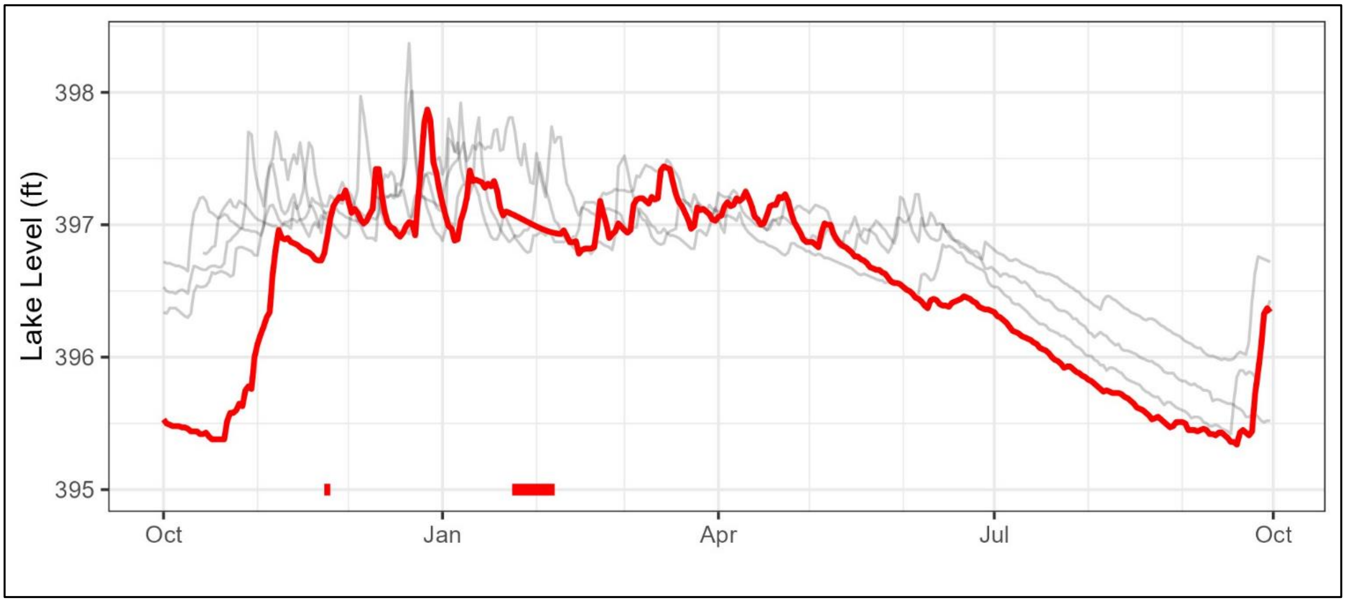
Continuous lake level measurements were recorded by King County using a level logger mounted on a dock at station ECHLK (see Figure 3). The volume of water in the lake for each day was estimated based on the lake level and lake bathymetry, and the daily changes in volume were calculated. Volumes were summed at a monthly basis.

Data gaps in lake level were small (less than 5 percent) and include:

- November 23 to 25, 2022
- January 24 to February 7, 2023

Lake levels during the gap periods were estimated using Piecewise Cubic Hermite splining interpolation. Splining was used to provide a smooth approximation of the lake level. The data gaps were relatively short and are not expected to greatly impact the monthly summary values. Figure 11 presents lake levels during the study period (red line) with comparison to previous years (grey lines). Lake levels were lower than usual in October 2022 and mid-June to mid-September 2023. Figure 12 presents the lake surface area during the study period (red line) that mirrors the lake level.

Figure 11. Echo Lake Level for Water Year 2023 Compared to Historic Levels (2019 to 2022).

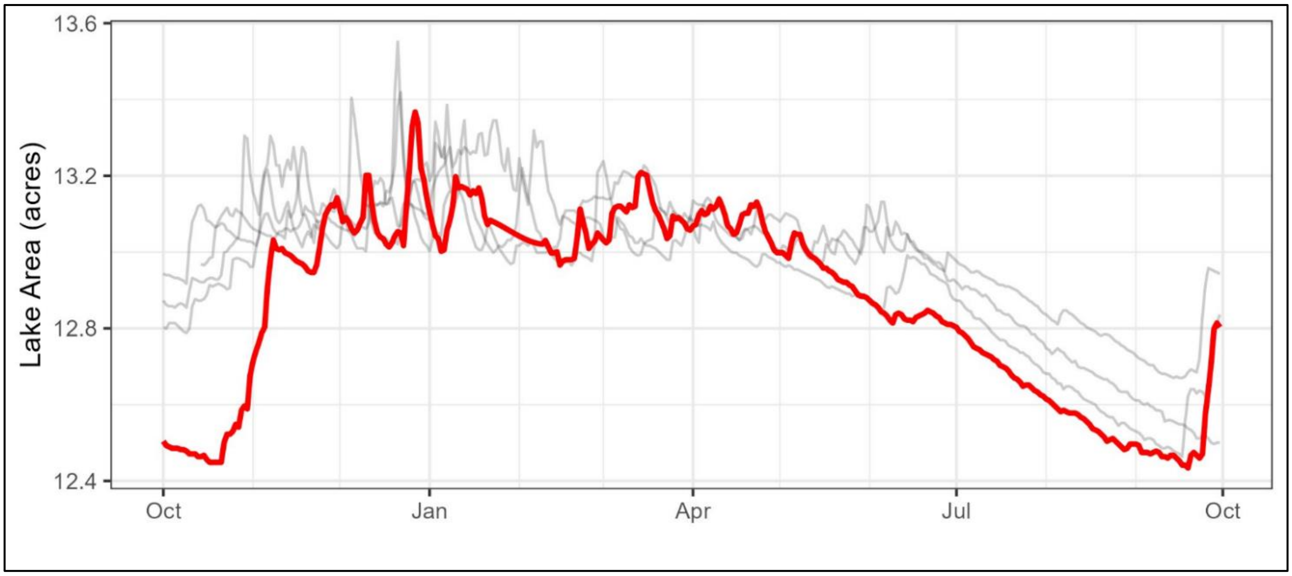


Water year 2023 shown as red line, past years shown in grey, and red area at bottom represents filled data gaps.

Precipitation

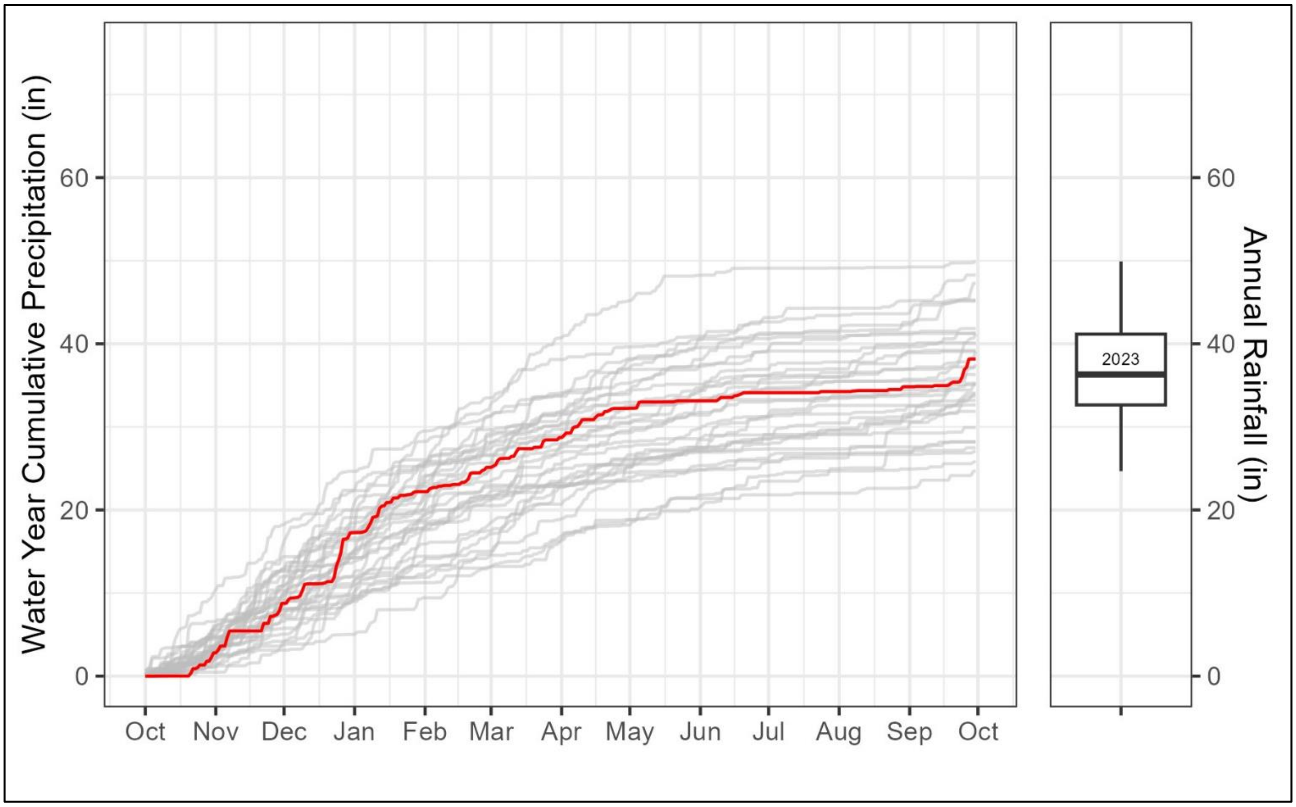
Daily rainfall data from the Boeing Creek precipitation station (04u) operated by King County (2024c) were used and multiplied by the lake surface area (based on lake level) to calculate the volume of direct precipitation. Water year 2023 was about typical with a total of 38.2 inches of rainfall, and the median rainfall between 1990 and 2023 was 36.3 inches (Figure 123).

Figure 12. Echo Lake Surface Area for Water Year 2023 Compared to Historic Areas (2019 to 2022).



Water year 2023 highlighted as with the red line, 2019 to 2022 shown in grey.

Figure 13. Daily Cumulative Rainfall (left) and Annual Water Year Annual Rainfall (right) at Boeing Creek Rain Gauge (1989 to 2023).



Water year 2023 shown as red line, 1989 to 2022 shown in grey (King County 2024c).

Evaporation

Evaporation depth was calculated using daily average air temperature and dew point from the Everett Airport. The daily evaporation depth was multiplied by the daily surface area of the lake to calculate total monthly evaporation volume.

To estimate evaporation, we used the simplified Penman equation (Linacre, 1977):

$$E = (700 * (T + 0.006 * h)/(100 - A) + 15 * (T - T_d)) / (80 - T)$$

Where:

- E - evaporation (mm/day)
- T - mean daily air temperature (deg C)
- h - elevation (m)
- A - Latitude (deg)
- T_d - dew point

The interpolated lake level estimates do not significantly affect the evaporation estimates for Echo Lake because the primary lake level data gap occurred during the winter when evaporation is less substantial at about 2 millimeters per day. Assuming that evaporation rate, if the lake area estimate was off by 2 acres on a given day, this would net a difference of only 16 cubic meters compared to an annual water outflow of 0.4 million cubic meters.

Surface Inflows

We estimated surface inflows coming from the DTS Facility, which includes the Aurora North and South drainages, and from the near-lake drainage area (ECHO-X). We used measured water levels at the DTS facility to estimate discharge leaving the facility, and we compared those estimates to measured discharge at the ECHO-IN station. We assumed there is no surface base flow for the nonmonitored basins (designated as ECHO-X drainage) and that all those loads would be captured in groundwater load.

Continuous five-minute-interval water level data for the DTS facility were provided by City staff. The data were corrected for sensor drift. The discharge in cubic feet per second from the facility was estimated based water level (DTS_{Level}) in the outlet structures in the facility using the following set of equations for each of three orifices (bottom #1 at 406 ft, middle #2 at 406 ft, and top #3 at 406.5 ft elevations) and the overflow riser (at 412 ft elevation) (Figure 14):

$$Discharge_{DTS} = Orficice_{Bottom} + Orifice_{Middle} + Orifice_{Top} + Riser$$

Where:

$$Orifice_{Bottom} = DTS_{Level} \geq 406 \begin{cases} sqrt\left((DTS_{Level} - 406) * 2 * 32.17\right) * \pi * r_{bottom}^{2} * C_{bottom} \\ 0 \end{cases}$$

$$where\ r_{bottom} = 0.204\ feet; C_{bottom} = 0.61$$

$$Orifice_{Middle} = DTS_{Level} \geq 408.002 \begin{cases} sqrt\left((DTS_{Level} - 408.002) * 2 * 32.17\right) * \pi * r_{middle}^{2} * C_{middle} \\ 0 \end{cases}$$

$$where\ r_{middle} = 0.221\ feet; C_{middle} = 0.61$$

$$Orifice_{Top} = DTS_{Level} \geq 408.5 \begin{cases} sqrt\left((DTS_{Level} - 408.5) * 2 * 32.17\right) * \pi * r_{top}^{2} * C_{top} \\ 0 \end{cases}$$

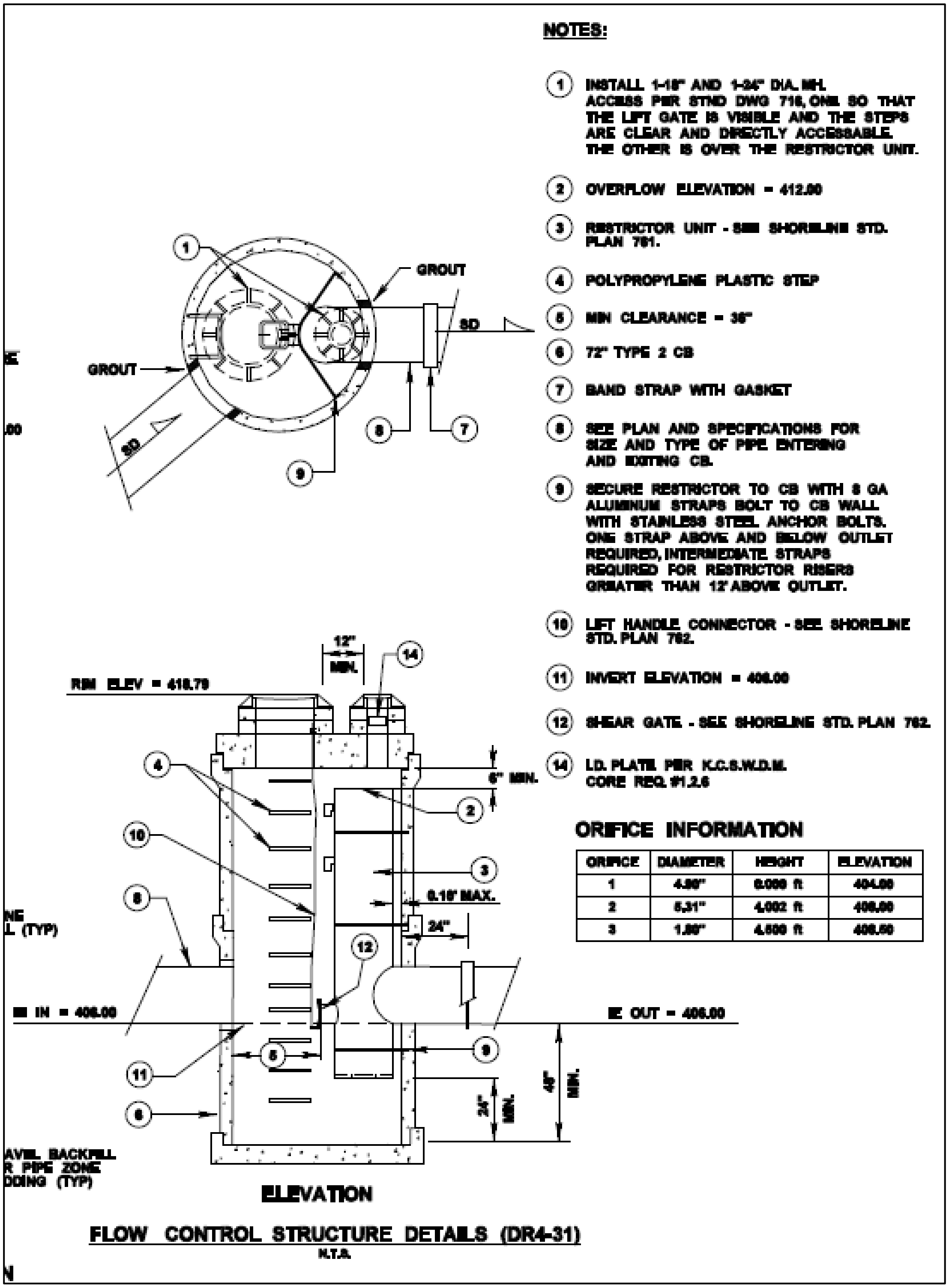
$$where\ r_{top} = 0.075\ feet; C_{top} = 0.61$$

$$Riser = DTS_{Level} \geq 412 \begin{cases} cw_{riser} * 2\pi * r_{riser} * (DTS_{Level} - 412)^{1.5} \\ 0 \end{cases}$$

$$where\ r_{riser} = 1.5\ feet$$

$$cw_{riser} = \frac{(DTS_{Level} - 412)}{r_{riser}} > 0.5 \begin{cases} 3.15 - 2.3 * \left(\frac{(DTS_{Level} - 412)}{r_{riser}} - 0.5\right) \\ 3.4 - 0.5 * \left(\frac{(DTS_{Level} - 412)}{r_{riser}}\right) \end{cases}$$

Figure 14. DTS Flow Control Structure Schematic.



NOTES:

① INSTALL 1-18" AND 1-24" DIA. MH. ACCESS PER STND DWG 716, ONE SO THAT THE LIFT GATE IS VISIBLE AND THE STEPS ARE CLEAR AND DIRECTLY ACCESSABLE. THE OTHER IS OVER THE RESTRICTOR UNIT.

② OVERFLOW ELEVATION = 412.00

③ RESTRICTOR UNIT - SEE SHORELINE STD. PLAN 761.

④ POLYPROPYLENE PLASTIC STEP

⑤ MIN CLEARANCE = 36"

⑥ 72" TYPE 2 CB

⑦ BAND STRAP WITH GASKET

⑧ SEE PLAN AND SPECIFICATIONS FOR SIZE AND TYPE OF PIPE ENTERING AND EXITING CB.

⑨ SECURE RESTRICTOR TO CB WITH 8 GA ALUMINUM STRAPS BOLT TO CB WALL WITH STAINLESS STEEL ANCHOR BOLTS. ONE STRAP ABOVE AND BELOW OUTLET REQUIRED, INTERMEDIATE STRAPS REQUIRED FOR RESTRICTOR RISERS GREATER THAN 12' ABOVE OUTLET.

⑩ LIFT HANDLE CONNECTOR - SEE SHORELINE STD. PLAN 762.

⑪ INVERT ELEVATION = 406.00

⑫ SHEAR GATE - SEE SHORELINE STD. PLAN 762.

⑭ I.D. PLATE PER K.C.S.W.D.M. CORE REQ. #1.2.6

ORIFICE INFORMATION

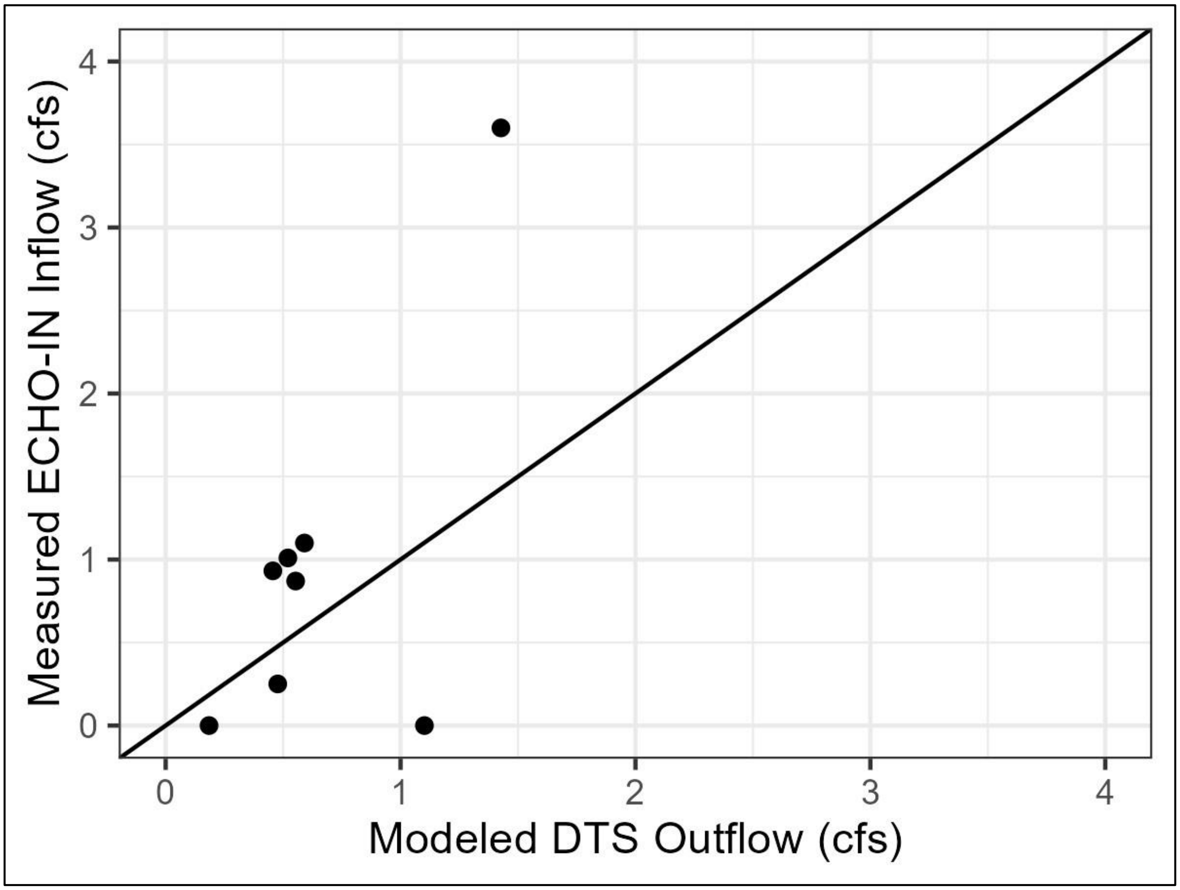
ORIFICE	DIAMETER	HEIGHT	ELEVATION
1	4.90"	0.000 ft	404.00
2	5.31"	4.002 ft	408.00
3	1.80"	4.500 ft	408.50

Orifice 1 is the bottom orifice, orifice 2 is the middle orifice and orifice 3 is the top orifice.

The modeled DTS outflow did not match the measured discharge at the ECHO-IN site. Large differences between the DTS outflow and ECHO-IN discharge were seen on October 31, 2022 and November 22, 2022. On October 31, 2022, no discharge was seen at ECHO-IN when the DTS water level was 408.07 feet, well above the DTS outlet elevation of 406 feet. On November 22, 2022, the measured discharge at ECHO-IN was 3.6 cfs and much higher than the estimated DTS outflow rate of 1.43 cfs based on a DTS elevation of 408.38 feet. According to the equations used for estimating DTS outflow, to reach a discharge rate of 3.6 cfs the DTS level would need to reach the riser overflow elevation of 412 feet (see Note 2 in Figure 14).

The higher measured discharge than the modeled outflow is partly attributed to the additional drainage area between the DTS facility and ECHO-IN station. The ECHO-IN site receives drainage from 12 acres of highly impervious area in addition to the 131 acres draining to the DTS facility (accounting for 8.4 percent of the 143 acres draining to ECHO-IN). There are no flow control facilities in this additional area, so there may be flashier flows that would result in higher peak discharge rates. To account for the additional drainage area, the modeled DTS monthly discharge volumes were multiplied by 1.09 (Figure 15).

Figure 15. Modeled DTS Outflow Versus Measured Discharge During 8 Monitoring Events at ECHO-IN.



For storm flow from the ECHO-X unmonitored drainage area, we implemented the Simple method (Schueler 1987). The technique requires a modest amount of information, including the watershed drainage area and impervious cover, and annual precipitation using the following equation:

$$V_{S,i} = R_{v,i} * P * A_i$$

Where

- V is the runoff volume for watershed i
- Rv is the runoff coefficient for watershed i
- P is the precipitation depth (m)
- A is the total watershed area for watershed i (m^2)

The runoff coefficient Rv is calculated using the following equation:

$$R_{v,i} = 0.05 + 0.9 * I_{a,i}$$

Where I_a is the impervious fraction for watershed i.

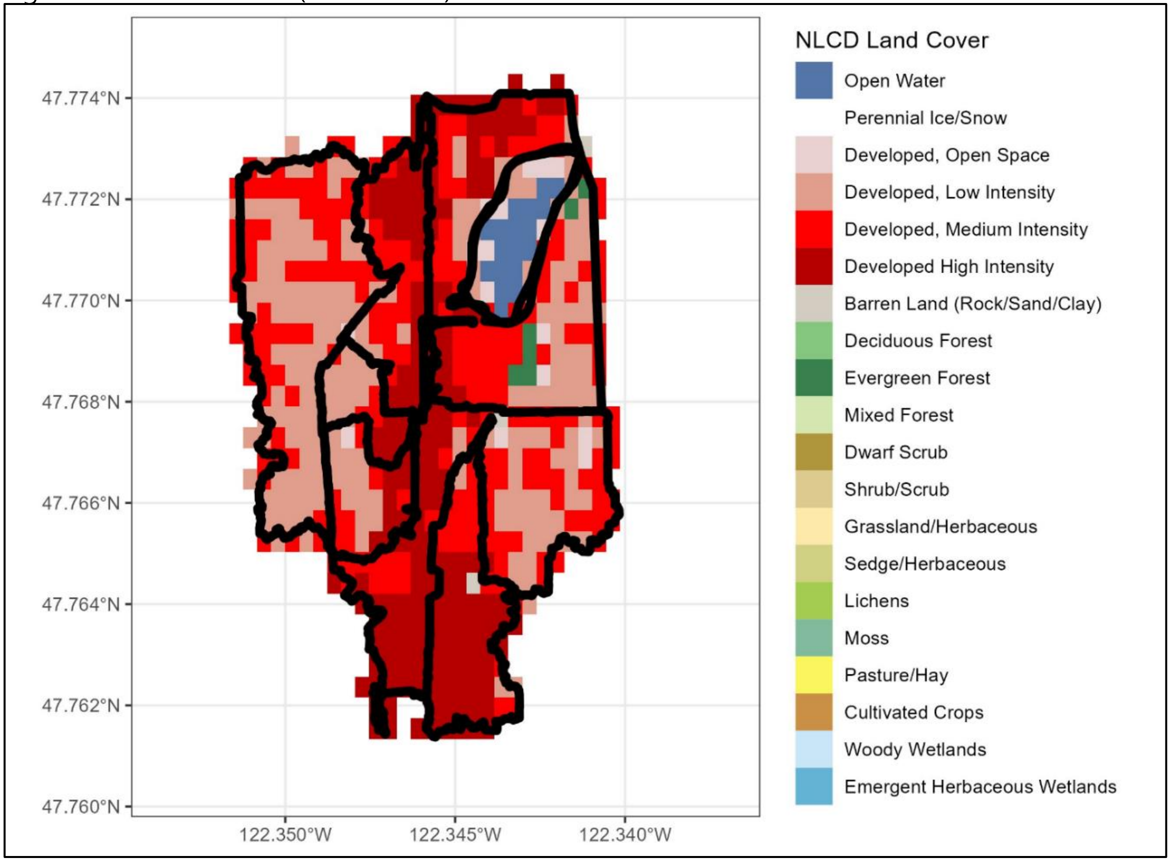
Drainage basin land cover and runoff coefficients are provided in Table 1. Land cover shown in Figure 16 with basin boundaries and in more detail in Figure 2. Due to the granularity of the National Land Cover Database (NLCD) at 30 m by 30 m cells, there some misclassifications (Figure 16). For example, about 6 acres of Echo Lake is characterized as developed due to land cover cells at the border of the lake.

Lake Outflow

Discharge at the lake outlet (ECHO-OUT) was measured using a current meter to measure the velocity and depth of water in the 24-inch inlet pipe located at the outlet manhole. The instantaneous discharge measurements and the lake level were used to develop a rating curve (Figure 17). Seven watershed monitoring events were used to develop the rating curve. There were four additional monitoring events where no outflow was observed. This rating curve was used to calculate daily discharge across the monitoring period, including the period with interpolated lake level values (Figure 18).

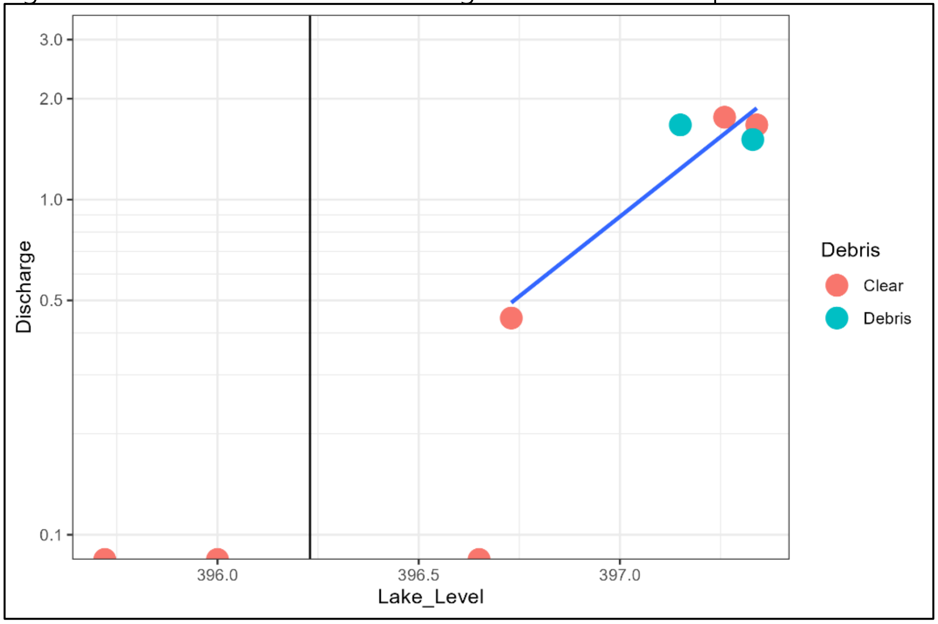
The lake outlet was impacted by debris on several occasions. City staff and lake residents cleared debris from the outlet. On the two occasions when debris was present while taking discharge measurements, City staff measured discharge before and after clearing debris (Table 8). After clearing debris, there were significant increases in discharge on each of the two occasions. Lake discharge increased from 0.065 cfs to 1.51 cfs on January 18, 2023, and from 0.24 cfs to 1.67 cfs on April 6, 2023. The post-debris clearing measurements were used in the rating curve and are shown as “Debris” points in Figure 17.

Figure 16. Land Cover (NLCD 2021) in the Echo Lake Watershed.



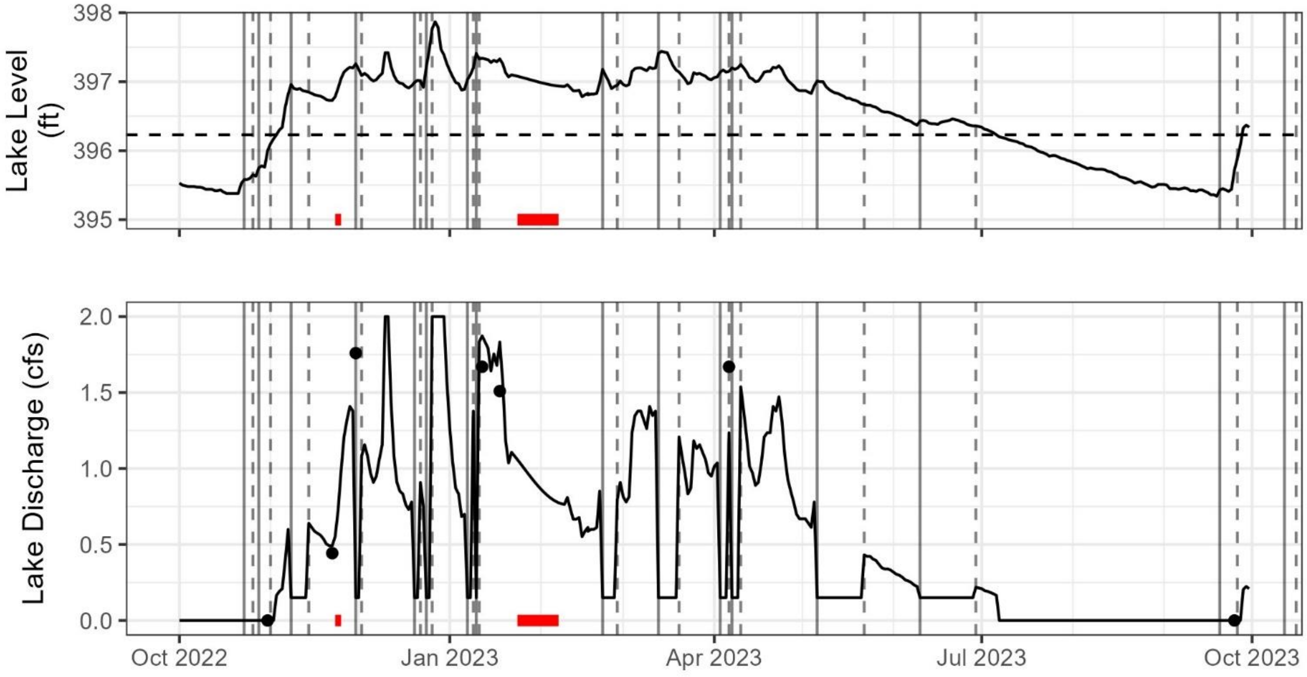
Basin outlines shown in black. 2021 NLCD from MRLCC 2023.

Figure 17. Echo Lake Outlet Discharge-Level Relationship.



Note y-axis is on log-scale. Vertical line is the invert elevation of the lake outlet pipe (396.23 feet). Best fit line equation: Discharge = exp(-869.9)*exp(Level)^2.19 (R^2 = 0.88). Debris indicates the discharge *after* debris was cleared.

Figure 18. Echo Lake Outlet Estimated Discharge.



Horizontal dashed line represents the elevation of the lake outlet structure (396.23 feet). Vertical lines represent the estimated appearance of debris (solid) and the known clearing of debris (dashed). Measured discharge (post debris clearance) are shown as points. Red bars represent periods of missing lake level measurement data

Table 8. Measured Echo Lake Outflow Discharge Before and After Discharge Debris Clearing.

Date	Lake Level	Debris Present?	Discharge (cfs)	Discharge After Clearing Debris (if present) (cfs)
2022-10-31	396.00	No	0	NA
2022-11-22	396.73	No	0.44	NA
2022-11-30	397.26	No	1.76	NA
2023-01-12	397.34	No	1.67	NA
2023-01-18	397.33	Yes	0.065	1.51
2023-04-06	397.15	Yes	0.24	1.67
2023-09-25	397.72	No	0	NA
2023-10-20	396.65	No	0	NA

Importantly, the developed rating curve is therefore based on when there is no debris present at the lake outlet. The presence of debris results in a decreased outflow rate while also increasing the lake level. Using the rating curve alone when debris is present would result in overestimation of outflows. To account for this, we relied on the City's and resident records of clearing debris from the outlet and assumed that debris had appeared on the most recent day when the lake level increased by more than 0.05 feet. When debris was present, we estimated an outflow rate of 0.15 cfs, based on the average recorded discharge measurement when debris was present, and used the developed rating curve when debris was not present.

The rating curve was only developed for lake-level up to 397.34 feet (measured on November 30, 2022) but observed lake levels reached 397.87 feet. To avoid extrapolation and overestimating lake outflow, the maximum outflow was set to 2 cfs. Note that this only affected 7 days in the study period (December 10–11 and December 26–30) when the lake level exceeded 397.37 feet. The largest drop in lake volume was 0.32 feet from December 28 to December 29. Assuming a lake area of 13 acres, this drop is equivalent to 0.416 acre-feet, which equates to 2.1 cfs over a 24-hour period.

Once the lake level dropped below the outlet elevation in July 2023, no further surface outflow was observed through the remainder of water year 2023.

Groundwater

Echo Lake is located in a highly impervious watershed and the superficial geology is glacial till (Qvt), which is characterized with low permeability. Therefore, the watershed is expected to have relatively low infiltration and a minor shallow aquifer, resulting in low groundwater inflow to the lake.

Groundwater flows into and out of the lake were calculated as the residual difference between total water inputs minus total water outputs described above, and accounting for changes in lake storage volume. Positive net monthly residuals were attributed to groundwater inflow and negative net monthly residuals were attributed to groundwater outflow.

Results

Lake Inflows

Overall, most surface inflow enters Echo Lake via the DTS outflow (see Table 9). The Aurora North and Aurora South drainage contribute similar volumes to the DTS facility. Note that because DTS outflow was estimated based on measured water level at the facility, the total volumes do not match the volume estimated via the simple method. Together, the Aurora North and South drainages were estimated to contributed approximately 300 thousand cubic meters per year, whereas 243 thousand cubic meters are estimated to have been discharged via the DTS facility.

Figure 19 presents the estimated discharge from the DTS facility. This hydrograph shows that base flow was observed leaving the DTS facility in June and sporadically in July and August 2023. City staff investigated potential causes and found that a construction site located in the Aurora South basin were not able to shut off a fire hydrant and redirected flows to the stormwater system. The discharge rate was estimated at 75 percent of a fire hose’s capacity according to Seattle Public Utilities (S. Grozev, pers. comms.). Assuming a 2.5-inch hose, this is approximately about 1,200 cubic meters per day (0.42 cfs). This is a little higher than what was observed at the DTS facility using the water level but it is expected that the diverted fire hydrant flows account for nearly all the observed summertime flows from May to

August 2023 when very little rain fell (0.91 inches in May, 0.98 inches in June, 0.14 inches in July, and 0.58 inches in August). The exact start and end date of the fire hydrant diversion is not known.

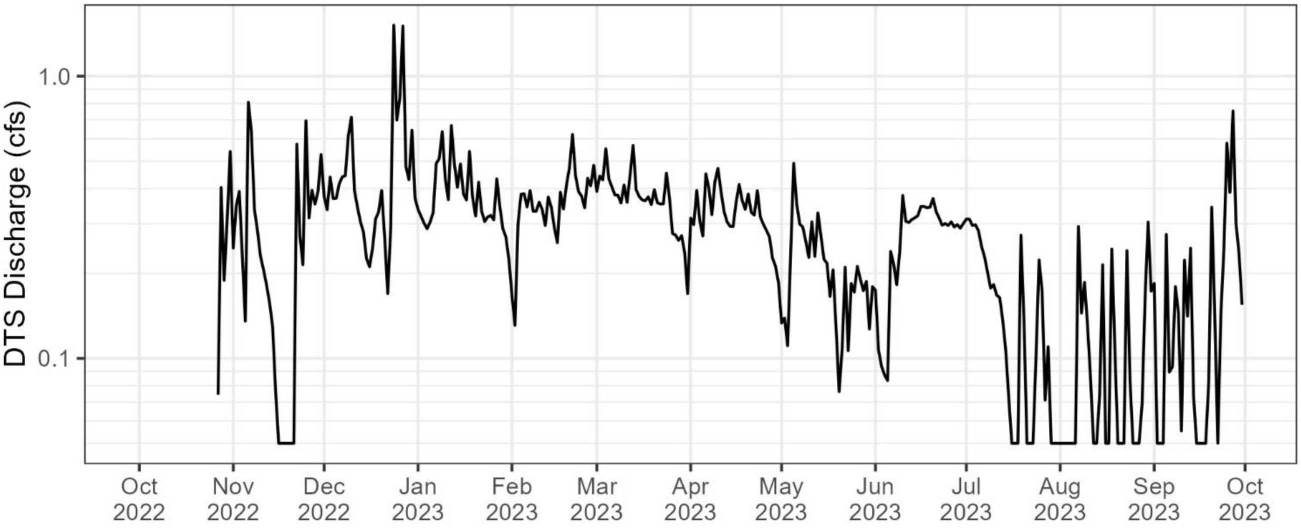
Table 9. Monthly Lake Inlet Flow Volumes.

Inflow Volume (1,000 m^3)									
		Estimated Via Simple Method				DTS Data		Simple	ECHO-IN +ECHO-X
Year	**Month**	**RES_FIRLANDS**	**AURORA_NORTH**	**SE_SKY**	**AURORA_SOUTH**	**DTS**	**ECHO_IN**	**ECHO-X**	**Total**
2022	10	5.5	9.5	4.7	12.5	14.2	15.5	7.6	**23.1**
2022	11	11.6	20.2	10.0	26.7	19.9	21.7	16.2	**38.0**
2022	12	16.6	28.8	14.3	38.0	36.1	39.4	23.2	**62.5**
2023	1	9.6	16.7	8.3	22.1	29.1	31.8	13.5	**45.2**
2023	2	6.2	10.7	5.3	14.2	24.8	27.0	8.6	**35.7**
2023	3	7.0	12.1	6.0	16.0	28.2	30.8	9.8	**40.5**
2023	4	6.8	11.9	5.9	15.7	24.4	26.6	9.6	**36.1**
2023	5	1.8	3.1	1.5	4.1	16.0*	17.5*	2.5	**19.9***
2023	6	1.9	3.3	1.7	4.4	19.9*	21.7*	2.7	**24.3***
2023	7	0.3	0.5	0.2	0.6	11.0*	12.0*	0.4	**12.4***
2023	8	1.1	2.0	1.0	2.6	6.5*	7.1*	1.6	**8.6***
2023	9	6.5	11.3	5.6	14.9	12.8	14.0	9.1	**23.1**
	Total	**74.9**	**130.0**	**64.7**	**171.8**	**243.1**	**264.9**	**104.7**	**369.6**

* May through August 2023 DTS volumes were impacted by a diverted fire hydrant that is believed to be responsible for the majority of inflow to the lake during this period.

ECHO-IN was estimated by multiplying DTS discharge by 1.09.

Figure 19. DTS Facility Observed Discharge.



Note the log scale and that the minimum discharge in the above chart is set at 0.05 cfs for display purposes.

Echo Lake Hydrologic Budget

The water year 2023 monthly hydrologic budget for Echo Lake is presented on a monthly basis in Table 10.. The budget had moderate residuals during each month, which are assumed to be groundwater inflow when positive during wet season months of November through May (high water table) and groundwater outflow when negative during dry season months of June through September (low water table). Figure 20 presents the annual hydrologic budget graphically and Figure 21 presents the summer hydrologic budget for May through October 2023 graphically, with lake inflows on the left and lake outflows on the right of each graph.

The annual net groundwater inflow was 125 thousand cubic meters, which is approximately one-quarter of the total inflow to the lake. The lake is a net groundwater importer based on this hydrologic budget. Recognizing its limitations, we believe the hydrologic budget provides adequate planning level estimates of the volume of water moving through Echo Lake for developing the phosphorus budget. The hydrologic budget would benefit from further calibration of the DTS outflow estimates, monitoring groundwater levels and modeling flow velocity/direction, and further development of a lake outflow rating curve that incorporates debris impacts.

Using the total lake inflow (546,013 m^3 per year) and a lake volume of 276,189 m^3, we estimate that the lake residence time was 0.51 years, which means that the whole lake volume flushed fairly rapidly at 2 times per year.

During the summer (May to September), the lake level decreased as outputs exceed inputs until storms return in September. Surface outflow and evaporation were approximately equal in importance for water export.

Table 10. Echo Lake Water Budget (1,000 m^3).

Year	Month	Direct Precipitation	Surface Inflow	Net Ground-water In	TOTAL INFLOW	Lake Evaporation	Lake Outflow	Net Ground-water Out	TOTAL OUTFLOW	Change in Lake Volume
2022	10	3.6	23.1	0.0	26.7	6.0	0.0	13.5	19.6	7.2
2022	11	8.0	38.0	13.0	59.0	3.0	37.2	0.0	40.2	18.8
2022	12	11.5	62.5	10.3	84.4	1.9	82.5	0.0	84.4	0.0
2023	1	6.7	45.2	33.6	85.5	3.3	86.1	0.0	89.4	-3.9
2023	2	4.2	35.7	7.7	47.6	2.8	44.7	0.0	47.5	0.2
2023	3	4.8	40.5	27.6	73.0	4.1	68.6	0.0	72.7	0.3
2023	4	4.7	36.1	28.1	68.9	4.3	67.0	0.0	71.3	-2.4
2023	5	1.2	19.9	4.7	25.8	7.2	23.4	0.0	30.6	-4.8
2023	6	1.3	24.3	0.0	25.6	7.2	14.0	7.4	28.6	-3.0
2023	7	0.2	12.4	0.0	12.6	9.2	2.7	8.1	20.1	-7.5
2023	8	0.7	8.6	0.0	9.4	9.6	0.0	4.8	14.5	-5.1
2023	9	4.3	23.1	0.0	27.4	7.1	1.6	6.4	15.0	12.4
	TOTALS	**51.3**	**369.6**	**125.1**	**546.0**	**65.6**	**427.9**	**40.3**	**533.8**	**12.3**

TOTAL INFLOW = Sum of Surface Inflow (Table 9), Direct Precipitation, and Net Groundwater In, which was calculated as positive residuals from total surface inputs minus outputs, and subtracted from total surface inputs to get TOTAL INFLOW. Similarly, Net Groundwater Out was calculated as negative residuals from total surface inputs minus outputs, and subtracted from total surface outputs (evaporation and outflow) to get TOTAL OUTLOW.

Figure 20. Echo Lake Annual Water Budget (October 2022 to September 2023) (1000 m^3).

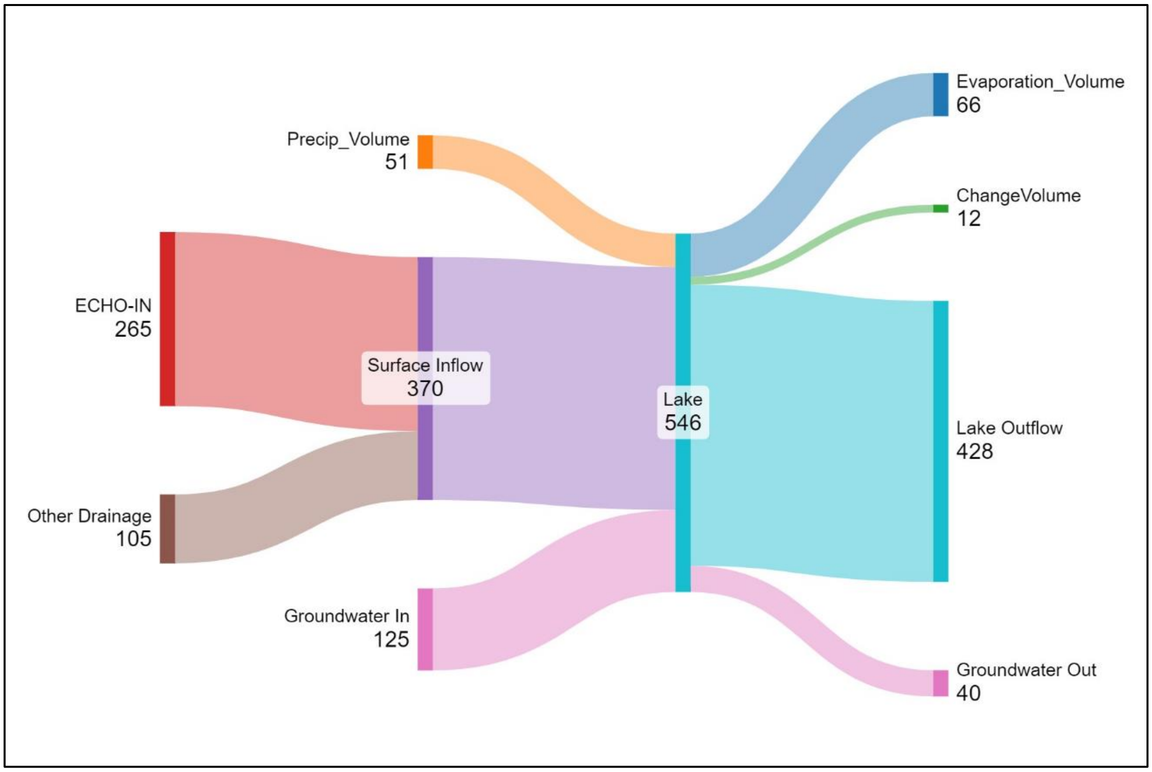
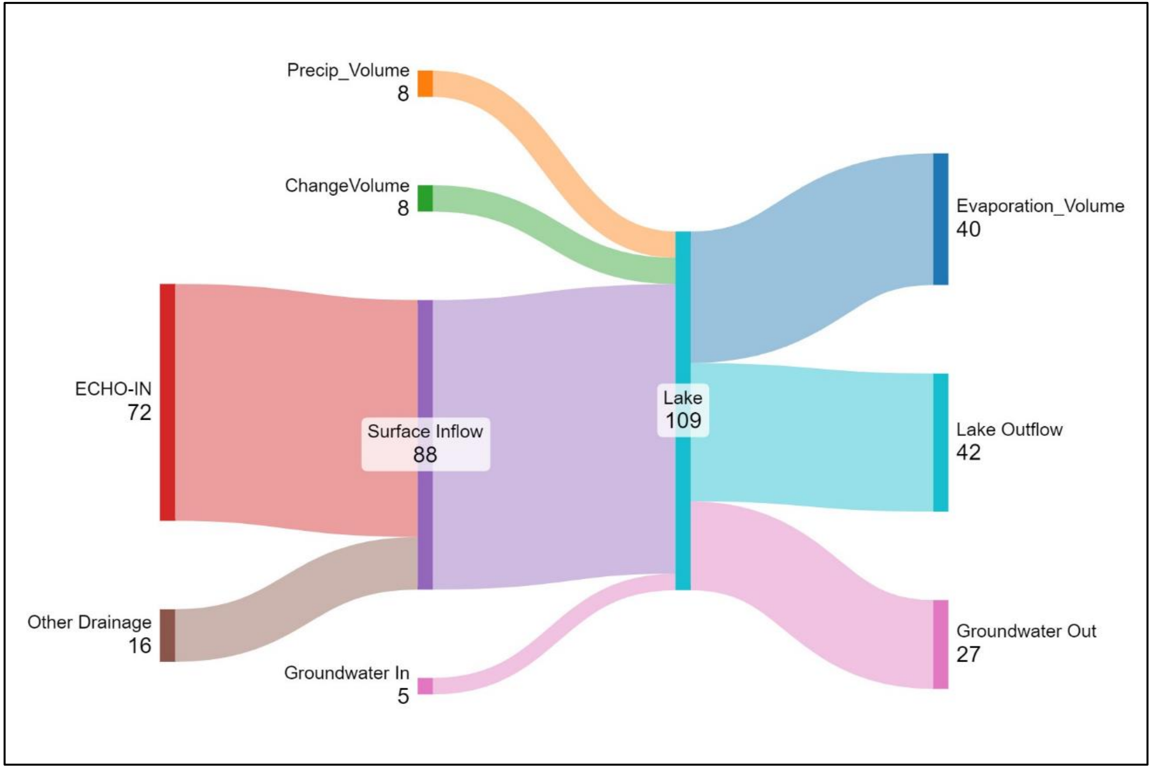


Figure 21. Echo Lake Summer Water Budget (May to September 2023) (1000 m^3).



Echo Lake Phosphorus Budget

Development

Using the water budget as a foundation, a phosphorus budget was created for Echo Lake that accounts for all movement of phosphorus into and out of the lake and within the lake itself. The difference between the total monthly external phosphorus inputs and outputs plus the change in phosphorus mass within the lake water from the previous month equals the amount of phosphorus retained in the lake for each month, where:

$$Retention\ (P_{ret}) = Inputs\ (P_{in}) - Outputs\ (P_{out}) + Lake\ Storage\ Change\ (\Delta P_{Lake})$$

The lake phosphorus retention amount is calculated as the difference between measured total phosphorus inputs and outputs and adding the change in the amount of phosphorus stored in the lake. The lake phosphorus retention incorporates measurement errors and unmeasured sources and losses, which primarily include internal phosphorus loading and sedimentation, respectively (Steinman and Spears 2020).

Precipitation

The total phosphorus concentration in rainfall is estimated to be 0.024 mg/L. This value is based on the measured values ranging from 0.008 to 0.033 mg/L for five lakes in western Washington, and accounts for all atmospheric deposition (Ecology 2013). The total phosphorus concentration in rain was multiplied by the monthly precipitation volume to estimate phosphorus inputs from direct precipitation and other atmospheric deposition on Echo Lake.

Surface Inflow

Surface inflow phosphorus loads were calculated by surface inflow volume by the average total phosphorus concentration, respectively, for each monitoring site (see Table 12 in Appendix A). Total phosphorus concentration in stormwater discharge from the ECHO-X drainage basin was estimated as the average concentration for all inlet stormwater samples.

Outlet Flow

No lake outlet samples were collected for the study. Monthly average surface water concentrations of total phosphorus were multiplied by the lake outlet flow volume to estimate phosphorus outputs from this source.

Lake Storage

The monthly amount of total phosphorus in the lake was calculated by multiplying monthly volume-weighted average total phosphorus concentrations by monthly lake volume calculated as part of the hydrologic budget. Monthly changes in the total amount of phosphorus in the lake were then calculated.

Groundwater

Groundwater total phosphorus concentrations were not monitored. No samples collected from an inlet station are expected to be representative of groundwater because they were taken from the stormwater conveyance network during eight storm events and one base flow event, and unusually high total phosphorus concentrations were observed in the base flow samples. The total phosphorus concentration for groundwater entering Echo Lake was estimated to be 50 µg/L, which is the approximate average for base flow samples from the mouth of McAleer Creek (King County 2024d).

Groundwater phosphorus loading to the lake was calculated by multiplying the monthly volume of groundwater input (if there was a net input) by the estimated groundwater total phosphorus concentration. Groundwater phosphorus export from the lake was calculated by multiplying the monthly volume of groundwater output (if there was a net output) by the lake's monthly volume-weighted average concentration of total phosphorus.

Internal Loading – Sediment Release

Internal phosphorus loading by sediment phosphorus release into the lake was calculated by several methods described by Nurnberg (2009) and Steinman and Spears (2020), which include the hypolimnion mass accumulation, mass balance residual, and various sediment phosphorus release rate equations.

Hypolimnion Mass Accumulation Method

The hypolimnion mass accumulation method calculates the monthly increase in the amount of phosphorus that accumulates in the hypolimnion (bottom layer) of lake for each summer month when dissolved oxygen concentrations near the sediment surface are low (less than 2 mg/L) and external inputs are low. This method may underestimate internal loading because sediment oxygen concentrations can be much lower than those measured in the water in both the surface and bottom layers (epilimnion and hypolimnion). In addition, the hypolimnion mass accumulation method does not account for potential in sediment release in the surface layer from high pH conditions caused by rapid algae growth and carbon dioxide consumption during summer algae blooms.

Mass Balance Residual Method

The mass balance residual method uses the phosphorus residual in the mass balance equation (lake phosphorus retention mass calculated as input minus output plus lake storage) as an estimate of net gain from internal loading by accounting for loss by sedimentation. Monthly sedimentation losses during the summer stratification period were estimated as an average of the mass balance residuals calculated for the winter months when internal loading is assumed to be negligible because the lake was mixed, oxygenated, and neutral pH.

Sediment Release Equations

In warm monomictic lakes, which are stratify into two thermal layers during the summer and mix from top to bottom during the winter, summer internal load may be estimated using the following equation:

$$L_{int} = RR * AF$$

Where:

RR = areal release rate of phosphorus in mg/m^2/day

AF = anoxic factor in the sum of days per period with different oxycline depths

AF = $sum\ (t_i * a_i)/A_0$

Where:

t_i = period of anoxia in days for each oxycline period

a_i = corresponding sediment area in m^2 for each oxycline period

(A_0) = lake surface area in m^2

Two sediment release equations were used based on the mobile phosphorus concentrations in the upper 10 cm of sediment in Echo Lake, including the Nurnberg (1988) and Pilgrim et al. (2007) equations. The Nurnberg (1988) equation (R^2 = 0.87 for 14 lakes) is:

$$RR_{Nurnberg} = -1.38 + 0.285 * P_{Sed,Fe,WW}$$

Where:

$RR_{Nurnberg}$ = sediment release rate estimated using the Nurnberg (1988) equation in mg/m^2/day

$P_{Sed,Fe,WW}$ = wet-weight iron-bound phosphorus sediment concentration in µg/g

From the Echo Lake sediment samples, the $P_{Sed,Fe,WW}$ were 59.9 µg/g at the deep station as an average of the surface 10 cm and 8.4 µg/g in the shallow station. Therefore, predicted release rate would be 15.7 mg/m^2/day at the deep station and 1.0 mg/m^2/day in the shallows.

The Pilgrim et al. (2007) equation (R^2 = 0.90 for 14 lakes) is:

$$RR_{Pilgrim} = 15.1 * P_{Sed,Mobile} - 0.7$$

Where:

$RR_{Pilgrim}$= sediment release rate estimated using the Pilgrim et al. (2007 equation) in mg/m^2/day

$P_{Sed,Mobile,WW}$ = wet-weight mobile phosphorus sediment concentration in g/m^2/cm

From the Echo Lake sediment samples, the $P_{Sed,Mobile,WW}$ was 0.75 g/m^2/cm at the deep station as an average of the surface 10 cm and 0.09 g/m^2/cm at the shallow station. Therefore, predicted release rate would be 10.6 mg/m^2/day at the deep station and 4.3 mg/m^2/day in the shallows.

AF is the expression of the period of anoxia and the fraction of the sediments experience anoxia:

$$AF = \sum_{i=1}^{n} t_i * a_i / A_0$$

Anoxia was observed below 6 m from May 8 to October 16, 2023. We would therefore calculate AF as 161 days * 22,600 m^2 / 52,798 m^2 = 69 days. This estimate is similar to the 70 days predicted using the Nurnberg (1996) anoxic factor equation for polymictic lakes, which are always mixed and too shallow to stratify in the summer ($R^2 = 0.67$ for 70 lakes) as follows:

$$AF_{pred} = -36.2 + (50.1 * \log_{10}(TP_{Summer}) + 0.762 * \frac{\bar{z}}{\sqrt{A}}$$

Where:

TP_{Summer} = mean summer (May to October) volume-weighted total phosphorus concentration in µg/L (30.3 µg/L).
$\bar{z}$ = mean depth in m.
A = lake surface area in km^2.

Biological Contributions

Waterfowl

Waterfowl data was collected for this project through daily counts by volunteer shoreline residents: Kathie Brodie, Patrick Deagen, Audrey Hare, and Ann Michel. Counts of waterfowl at Echo Lake were taken on 177 days between December 2022 and October 2023 from the shorelines at various times of the day. When more than one count existed for a single day, only the maximum count for each bird was considered. Approximately 2,618 waterfowl were counted at Echo Lake during this period. Waterfowl observed included geese, ducks (including mergansers, buffleheads, and grebes), cormorants, coots, gulls, herons, and wigeons. Most of the waterfowl observed were ducks, accounting for approximately 40 percent of the total annual bird count at the lake, followed by cormorants (20.4 percent), and geese (19.9 percent). According to this dataset, most waterfowl visit the lake between September and March, with geese, gulls, and cormorants forming the largest flocks (i.e., of 40–100 individuals). See the *Lake Observations* section of the *Lake and Watershed Monitoring Report* (Appendix A) for more detail.

Estimation of phosphorus loading from waterfowl was performed following the methods of Boros (2021) using published waterfowl excrement rates and residential time factors (Manny et al. 1994, Marion et al. 1994, and Boros, 2021). Phosphorus loading rates from gulls vary substantially by species and region, so an average rate was assumed for all gulls at Echo Lake from those reported in Boros (2021), Gould and Fletcher (1978), Hahn et al. (2007), and Winton and River (2017) (Table 9). Non-waterfowl bird species were not considered in this loading estimation.

Table 9. Literature Values for Bird Excrement Loading Rates and Residential Time Factors.

Bird Type	Residual Time Factor	Excrement Loading Rate (g P/day)	Source(s)
Geese	0.6	0.49	Boros 2021, Manny et al. 1994
Ducks[a]	1.0	0.20	Manny et al. 1994, Boros 2021
Mergansers & Grebes	1.0	0.19	Manny et al. 1994, Boros 2021
Cormorants	1.0	4.58	Marion et al. 1994, Boros 2021
Coots	1.0	0.2	Boros 2021
Gulls	0.6	0.4[b]	Boros 2021, Gould and Fletcher 1978, Hahn et al. 2007, Winton and River 2017
Wigeons	0.8	0.18	Manny et al. 1994, Boros 2021
Herons	0.8	3.78	Marion et al. 1994, Boros 2021

[a] The category conservatively assumes ‘ducks’ are diving ducks with respective RTF and loading rates, rather than the slightly lower RTF and loading rates of dabbling ducks (e.g., wigeons).

[b] Rate assumed from wide range in excrement phosphorus concentrations and loading rates for various gull species in literature (e.g., 0.07–1.5 g/day).

Rather than estimate loading using the daily mean abundances of each species per month, which would be multiplied by the days in each month (as in Boros [2021]), we calculated daily loading from the rich dataset of available daily bird observations collected by volunteers. To fill data gaps for those days when bird observations were not recorded (n=155), we interpolated counts from the available data (n=177 out of 332 days). Interpolations were performed for each major bird type recorded (ducks, geese, coots, grebes, mergansers, wigeons, herons, cormorants, and gulls). We then calculated daily load using the equation below, modified as noted from Boros (2021):

$$Load = A * E * RTF$$

Where:

A – daily abundance of a given species
E – daily net rate of excrement loading (e.g., mass phosphorus per individual per day)
RTF – residential time factor (proportion of a day that waterbird spends at lake)

Daily loads for each bird type were then summed together and across all days from December 2022 to October 2023 to arrive at the rate of annual phosphorus loading by waterfowl in Echo Lake. Using interpolated daily data rather than monthly means improved the accuracy of our loading estimations. Overall, phosphorus loading from waterfowl was minimal (3.7 kg total December 2022 through October 2023) compared to other regional lakes and phosphorus sources in the Echo Lake watershed. Of that amount, cormorants were estimated to contribute 78 percent (2.9 kg) due the high concentration of phosphorus in their excrement.

Aquatic Macrophytes

Aquatic macrophytes are aquatic plants in lakes that include floating-leaved plants, submersed plants, and submersed macroalgae but not emergent shoreline plants. Phosphorus release from aquatic macrophytes was not explicitly estimated because macrophyte biomass data were not available. Macrophyte contribution may be evaluated by examining the residual in the phosphorus budget in the late fall, when the macrophytes undergo senescence, and is typically small unless a lake is covered by dense invasive species.

Fish Stocking

WDFW has stocked the lake with rainbow trout since at least 1995, with between 0 and 795 pounds of fish stocked annually. On April 26, 2023, 350 pounds of legal-size rainbow trout were stocked in Echo Lake (WDFW 2024a), approximating the 29-year annual average of 390 pounds.

Fish were not explicitly included in the nutrient budget. According to a study of rainbow trout diet and effluent, bioavailable phosphorus excreted from rainbow trout amounted to about 7 milligrams of phosphorus per kilogram of fish mass per day (mg-P/kg_{fish} /day) when fed no more than the required nutrition to support juvenile trout (Flimlin et al. 2003). This rate would translate to about 1.06 milligrams of bioavailable phosphorus per trout per day these trout excrete at the same rate as rainbow trout in the study and assuming each fish weighed about 151 grams (0.333 lbs; i.e., the average weight of all trout stocked in Echo Lake in 2023). However, assuming a reduced bioavailable phosphorus excretion rate of 4 mg/kg fish/day from feeding on live food in the lake [compared to the study diet of hatchery feed], the rate of phosphorus loading from fish excrement would translate to just 0.6 milligrams of bioavailable phosphorus per trout per day.

Assuming all fish stocked in 2023 were present in the lake on average for 60 days until caught and removed, annual loading from excretion by 159 kg of stocked trout in 2023 would amount to about 0.232 kg (0.51 lbs) of bioavailable phosphorus in 2023. Despite the limitations (e.g., duration of trout in lake and adjusted excretion rate for diet changes), this estimation suggests the contribution of stocked trout to the 2023 phosphorus load in Echo Lake is negligible.

While trout stocking may not directly increase phosphorus loading to the lake from fish excrement, trout stocking can have food web impacts by their consumption of zooplankton and the resulting reduced grazing of algae by zooplankton in the lake. See the algae and zooplankton results in the attached Lake and Watershed Monitoring Report (Appendix A) and/or the *Biomanipulation* management method section below for potential impacts from food web (e.g., trophic cascade) interactions. Quantitative evaluation of future trout stocking on nutrient concentrations and frequency/timing of algae blooms could be performed by statistically comparing conditions before and after trout stocking, and/or conditions between the years when trout were stocked and those years when trout were not stocked.

Results

Lake Inflows

The monthly and annual phosphorus loads from the inlets are presented in Table 10. As discussed in the water budget chapter previously, the discharge volume estimates for the Echo In basin are lower than the sum of the Aurora North and Aurora South basins due to the differences in the methods for estimating discharge volume in these basins. We also see that the phosphorus loads for the Echo In basin (43.6 kg/yr) are lower, sometimes substantially, than the sum of the loads from the two Aurora basins (69.9 kg/yr). Some of this difference may be attributed to the settling and loss of particulate phosphorus in the DTS.

Table 10. Monthly Lake Inlet Total Phosphorus Loads (kg).

Year	Month	RES_FIRLANDS	AURORA_NORTH	SE_SKY	AURORA_SOUTH	ECHO_IN	ECHO-X	TOTAL
2022	10	0.7	1.1	4.1	4.0	2.6	1.4	3.9
2022	11	1.4	2.4	8.8	8.4	3.6	2.9	6.5
2022	12	2.0	3.5	12.5	12.0	6.5	4.2	10.7
2023	1	1.2	2.0	7.3	7.0	5.2	2.4	7.7
2023	2	0.7	1.3	4.7	4.5	4.5	1.6	6.0
2023	3	0.8	1.5	5.3	5.1	5.1	1.8	6.8
2023	4	0.8	1.4	5.2	5.0	4.4	1.7	6.1
2023	5	0.2	0.4	1.3	1.3	2.9	0.4	3.3
2023	6	0.2	0.4	1.4	1.4	3.6	0.5	4.1
2023	7	0.0	0.1	0.2	0.2	2.0	0.1	2.0
2023	8	0.1	0.2	0.9	0.8	1.2	0.3	1.4
2023	9	0.8	1.4	4.9	4.7	2.3	1.6	3.9
Annual Load (kg)		**9.1**	**15.6**	**56.5**	**54.3**	**43.6**	**18.9**	**62.5**
Drainage Area (hectares)		16.6	24.7	8.1	25.5	57.9	19.0	76.9
Aerial P Load (kg/ha-yr)		**0.55**	**0.63**	**6.98**	**2.13**	**0.75**	**0.99**	**0.81**

* May through August 2023 DTS volumes were impacted by a diverted fire hydrant that is believed to be responsible for the vast majority of inflow to the lake during this period.

ECHO-IN was estimated by multiplying DTS discharge by 1.09.

We also see that the estimated annual load from the SE Sky basin (56.3 kg) is slightly greater than the downstream Aurora South basin (54.3 kg). This is driven by the over 2.8-times higher mean total phosphorus concentration found at the SE Sky station (872 µg/L) than at Aurora South station (316 µg/L), while the discharge volume for SE Sky is 38 percent of the Aurora South volume.

Table 12 includes the annual unit-area (aerial) phosphorus loads for each basin by dividing the total annual load by the basin area. The annual aerial phosphorus loads were much higher for the SE Sky basin

(6.98 kg/ha-yr) than all other basins and were lowest for the Residential Firlands and Aurora North basins (0.55 and 0.63, respectively). The annual aerial phosphorus load for the Aurora South basin (2.13 kg/ha-yr) and much higher than the Aurora North basin (0.63 kg/ha-yr) due to input from the SE Sky basin. The annual aerial phosphorus loads for the SE Sky basin (6.98 kg/ha-yr) are also much higher than median values reported for roads (1.10 kg/ha-yr), commercial land use (0.91 kg/ha-yr), and residential land use (0.55–0.70 kg/ha-yr depending on density) (NALMS 2007).

These findings clearly show that SE Sky basin is a primary candidate for phosphorus source control and treatment. Proper control/treatment would be expected to decrease the annual aerial phosphorus loading in the SE Sky basin to at least 1.0 kg/ha-yr. A decrease from 8.1 to 1.0 kg/ha-yr would decrease the annual phosphorus loading from 56.5 to 8.1 kg in the SE Sky basin and the same amount from 54.3 to 5.9 in the Aurora South basin, and result in an annual aerial phosphorus loading of 0.7 kg/ha-yr in the Aurora South basin which is similar to the 0.6 kg/ha-yr estimated for the Aurora North basin.

Internal Loading

Hypolimnion Mass Accumulation Method

The monthly sediment phosphorus release amount was calculated as the monthly increase in the hypolimnetic phosphorus mass in the lake for May to October 2023 when dissolved oxygen concentrations were less than 2 mg/L near the sediment surface at the deep lake station and external phosphorus inputs were low at 19.2 kg. The phosphorus mass accumulation data are presented in Table 11. The total gain in hypolimnion phosphorus mass in summer of 2023 was 30.1 kg.

Table 11. Internal Phosphorus Loading by Hypolimnion Mass Accumulation Method.

Sample Date	Depth (m) at DO < 2 mg/L	Bottom Measured DO (mg/L)	Lake Hypo TP (µg/L)	Lake Hypo Mass (kg)	TP Mass Gain (kg)
2023-05-08	NA	NM	81	3.7	--
2023-05-21	6.5	0.14	209	9.6	5.9
2023-06-04	6	0.19	380[a]	17.5	7.9
2023-06-25	6	0.16	551	25.4	7.9
2023-07-09	5.5	0.19	146	6.7	-18.7
2023-07-23	5	0.44	128	5.9	-0.8
2023-08-07	4	0.51	257	11.9	6.0
2023-08-21	4	0.46	184	8.5	-3.4
2023-09-11	5	0.56	226	10.4	1.9
2023-09-24	NA	NA	63.7	2.94	-7.5
2023-10-16	6	0.06	74.0	3.42	0.5
2023-10-30	NA	5.16	42.4	1.96	-1.6
May to October Hypolimnetic Gain for Total Internal Loading					**30.1**

NM= not measured; NA= not applicable

[a] This value is interpolated between from the May 21 and June 25 samples because the June 4 sample appeared to included lake sediment with measured TP at 4,050 µg/L.

Mass Balance Residual Method

The phosphorus residual during winter months averaged -9.0 kg/month, which was assumed to be the average sedimentation rate for the lake. This rate was added to the summer (May to September 2023) residuals, and the positive values were summed to estimate the internal load via mass balance. October 2022 was not included because it was the start of the monitoring period and therefore does not include the change-in-lake-storage from the previous month. The sum of the net phosphorus gain from May to September 2023 totaled 35.1 kg. To estimate the gain for May to October, the value was multiplied 1.25 to yield an estimate of 43.9 kg for internal loading based on the mass balance method (Table 124).

Table 12. Internal Phosphorus Loading by the Mass Balance Residual Method.

Year	Month	Mass Balance Residual (kg)	Sedimentation Rate Estimate (kg)	Summer Residual + Sedimentation (kg)
2023	5	-4.2	-9.0	4.9
2023	6	8.8	-9.0	17.8
2023	7	-15.6	-9.0	-6.5
2023	8	3.4	-9.0	12.4
2023	9	-9.0	-9.0	0.0
Sum of Positive May-Sept Residuals + Sedimentation				**35.1**
Multiplied by 1.25 to Include October for Total Internal Loading				**43.9**

Note the residuals presented this table is before applying the estimates for internal cycling (sediment release and sedimentation)

Sediment Release Equation Method

The phosphorus load estimates based on predicted flux and anoxic factor (i.e., Nurnberg 1988 and Pilgrim et al. 2007), ranged from 39.2 to 58.0 kg, which is higher than the hypolimnion mass accumulation estimate (30.1 kg) but similar to the mass balance residual estimate (43.1 kg). In-situ or laboratory sediment phosphorus flux monitoring would provide meaningful insight to confirm the sediment release rate.

Internal phosphorus loading estimates are presented in Table 13. Internal phosphorus loading estimates ranged from 30.1 to 58.0 kg/year among the four methods used. An average value of 44.5 kg/year was used for the phosphorus budget.

Table 13. Internal Loading Estimates.

Internal Load Estimate Method	Flux Estimate ($mg/m^2/day$)	Anoxic Factor (days)	L_{int} ($mg/m^2/year$)	Load (kg/year)
Nurnberg 1988 Iron-bound Phosphorus Sediment	15.7	70	1099	58.0
Pilgrim 2007 Mobile (Iron-bound + Labile) Phosphorus in Sediment	10.6	70	742	39.2
Summer Hypolimnetic Phosphorus Mass Accumulation	*8.1*	70	570	30.1
Summer Mass Balance Residual (mean summer residual [sediment release – sedimentation] – mean winter residual [sedimentation])	*11.9*	70	831	43.9
Average	***12.0***	***70***	***843***	**44.5**

Flux estimates for the Summer Mass Accumulation and Mass Balance Residual methods are back-calculated based on the average anoxic factor.

Echo Lake Phosphorus Budget

The Echo Lake phosphorus budget is presented on a monthly basis in Table 14, and graphically presented for the entire year in Figure 22 and for the summer only in Figure 23, where inputs are on the left and outputs are on the right of the graphs. Surface inflows and internal loading dominate phosphorus loading to Echo Lake. Annually, the internal loading contributes 39 percent of all phosphorus loads to the lake, and internal loading contributes 70 percent of the loads during the summer (Figure 22; Table 14). There is a modest net positive residual in the annual budget (12.8 kg), indicating an unquantified input or overestimation in export, and a minor negative residual in the summer budget (10.4 kg). The sedimentation rate appears reasonable but may have been underestimated for the summer months because they are based on residuals for winter months when waters were likely more turbulent, which could account from some of the negative summer residual.

Some of the annual positive residual could have been from waterfowl fecal deposits and aquatic plant decay that were not included in the annual phosphorus budget. The annual phosphorus load from waterfowl was estimated at about 4 kg and most of that occurred during the winter months when waterfowl were most abundant (see Appendix A). Phosphorus loads were not estimated for aquatic plant decay but would be expected to occur primarily during the early winter plant senescence period (e.g., October through December). The highest positive residuals were observed in November, December, and June (see Table 146). Thus, much of the winter positive residual may have been from waterfowl fecal deposits and aquatic plant decay.

Most of the phosphorus entering the lake settles to the lake bottom (68 percent) (Figure 22; Table 14), whereas 30 percent leaves via the lake outlet and 22 percent is exported via groundwater outflow. Some of the phosphorus settling to the lake sediments is active and may later be released into the water column. The sediment samples indicated that about 10 to 40 percent of phosphorus in the biologically active zone (0 to 10 cm) was active and can be released from iron or labile organic matter.

The groundwater load estimates are based on the average total phosphorus concentrations in McAleer Creek and the residual in the water budget, presented in the previous chapter. These estimates are very sensitive to the accuracy of the water budget estimates and the assumption that base flow and groundwater phosphorus concentrations are similar. Furthermore, a net negative groundwater residual (i.e., where there is more volume leaving than entering the lake as groundwater) does not mean there is no groundwater inflow to the lake. In this way, these groundwater load estimates are only a partial picture.

During the summer (May to October) period (Figure 23), it is estimated that most of the phosphorus load came from internal loading (44.5 kg [69.8 percent]). The next most important source were surface inflows (29.4 percent). The summer surface inflow load may be overestimated because the diverted fire hydrant is expected to have lower total phosphorus concentrations than stormwater runoff. For planning purposes, there is expected to be lower surface inflows in the summer months and therefore lower loading than what was estimated in summer 2023. There was a minor negative residual of (-10.4 kg), which appears to be driven by the highly variable TP concentrations in the hypolimnion, causing loss in estimated lake storage.

During the May to October period, incoming phosphorus either settled to the lake bottom or remained in the surface water. A small amount left via the lake’s outlet and groundwater outflow. The decrease in surface outflow was primarily driven by limited lake discharge, in balance with decreased inflow to the lake.

Table 14. Monthly Phosphorus Loads to Echo Lake.

		Surface Input Mass (kg)		Internal Load (kg)	Groundwater Mass (kg)		Surface Output (kg)	Mass Balance (kg)		
Year	**Month**	**Precipitation**	**Surface Inflow**	**Sediment Release**	**Inflow**	**Outflow**	**Lake Outflow**	**Change in Storage**	**Sediment-ation***	**Residual***
2022	10	0.1	3.9	7.4	0.0	0.6	0.0	0.0	9.0	-1.8
2022	11	0.2	6.5	0.0	0.7	0.0	6.2	0.0	9.0	7.8
2022	12	0.3	10.7	0.0	0.5	0.0	14.7	3.2	9.0	15.4
2023	1	0.2	7.7	0.0	1.7	0.0	11.0	-13.3	9.0	-2.8
2023	2	0.1	6.0	0.0	0.4	0.0	4.8	-5.3	9.0	2.0
2023	3	0.1	6.8	0.0	1.4	0.0	6.3	-3.5	9.0	3.5
2023	4	0.1	6.1	0.0	1.4	0.0	4.1	-8.3	9.0	-2.7
2023	5	0.0	3.3	7.4	0.2	0.0	0.9	-1.5	9.0	-2.6
2023	6	0.0	4.1	7.4	0.0	0.8	0.4	11.6	9.0	10.3
2023	7	0.0	2.0	7.4	0.0	0.4	0.1	-14.0	9.0	-14.0
2023	8	0.0	1.4	7.4	0.0	0.3	0.0	4.5	9.0	5.0
2023	9	0.1	3.9	7.4	0.0	0.3	0.0	-5.3	9.0	-7.4
Annual Totals										
Mass (kg)		1.2	62.5	44.5	6.3	2.4	48.6	-31.8	108.1	12.8
Percent		**1.1%**	**54.6%**	**38.9%**	**5.5%**	**1.5%**	**30.5%**	--	**68.0%**	--
Summer (May to October) Totals										
Mass (kg)		0.3	18.7	44.5	0.2	2.4	1.4	-4.6	54.1	-10.4
Percent		**0.4%**	**29.4%**	**69.8%**	**0.4%**	**4.2%**	**2.4%**	--	**93.3%**	--

* Sedimentation rate is based on the average winter (January – April) residual.

* Residual = (Lake Outflow + Sedimentation + Change in Storage + Groundwater Outflow) – (Surface Input + Internal Loading + Groundwater Inflow).

Figure 22. Annual Phosphorus Budget (kg) for Echo Lake.

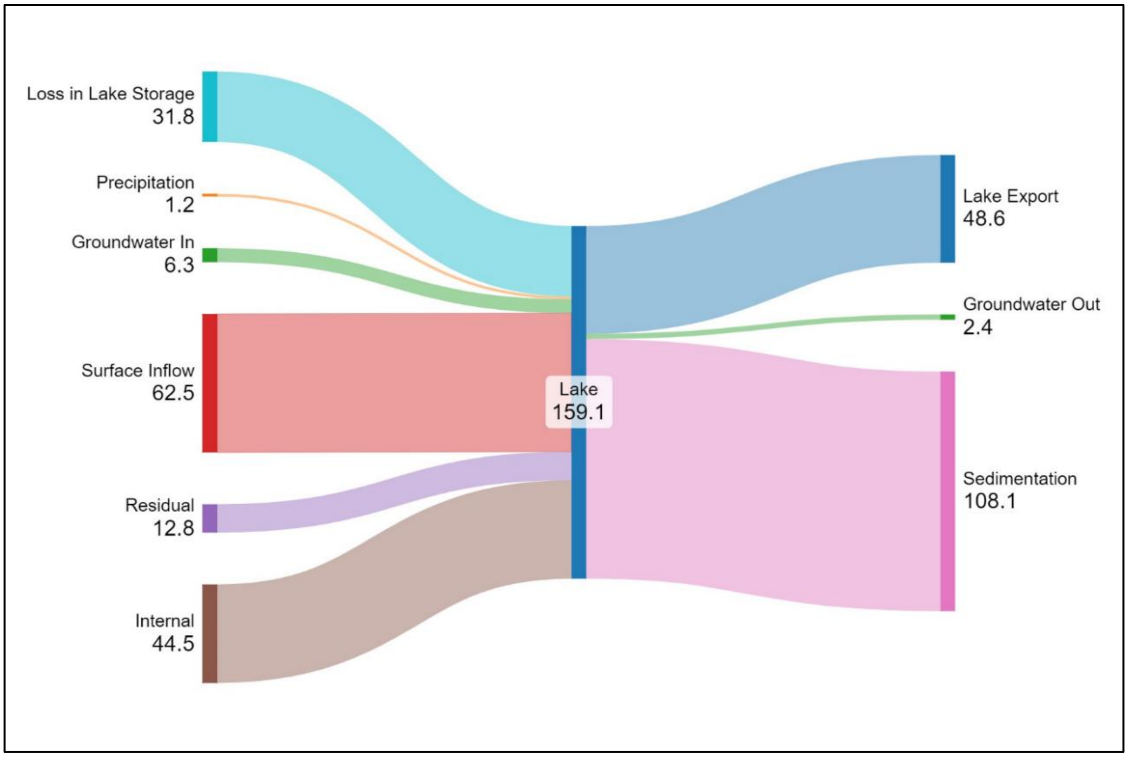
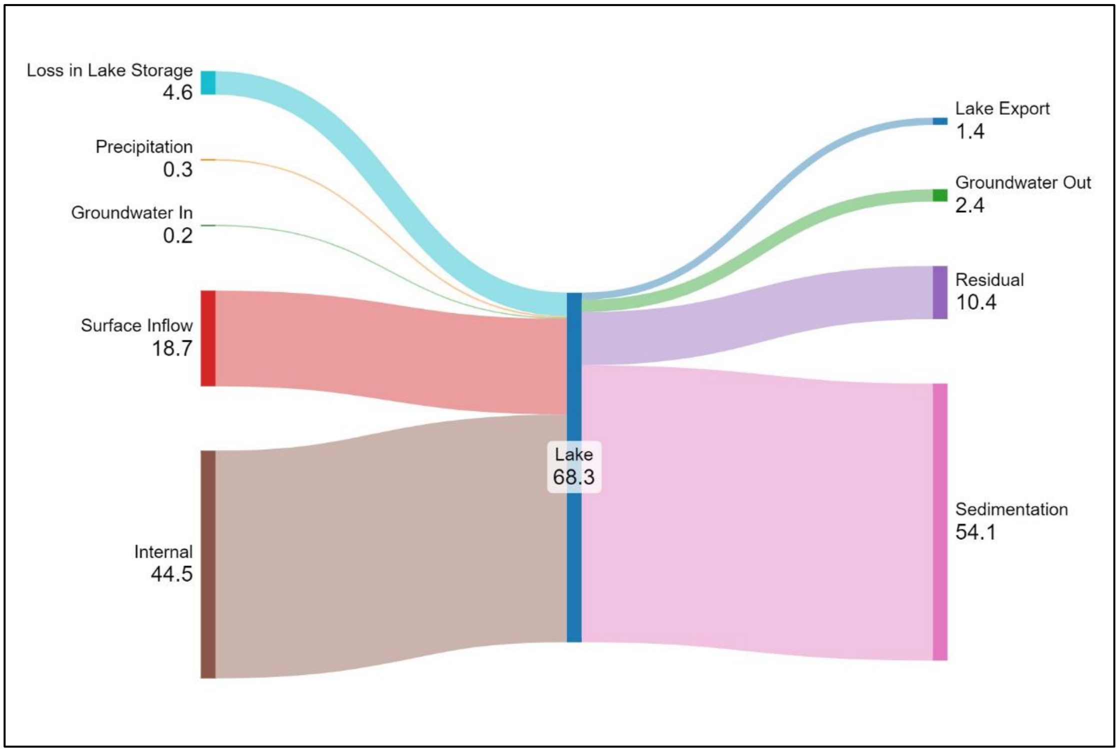


Figure 23. Summer (May to October) Phosphorus Budget (kg) for Echo Lake.



Summary of Findings

What is Causing or Contributing to Cyanobacteria Blooms in Echo Lake?

Echo Lake is a meso-eutrophic lake with high algal productivity, high phosphorus concentrations, and moderate water clarity. Lake monitoring in 2023 found elevated chlorophyll-a concentrations in April, August, and October. Blooms in August and October were likely dominated by cyanobacteria.

When cyanobacteria populations reach high densities, they often produce cyanotoxins at levels that are harmful to human health. Blooms in Echo Lake are often toxic but cyanotoxins infrequently exceed state guidelines and risk the health of humans or wildlife. Microcystin is the primary cyanotoxin in Echo Lake that exceeded state guidelines in 6 of the past 15 years of monitoring. The highest microcystin concentrations typically occur in September and October from fall cyanobacteria blooms. Anatoxin-a exceeded state guidelines only in the spring of 2021.

Cyanobacteria may have several competitive advantages over other algae, including the ability to fix nitrogen and store phosphorus (two crucial nutrients for growth). In addition, most can regulate their buoyancy, moving up and down in the water column; they have low energy demands; and they are generally unpalatable to grazers that eat algae. Monitoring data from 2022–2023 indicate algae are limited by both nitrogen and phosphorus based on the low concentrations of both dissolved inorganic nutrients and the TP:TN ratios (see Appendix A).

Where is the Excess Phosphorus Coming From?

There are two major pathways of phosphorus to Echo Lake: (1) internal release from lake sediments and (2) stormwater runoff. Most of the stormwater phosphorus is loaded to the lake during the winter months and falls to the lake sediments, where it is later released via the internal load during the summer algae bloom season.

The sediments of Echo Lake are rich in phosphorus bound to organic matter (e.g., decomposing algae, waterfowl feces, and leafy plant debris). During the summer, there are low levels of oxygen at depth, which changes the chemical structure of iron which then releases bound phosphorus. Furthermore, warmer temperatures increase microbial decay of sediment organic matter, which releases bound phosphorus up into the water column for algae uptake.

The primary sources of accumulated sediment phosphorus are watershed stormwater runoff and settled algae. Controlling external watershed loading of phosphorus, along with internal sediment release, will be important in the long term for mitigating algae blooms and curbing the replenishment of internal sediment loads.

Cyanobacteria Management Methods

This chapter provides a summary of potential internal and external lake management methods for cyanobacteria control, their advantages and disadvantages, and their suitability for implementation in Echo Lake. Internal methods include lake physical, chemical, and biological methods. External methods are focused on the watershed.

Actions assessed as suitable for implementation in Echo Lake are highlighted in green in Table 15 and further described in the *Methods Considered* section below. Actions determined not suitable for implementation in Echo Lake and the rationale for this determination are detailed in the *Methods Rejected* section. The assessed suitability of each method for Echo Lake is based on a qualitative assessment on a relative scale of low, moderate, or high for the following factors:

- Effectiveness at meeting lake management objectives
- Long-term cost of method implementation
- Risk for impacts to the environment and non-target organisms
- Feasibility of method implementation based on site-specific conditions that may limit its success

The next chapter recommends consideration of specific methods among those considered suitable for Echo Lake. These recommendations will be evaluated by the City and considered against other priority watersheds and available funds.

Table 15. Cyanobacteria Management Feasibility Screening.

Method	Effectiveness	Cost	Impact Risk	Feasibility	Suitability
Lake Physical Methods (Internal)					
Lake Mixing – Surface Mixing by SolarBees	Low-Moderate	Low-Moderate	Low	Moderate-High	No – uncertain effectiveness
Lake Mixing – Whole-lake Mixing by Aeration	Low-Moderate	Moderate	Low	Moderate	No –uncertain effectiveness
Sonication	Low-Moderate	Moderate	Low-Moderate	Low	No –uncertain effectiveness
Lake Dilution	Moderate	High	Low	Low	No – high cost
Hypolimnetic Oxygenation/ Aeration	Moderate-High	High	Low	Moderate	Yes
Ozone/ Microbubbles/ Nanobubbles	Low	Moderate	Low	Low	No – not effective, experimental
Hypolimnetic Withdrawal	Low	Moderate	High	Low	No – downstream impacts

Table 17 (continued). Cyanobacteria Management Feasibility Screening.

Method	Effectiveness	Cost	Impact Risk	Feasibility	Suitability
Dredging	Low-Moderate	Very High	Moderate	Low	No – high cost/benefit
Shading (Dyes)	Moderate	Moderate	High	Low	No – not feasible
Improve Outlet Conveyance Capacity	Low	Low	Low	High	No – not effective
Lake Chemical Methods (Internal)					
Algaecide treatment	Moderate	Low-Moderate	Low-Moderate	Moderate	Yes – limited to toxic blooms
Phosphorus Inactivation - Alum Treatment	High	Moderate	Low-Moderate	Moderate	Yes
Phosphorus Inactivation - Lanthanum Treatment	High	Moderate	Low-Moderate	Moderate	Yes
Phosphorus Inactivation - Proprietary Products	High	Moderate	Low-Moderate	Moderate	Yes
Phosphorus Inactivation - Iron Treatment	Low	Low	Low	Low-Moderate	No – not effective in anoxic hypolimnion
Phosphorus Inactivation - Calcium Treatment	Low-Moderate	Low-Moderate	Low	Low	No – not effective with low hardness
Lake Biological Methods (Internal)					
Carp removal	Low	Moderate-High	Low-Moderate	Low	No – not effective, low population
Biomanipulation (zooplankton or piscivore stocking)	Low	Low-Moderate	Low-Moderate	Low	No – not feasible, low effectiveness
Macrophyte plantings	Low	Moderate	Low	Low	No – not effective
Barley Straw	Low	Low	Low-Moderate	High	No – uncertain benefit
Watershed Methods (External)					
Source Control (shoreline and waterfowl, yards, pet waste, businesses, construction)	Low-Moderate	Moderate	Low	Moderate	Yes
Stormwater Management (training, tracking, and education; system maintenance; retrofits)	Low-Moderate	Low-High	Low	Moderate	Yes
Stream Phosphorus Inactivation	Low-Moderate	Moderate	Moderate	Low	No – stormwater phosphorus treatment preferred

Methods Considered

In-Lake Methods

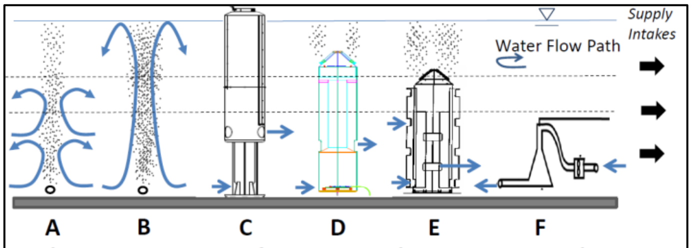
The following sections summarize the most feasible lake management techniques that may be used to improve the algae community and meet the water quality objectives. All techniques that are considered feasible have the ability to effectively reduce the magnitude and frequency of toxic cyanobacteria blooms. There are advantages and disadvantages to each management technique, some are more experimental with limited scientific studies of effectiveness, and there are wide differences in initial and long-term costs. Table 15 provides a comparative summary of these techniques. The lake management techniques that were considered not to be cost effective are presented in the next section of this plan with rationale for their elimination.

It is important to recognize that any lake management technique aimed at controlling algae, if successful, is likely to affect aquatic macrophyte populations. Clear water from less algae means more sunlight for plant growth. Since most plants obtain their nutrients from the sediments rather than the water, lake nutrient reduction techniques typically do not impact them. Although phosphorus inactivation methods reduce nutrient availability in sediments where most aquatic macrophytes obtain nutrients, macrophyte roots typically penetrate below the inactivation zone (upper 10 centimeters) and are not affected by inactivation treatments. Lake management should focus on achieving the appropriate ecological balance between algae and plants, since too much of either can be problematic.

Hypolimnetic Oxygenation and Aeration

Hypolimnetic oxygenation or aeration techniques are implemented to combat hypolimnetic anoxia by maintaining or increasing DO levels in the hypolimnion while preserving thermal stratification. Hypolimnetic oxygenation uses pure oxygen, whereas hypolimnetic aeration uses air to maintain oxygen levels. Maintaining oxygenated conditions in the hypolimnion transfers oxygen into the underlying surficial sediments to suppress the release of phosphorus and nitrogen from sediments, settled particulate matter, and groundwater inflow. Maintaining stratification reduces the mixing of nutrient-rich hypolimnion water to the epilimnion.

Hypolimnetic aeration/oxygenation systems typically involves the installation of diffuser tubes or plates on the lake bottom to inject air or oxygen into the bottom of the hypolimnion. A vertical structure is needed to carry the released bubbles and associated water up to the top of the hypolimnion (partial lift) or epilimnion (full lift). Once there, bubbles are released at the lake surface and the aerated water is discharged near the lake sediments. A summary of lakes where hypolimnetic oxygenation or aeration have been deployed is provided in Table 16.



Schematic Diagrams of Aeration and Oxygenation Techniques

A variety of apparatus is available for managing thermal stratification and respiration in water supply reservoir systems. Some prevent stratification. Some adjust the location of the thermocline to expand epilimnetic mixing depth or establish high quality layers at the elevation of a raw water intake. Some add oxygen to the hypolimnion without changing stratification.

A. Line Diffuser with Low Enough Gas Flow to Maintain Stratification
B. Line Diffuser with High Enough Gas Flow to Prevent Stratification
C. Traditional Full-Lift Hypolimnetic Aeration
D. Submerged Partial-Lift Hypolimnetic Aeration
E. Depth-Selective Layer Aeration
F. Conical Oxygen Contactor, A.K.A. “Speece Cone”.

Modified from: Moore, et.al, 2015

Table 16. Hypolimnetic Oxygenation and Aeration System Examples.

Lake, Location	Install Year	Lake Characteristics	System	Effect on Phosphorus Release	Source
Newman Lake Spokane County, Washington	1992 (renovation planned as of 2022)	Mean depth = 5.8 m Max depth = 9.1 m Area = 490 ha	Hypolimnetic oxygenation with Speece Cone and alum emitter	Decrease in lake phosphorus concentrations	Moore et al. 2012
Stevens Lake Snohomish County, Washington	1994 (retired in 2012)	Mean depth = 20.5 m Max depth = 46 m Area = 421 ha	Hypolimnetic aeration	Reduced sediment phosphorus. Decrease in effectiveness in final years attributed to saturation of iron-binding sites for phosphorus	Snohomish County and TetraTech 2012
Lake Fenwick Kent, Washington	1994 (renovated in 2020)	Mean depth = 4.0 m Max depth = 9.4 m Area = 9 ha	Hypolimnetic aeration	Not evaluated.	Ecology 2002
Falling Creek Reservoir Vinton, Virginia	2013	Mean depth = 4.0 m Max depth = 9.3 m Area = 11.9 ha	Hypolimnetic oxygenation with Oxygen Saturation Technology	Increased DO and maintained thermal stratification. Decrease in hypolimnion TP and SRP during operation	Gerling et al. 2014
Sarah's Pond Orleans, Massachusetts	2021	Mean depth = 3 m Max depth = 5.3 m Area = 2.3 ha	Hypolimnetic oxygenation with Oxygen Saturation Technology	Reduction in sediment phosphorus release. Decreased effectiveness due to electrical service shutdown and expanded anoxic area due to hot weather.	Wagner 2022

See Preece et al. 2019 for an expanded list of hypolimnetic oxygenation systems.

Oxygen Saturation Technology (OST) is a relatively new, patent-pending innovation used to administer precise concentrations of oxygen at strategic depths in a waterbody, also known as side-stream supersaturation (SSS). The OST's design eliminates bubbles, which eliminates turbulence, sediment resuspension, and undesirable mixing of the stratified layers. Unlike conventional hypolimnetic oxygenation systems, these systems can maintain dissolved oxygen (DO) levels as high as 20 mg/L directly over and into the sediments, where oxygen is needed most. Traditional hypolimnetic aeration systems typically rely on passive diffusion of air, which is only 21 percent oxygen, to saturate bottom waters up to approximately 11 mg/L. OST can supersaturate bottom waters to much higher concentrations because it uses mechanical mixing with pure oxygen. These high dissolved oxygen levels (exceeding those from simple saturation with the air) are important to overcome the high oxygen demand of organic-rich sediments in eutrophic lakes. Traditional hypolimnetic aeration systems can fail because they do not meet the sediment oxygen demand.

An OST system functions by transporting approximately 95 percent pure oxygen from an onshore facility to an in-lake device where the water is supersaturated with oxygen. The water is then injected back into deep areas of the lake where it disperses over the sediment surface. The oxygenated water can coat and penetrate the sediments, preventing the release of phosphorus from iron-phosphate complexes and allowing the oxidized iron to bind to phosphate released by microbial decay of organic matter. The onshore facility consists of a compressor and an oxygen generator and requires a 220V electrical hook-up. There is no storage of oxygen on premises. The compressors will generate noise and sound insulation of the onshore facility is recommended.

Generally, the cost of installing a hypolimnetic aeration system can range from hundreds of thousands to millions of dollars. Importantly, the cost of the system is not a one-time expense. It requires ongoing maintenance to ensure it operates efficiently. The maintenance cost can include electricity bills for running the system, periodic cleaning and replacement of diffuser membranes, and inspection of the system components. For example, the hypolimnetic aeration system installed in Lake Stevens in Snohomish County in the 1990s ultimately failed. Now algae blooms in that lake are being controlled by alum treatments. Installation and operating costs for that system over a 10 year period was $1,240/hectare/year (Cooke et al. 2005), or about $5 million for 10 years in a 421 hectare lake. A hypolimnetic aeration system was installed in Lake Fenwick in King County in the 1990s, and recently this 10.4 hectare lake (about twice of Echo Lake) was upgraded at a cost of $900,000.

OST has the secondary benefit of increasing fish habitat and reducing the potential for oxygen-related fish mortality. This is a significant benefit to trout and other cold-water fish that are restricted ("squeezed") to the mid-depths of Echo Lake in the summer because the surface layer is too warm and the cold bottom layer does not have any oxygen to survive (see Appendix A). Oxygenation of lake bottom waters also increases the diversity and abundance of benthic invertebrates in deep areas of the lake that are not able to live in anoxic water, and the abundant invertebrates increase fish food, health, and abundance.

Advantages

An oxygenation system:

- Reduces phosphorus release from anoxic sediments.
- Increases phosphorus retention within the lake and decreases phosphorus export downstream and water quality impacts (e.g., increased algae blooms or oxygen demand) resulting from phosphorus export.
- Increases deep water oxygen concentrations, which improves fish habitat and aquatic life uses.
- Degrades organic matter and cyanotoxins faster by using aerobic microbes.
- Is a non-chemical alternative.

In addition to these advantages, new oxygen saturation technology (OST) pumping oxygenated water to and from hypolimnion is very promising for small lakes because it is more effective and cheaper than traditional oxygenation systems.

Disadvantages

An oxygenation system:

- May resuspend of sediment layer nutrients/ions in the water column if not properly installed.
- Requires installation and operational cost (electricity).
- Is ineffective in shallow lakes/ reservoirs with a large surface area and weak to no stratification.
- May require continuous operation during the summer stratification period.
- Causes sedimentation of oxidized organic matter.
- Can be ineffective when external nutrients are not controlled.

Suitability for Echo Lake

Hypolimnetic oxygenation may be a suitable management technique in Echo Lake. One of the dominant sources of phosphorus is from the lake's sediment. The release is believed to be caused by the absence of oxygen, allowing the desorption of phosphorus from iron compounds. It is important to note that hypolimnetic oxygenation would support phosphorus retention in the deep-water sediments, but internal cycling in the shallow sediments due to microbial decay of organic material would persist.

For Echo Lake, the OST onshore facility could be placed on publicly owned land in Echo Lake Park. The building would need to be approximately 10-foot-by-10-foot to accommodate the oxygen generator, air compressor, and 120-gallon air receiver. The compressor will generate noise, and therefore sound insulation is recommended. A 220-volt electrical hookup would need to be established for the equipment. Additionally, the building should be suitably secure to prevent break-ins and vandalism or theft. Trenching of the oxygen supply and powerlines to the lake shore is recommended to prevent damage and other hazards.

Planning Level Costs

The OST system is a lower-cost alternative because it is much smaller and easier to install for an equivalent or higher oxygenation rate compared to traditional hypolimnetic oxygenation and aeration systems. The system is floated out to the install location and sunk to the desired depth. The cost breakdown of an OST system is provided below in Table 19. Overall, an OST system is estimated to initially cost $175,000 (midpoint of manufacture estimate range of $156,000 to $195,000 including installation), and the building construction and electrical hookup is estimated to cost $60,000 (assumed to be located in Echol Lake park and including sound insulation). Permitting and engineering oversight is estimated at $70,500 (30 percent of OST and building cost). We included 10.4 percent tax and 20 percent contingency based on the OST and building cost, for a total installed cost of $377,000. Ongoing maintenance and operation cost is estimated to average of $9,000 per year, including tax and a 20 percent contingency.

Table 17. Echo Lake Oxygen Saturation Technology Cost Estimate.	
Initial Capital Costs	
OST System (Including Installation) 1x Oxygen Generators 1x Air Compressors 1x 120-gallon Air Receivers Oxygenation Chamber Energy Dissipating Headers Submersible Pump Oxygen and Power Lines	$175, 000 (Midpoint of $156,000 to $195,000 range quoted by manufacturer)
Building and Electrical Hookup Includes Sound Insulation (assumed to be sited in Echo Lake Park)	$60,000
Permitting and Engineering Oversight (assumed at 30 percent of OST and building cost)	$70,500
Tax (10.4% of OST and building)	$24,440
Contingency (20% of OST and building)	$47,000
Total	$377,000
Annual Operation and Maintenance	
Electricity (assuming $0.12/kWh, operating 10 hp compressors/pump from June to October)	$2,300
Compressor Rebuild (every 2 years at $5,000 each)	$2,500
Replace Submersible Pump (every 10 years at $10,000 each)	$1,000
Zeolite Replacement (every 5 years at $5,000)	$1,000
Tax (10.4%)	$700
Subtotal O&M (annualized)	$7,500
Contingency (20%)	$1,500
Total	$9,000

Algaecide Treatment

Algaecides provide short-term algae control by killing the algae and cyanobacteria in the water column. However, algaecides may affect other aquatic biota to varying degrees and accelerate recycling of nutrients. Algaecides are effective only while the active ingredient is in the water column and available for uptake by the algae (Cooke et al. 2005). Typically, two or more applications must occur within the same season to provide effective control of algae and cyanobacteria throughout the season. Algaecides do not reduce phosphorus or nitrogen concentrations and do not provide long-term control. In fact, they increase recycling of phosphorus, which is released from the decaying algae and increases the concentration of dissolved phosphorus for uptake by algae when the algaecide stops working within days of the application.

Currently, endothall (e.g., Hydrothol® 191) and sodium carbonate peroxyhydrate (e.g., PAK 27 or Phycomycin) are the only algaecides permitted for use in the State of Washington. The primary algaecide utilized in Washington State is sodium carbonate peroxyhydrate. When applied to the lake, this compound breaks down into hydrogen peroxide and sodium carbonate. The hydrogen peroxide oxidizes and thus kills the target algae. After contact, the hydrogen peroxide breaks down harmlessly into water and oxygen. When properly applied at a low rate, this algaecide is selective for cyanobacteria, which are lacking a cell wall, and does not harm many of the more beneficial green algae that are protected by a cell wall. When sodium carbonate peroxyhydrate is applied in accordance with directions on the label, no harm is expected to birds, other terrestrial animals, freshwater fish, or freshwater invertebrates (EPA 2011).

Sodium carbonate peroxyhydrate can also be used to kill *E. coli* and other fecal coliform bacteria that often cause beach closures due to waterfowl droppings and other fecal sources. Small peroxyhydrate treatments limited to the waters in the vicinity of a closed beach can be used to reduce *E. coli* counts to levels below the threshold for public safety closures.

Advantages

- Rapid water quality improvement
- Inexpensive management option
- Sodium carbonate peroxyhydrate algaecides:
    - Have no use restrictions and are non-toxic to wildlife.
    - Oxidize intra-cellular cyanobacteria toxins and also kill fecal bacteria.
    - Can be applied at low rates to not impact most beneficial green algae.
    - Rapidly degrade into water and oxygen.
    - Do not accumulate in the environment.

Disadvantages

- Sodium carbonate peroxyhydrate algaecides:
    - Are effective short-term only, while the active ingredient is in the water.
    - May affect non-target plants or other aquatic organisms, if not applied according to the label.
    - Do not reduce nutrients, and can accelerate recycling of nutrients.
    - Typically require more than one application within the same season for effective control.
    - Require a 24-hour swimming restriction and can have possible toxic effects to fish (for Hydrothol 191).
    - Require a permit and licensed applicator.

Suitability for Echo Lake

Algaecides are not a cost-effective tool for ongoing, long-term algae management because they only work for a short time. However, they can be used on occasion in some years to control a toxic cyanobacteria bloom. Because blooms are difficult to predict, there may be logistical challenges in mobilizing a contractor rapidly enough to provide treatment. An algaecide treatment may only lessen a bloom for as little as 2 days. In addition to the higher costs, relying on algaecides as a sole management strategy would likely have negative ecological consequences.

Under certain situations, sodium carbonate peroxyhydrate treatments may be suitable for short-term treatment of the entire lake or for impacted swim beaches and isolated areas of scum accumulation. Lake residents are accustomed to using herbicides for aquatic plant control, and they are not likely to object to the use of algaecides. Sodium carbonate peroxyhydrate has no use restrictions or aquatic toxicity. When applied at a low rate, it primarily oxidizes cyanobacteria and cyanotoxins rather than beneficial green algae.

Planning Level Costs

The cost for the material and application of sodium carbonate peroxyhydrate treatment is approximately $250 per acre. A whole-lake treatment would cost approximately $3,250. However, multiple treatments may be required in a single year. Assuming three treatments per year, the cost of algaecide-only management would be about $10,000 per year.

Phosphorus Inactivation

Phosphorus in lake sediment or the water column can be inactivated by adding a flocculant or metal cation to bind with orthophosphate and/or particulate phosphorus in the water and/or sediment by treatment with one of the following chemical products:

- Alum
- Lanthanum
- Proprietary products
- Iron
- Calcium

These products are described separately below; however, iron and calcium were rejected, because they would not be effective due to anoxic and soft water conditions in Echo Lake (see *Methods Rejected*),

Alum Treatment

Applications of aluminum sulfate (alum), in a sufficient dose to inactivate all mobile sediment phosphorus, have been shown to be effective for at least 10 years in lakes with low watershed inputs (Cooke et al. 2005). When alum is added to water it forms a floc that grows in size and weight as it settles through the water column, sorbing inorganic phosphorus and incorporating particulate organic phosphorus through entrapment (Burrows 1977, Driscoll and Schecher 1990). The alum floc settles to the sediments, where it continues to control phosphorus by sorbing additional phosphorus that is present in the sediments. This forms a barrier to future phosphorus release from sediments into the water column.

The resultant phosphorus that is bound to aluminum in the lake sediments is very stable and is thought to be permanently bound (Rydin and Welch 1998).

Alum treatments have been used successfully in many lakes in Washington, and several strategies have been implemented in Washington and around the world to inactivate phosphorus in sediments and lakes, and from watershed inputs, including the following:

- Whole lake alum dose
- Multiple small alum doses
- Microfloc alum injection
- Inflow stream alum injection

Multiple small alum doses typically cost more than a whole lake alum dose, due to higher mobilization costs. Multiple small alum doses are more appropriate for lakes with high external loading, which would reduce the longevity of a whole lake alum dose. Multiple small alum doses are sometimes preferred over a large long-term dose for financial reasons or to reduce potential impacts of aluminum toxicity to aquatic organisms. Multiple small alum doses can be used to strip phosphorus from the water column and to inactivate sediment phosphorus.

Because of the acute toxicity concerns of aluminum under acidic conditions, sodium aluminate (a base) and alum (an acid) are added as a buffer to soft water lakes. This prevents the pH from dropping below the lower end of the acceptable range (i.e., 6.0), which can result in widespread fish kills. The ratio typically used for alum and sodium aluminate is 2:1 by volume. This ratio is appropriate for Echo Lake because it is a soft water lake. Sodium aluminate is expensive and adds a lot to the cost of an alum treatment. Sodium aluminate is usually not needed, even in soft water lakes, for low dose (less than 5 mg Al/L) water column stripping applications that do not include sediment inactivation.

Under the Aquatic Plant and Algae Management General Permit, a jar test must be completed prior to whole lake treatments only if a buffer other than sodium aluminate is used or if a ratio of liquid alum to liquid sodium aluminate differs from 2:1 by volume. Furthermore, monitoring under S6.B of the permit is required. This includes:

1. One surface water pH measurement in the morning, prior to any alum addition, and one surface water pH measurement 1 hour after alum addition has stopped for that day. These measurements may partially fulfill the permit conditions in S6.B.1.c.
2. The Permittee must monitor pH for the duration of the treatment and for 24 hours following treatment completion. For continuous monitoring, measurements must be taken at intervals no longer than 15 minutes. The monitoring location must be representative of waterbody-wide conditions. If the pH decreases to less than 6.2, the Permittee must stop the treatment, analyze for alkalinity, and take immediate steps to increase the pH.
3. For continuous injection treatments, the Permittee must measure pH at a minimum once every 2 weeks during the first month of continuous injection and thereafter once a month for the duration of the injection process. The Permittee must ensure that pH measurements represent waterbody-wide conditions, unless the injection system is in an isolated area in relation to the main waterbody (e.g., in a bay with a narrow

channel to the main waterbody). For isolated areas of waterbodies, the Permittee must measure pH at the end of the bay and in the main waterbody.

4. When performing any treatment using alum, the permittee must monitor for aluminum in the waterbody according to the following procedures:
5. Before the alum treatment, permittees must take water samples to establish a baseline for the following metrics:
    - pH
    - Dissolved organic carbon (DOC)
    - Total hardness (as $CaCO_3$)
6. Water samples must be representative of the treatment area, with at least one shoreline sample and one open water sample.
7. The latitude and longitude coordinates of water sample locations must be recorded in decimal degrees. Pre- and post-treatment water samples must be taken from the same locations.
8. During the alum treatment, pH must be monitored continuously.
9. Immediately after the alum treatment, the permittee must take water samples and test them for aluminum concentration. This measurement must include both total recoverable aluminum and dissolved aluminum.
10. The permittee must take water samples to test for total recoverable aluminum, pH, DOC, and hardness 2 weeks after the treatment.
11. The permittee must take water samples to test for total recoverable aluminum, pH, DOC, and hardness once per month for the 2 months following the alum treatment.
12. The permittee must take water samples to test for total recoverable aluminum, pH, DOC, and hardness quarterly until one year after the alum treatment date.
13. Reporting Aluminum Monitoring Data: The permittee will send all aluminum monitoring data to the Department of Ecology within 30 days of each sampling event. Permittees do not need to take any further action after measuring and reporting the results of these water samples.

Additionally, under the permit, an onsite storage facility is required for any treatment requiring 9,000 gallons of alum or more, or the project proponent must have a plan to store any unused alum or buffering products.

Advantages

- Instantaneous water column phosphorus control
- Long-term, stable sediment phosphorus control
- Floc rapidly settles to bottom
- Promotion of water clarity
- Cost-effective and widely successful

Disadvantages

- Potential impacts of aluminum toxicity to aquatic organisms (however, extensive use of a buffer and monitoring in our region has minimized this risk)

- Sediment phosphorus monitoring required for accurate dosage calculations
- Limited effectiveness when watershed load is dominant

Suitability for Echo Lake

Alum treatment would be a suitable management method to remove available phosphorus in Echo Lake because of the high internal loading rate during the algae growing season. In comparison to other phosphorus inactivation products, alum is more effective than iron in lakes with an anoxic hypolimnion. Alum is comparable in cost to lanthanum-modified clay but typically has greater longevity because it is applied at rates with a higher phosphorus binding capacity (e.g., 20 times more) than lanthanum-modified clay.

Similar to other in-lake management actions, accessing the lake with the necessary equipment (e.g., a boat) to the lake may pose a challenge due to no road access or boat launch on the lake.

Planning Level Costs

Planning level costs for water column stripping and sediment inactivation with alum are provided in the *Planning Level Comparison for Phosphorus Inactivation* subsection at the end of this section.

Lanthanum Treatment

Lanthanum (La^{3+}) has a strong affinity for phosphate (PO_4^{3-}), such that it chemically inactivates phosphate through precipitation and forms a mineral of extremely low solubility. Therefore, similar to alum treatments, it permanently binds the phosphorus. Lanthanum is available for application in lakes as lanthanum-modified bentonite (LMB), which is applied as a slurry. Bentonite is an adsorbent swelling clay commonly used as drilling mud. Unlike alum, however, LMB is not a coagulant and therefore does not trap and remove particles in the water column. Rather, LMB works mainly in the sediment to bind phosphate that would normally be released to the water through decomposition or changes in sediment chemistry. The lanthanum in LMB binds only to inorganic phosphate (soluble reactive phosphorus or orthophosphate) and does not address organic phosphorus until it degrades to phosphate. LMB can be applied in frequent small does to ‘strip’ the water column of inorganic phosphorus. Although alum treatment effectiveness and duration has been much better studied (see Cooke et al. 2005), there are many Phoslock and a few EutroSORB studies published to date worldwide (see Copetti et al. 2016). Kitsap Lake, in Bremerton, Washington, has undergone annual lanthanum treatments with notable improvements in water quality and no closures during the high lake use periods of June through August.

Lanthanum concentrations immediately following application may exceed estimated toxicity thresholds, particularly for zooplankton, and little study has been done for impacts on benthic organisms (Copetti et al. 2016). Generally, because lanthanum is applied in phosphorus-rich waters, the amount of free lanthanum ions is low as they bind to phosphate. Jar tests prior to application can be used to ensure proper dosage.

Phoslock® is the tradename of the original commercially available LMB product that was developed in Australia in the 1990s. EutroSORB® is an LMB product developed over the past few years by SeaPRO®, a major manufacturer of lake management chemicals. Currently, there are three formulas of EutroSORB®

used for sediment inactivation (EutroSORB® G), water column stripping (EutroSORB® G), and filtration of flowing waters (EutroSORB F). EutraSORB® WC has an undisclosed ingredient(s) to flocculate particulate phosphorus that is evaluated in the next section on *Proprietary Product Treatment*.

Advantages

- Permanently inactivates phosphorus water column and/or sediment
- Remains effective and non-toxic under all pH and oxygen conditions

Disadvantages

- Temporarily increases turbidity from clay
- Requires monitoring for accurate dosage calculations
- Has fewer case studies to evaluate effectiveness and duration of treatments compared to alum
- Has limited effectiveness when watershed load is dominant

Suitability for Echo Lake

Lanthanum treatment would be a suitable management method to remove available phosphorus in Echo Lake. Phoslock and EutroSORB G are currently permitted for use in Washington and are best used for sediment inactivation lasting one to several years. However, either of these products could be applied to strip phosphate from the water column with some additional product to inactivate phosphate released from recent sediments over a 1-year period. Similar to other in-lake management actions, accessing the lake with the necessary equipment (e.g., a boat) to the lake may pose a challenge due to no road access or boat launch on the lake.

In waterbodies with low alkalinity (< 20 mg/L), a jar test must be completed prior to treatment to identify proper dosing levels. Historic King County monitoring data indicate that Echo Lake is not sufficiently alkaline with measured in-lake alkalinity at 1 m at about 15 mg $CaCO_3$/L.

Planning Level Costs

Planning level costs for Phoslock and EutroSORB G are provided in the *Planning Level Comparison for Phosphorus Inactivation* subsection at the end of this section.

Proprietary Product Treatment

There are several proprietary formulations available on the market that provide binding sites for dissolved phosphorus in the water column and produce floccules that will pull particulates, including algae and sediment, from the water column. In this way, the products act similarly to alum.

Currently available products include EutroSORB WC, produced by SePRO, and MetaFloc, produced by Naturalake Biosciences. Both manufacturers claim that their products do not impact water chemistry (including pH) and have low toxicity to aquatic life and humans, but no case studies are as-of-yet available to support these claims.

Advantages

- Permanently inactivates phosphorus water column and/or sediment

Disadvantages

- Monitoring required for accurate dosage calculations
- Few case studies to evaluate effectiveness and duration of treatments
- Limited effectiveness when watershed load is dominant
- Uncertain stability and toxicity impacts, assumed to be similar to alum and lanthanum

Suitability for Echo Lake

There is no available information to support the claims of the manufacturers, regarding the effectiveness and low ecological impacts. However, if the claims hold true, these products could be effective alternatives to alum (which as toxicity and pH concerns) and lanthanum (which does not remove particulate phosphorus).

The above-described proprietary products are not currently approved in the Washington State Department of Ecology’s Aquatic Plant and Algae Management Permit. As such, an experimental application permit would need to be obtained for treatment in Echo Lake. This would likely entail thorough monitoring before, during, and after application.

Similar to other in-lake management actions, accessing the lake with the necessary equipment (e.g., a boat) to the lake may pose a challenge due to no road access or boat launch on the lake.

Planning Level Costs

Planning level costs for MetaFloc and EutroSORB WC are provided in the *Planning Level Comparison for Phosphorus Inactivation* subsection at the end of this section.

Planning Level Comparison for Phosphorus Inactivation with Alum, Lanthanum, and Proprietary Products

Approximate dose and cost estimates were prepared for the inactivation of phosphorus for water column stripping and sediment inactivation, using alum, lanthanum, and proprietary blends under current conditions with an anoxic hypolimnion for comparison to the cost for hypolimnetic oxygenation. These doses are based on available data for phosphorus in the water column and sediments. They are expected to last approximately 5 years based on continued moderate amounts of watershed and groundwater phosphorus loading. Table 20 provides the dosing and cost assumptions used for developing estimates.

Table 20. Assumptions for Dose and Cost Estimates for Phosphorus Inactivation Chemicals.

Approach	Ratio to Phosphorus	Cost per Unit
Alum (Buffered with Sodium Aluminate)	20 Al : 1 P (by mass)	Alum: $2.10/gal; Buffer: $5.10/gal (in 2:1 ratio)
Alum (Unbuffered)	20 Al : 1 P (by mass)	$2.10/gal
Lanthanum (EutraSorb G)	50 product: 1 P or 5 La : 1 P (by mass)	$3.00/kg
Lanthanum (Phoslock)	100 product: 1 P or 5 La : 1 P (by mass)	$6.60/kg
Proprietary Blend – MetaFloc	1.3 gallons : 1 kg	$75/gal
Proprietary Blend – EutroSORB WC	1.28 gallons : 1 kg	$200/gal

Water stripping doses were developed assuming (1) that 17 kg of phosphorus in the water column would inactivate in the first year of treatment (2025) and (2) that subsequent phosphorus levels for treatment would be 25 percent lower (12 kg). Table 181 provides cost estimates for water stripping using unbuffered alum, lanthanum modified bentonite (Phoslock and EutroSORB G), and proprietary products (MetaFloc and EutroSORB WC). An unbuffered dose of alum is appropriate due to the low alum dose required for only water column stripping (dose of 1.2 mg/L Al). The assumptions include a contractor fee of $30,000 for mobilization and application, and a consultant fee of $40,000 for monitoring and oversight. A 15 percent contingency is included.

Table 18. Water Column Phosphorus Stripping Cost Estimates.

Phosphorous Inactivation Product	Application Dose	Materials Cost	Mob/ Application	Tax (9.25%)	Oversight, Monitoring	Contingency (+15%)	Total Year 1 Cost	Total Year 2 Cost
Unbuffered Alum	1,506 gal	$3,164	$30,000	$3,184	$40,000	$9,087	**$85,434**	**$84,351**
PhosLock	1,657 kg	$10,937	$30,000	$3,930	$40,000	$11,217	**$96,084**	**$92,338**
Eutrosorb G	829 kg	$2,486	$30,000	$3,119	$40,000	$8,901	**$84,505**	**$83,654**
MetaFloc	47 gal	$3,556	$30,000	$3,221	$40,000	$9,194	**$85,970**	**$84,752**
Eutrosorb WC	47 gal	$9,333	$30,000	$3,776	$40,000	$10,777	**$93,886**	**$90,690**

Sediment inactivation doses were estimated based on an average sediment mobile phosphorus concentration of 509 mg/kg-DW and a treatment area of 39,000 m^2 (below 3 meters deep) to inactivate 471 kg of phosphorus in sediments to a depth of 10 centimeters. The sediment inactivation doses include water column stripping of 17 kg. The estimated cost of sediment inactivation ranged from $176,100 for EutroSORB G to $489,800 for Phoslock (Table 19). These costs are for one application to Echo Lake and the effectiveness longevity varies considerably for each activation product due to their differences in the phosphorus binding capacity. Alum treatments have greater longevity that lanthanum and proprietary products because the phosphorus binding capacity is much higher for alum at the application doses listed in Table 21.

Table 19. Sediment Phosphorus Inactivation and Water Column Stripping Treatment Cost Estimates.

Phosphorus Inactivation Product	Application Dose	Materials Cost	Mobilization + Application	Tax (9.25%)	Oversight, Monitoring	Contingency (+15%)	Total Cost
Buffered Alum	18,892 gal alum 9,446 gal buffer	$86,901	$30,000	$11,223	$40,000	$25,219	**$193,342**
PhosLock	48,803 kg	$322,102	$30,000	$33,802	$40,000	$63,885	**$489,789**
EutroSORB G	24,402 kg	$73,205	$30,000	$9,908	$40,000	$22,967	**$176,079**
MetaFloc	1,396 gal	$104,683	$30,000	$12,930	$40,000	$28,142	**$215,754**
EutroSORB WC	1,374 gal	$274,860	$30,000	$29,267	$40,000	$56,119	**$430,245**

Note: These costs are for one application to Echo Lake and the effectiveness longevity varies considerably for each in activation product.

The longevity of sediment inactivation treatments is dependent on the control of external loading, phosphorus binding capacity of the application dose, and stability of the bonds between the inactivation chemical and sediment phosphorus. We have developed ranges of costs for a 20-year period assuming a longevity of 2 to 3, 5, and 10 years, including a 5 percent escalation per year (Table 20). Note that these estimates include a dosage on the 20th year. We have also estimated the cost of annual water stripping.

Table 20. Estimated Long-Term Cost of Phosphorus Inactivation through Water Stripping or Sediment Inactivation.

Phosphorus Inactivation Chemical	Annual Water Stripping	Long-term 20-year Cost ("Reset" every 10 years)	Long-term 20-year Cost ("Reset" every 5 years)	Long-term 20-year Cost ("Reset" every 2 to 3 years)
Buffered Alum	–	$1,020,000	$1,670,000	$3,560,000
Unbuffered Alum	$2,660,000	–	–	–
PhosLock	$2,920,000	$2,590,000	$4,230,000	$9,010,000
EutroSORB G	$2,640,000	$930,000	$1,520,000	$3,240,000
MetaFloc	$2,670,000	$1,140,000	$1,860,000	$3,970,000
EutroSORB WC	$2,860,000	$2,270,000	$3,720,000	$7,910,000

Table 21 provides a high-level summary and comparison of the evaluated water column inactivation chemicals suitable for Echo Lake. As noted in the *Methods Rejected* section below, iron treatments may be a less expensive and suitable phosphorus inactivation chemical alternative if the hypolimnion is oxygenated.

Table 21. Comparison of Water Column Phosphorus Inactivation Chemicals.

Water Column Inactivation Method	Alum	Lanthanum	Proprietary Blend
Commercial Products	Available from general chemical suppliers	Phoslock EutroSORB G	MetaFloc EutroSORB WC
Mode of Inactivation	Forms stable complexes with dissolved phosphorus. Forms floccules that pull particulate phosphorus (i.e., algae and sediment from the water column. Stable at pH 6 to 9.	Forms stable complexes with dissolved phosphorus. Binding efficiency is highest between pH 5 and 7. Dissolution may occur at elevated pH levels (>9).	Form complexes with dissolved phosphorus. Most blends include a floccule agent that, like alum, will pull particulate phosphorus (i.e., algae and sediment from the water column.
Application Approach	Applied at water surface and settled to the sediment. Alum is expected to sink and incorporate into the lake sediments.	Applied as lanthanum modified bentonite or as lanthanum salt across the water's surface. Expected to incorporate into the lake's sediments.	Applied at water surface and settled to the sediment.
Potential Negative Consequences	Aluminum toxicity to aquatic life may occur if inadequate buffer is applied. This can be prevented through rigorous planning and monitoring as required by the permit.	Lanthanum concentration immediately following application may exceed estimated toxicity thresholds, particularly for zooplankton, and little study has been done for impacts on benthic organisms. Generally, because lanthanum is applied in phosphorus-rich waters, the amount of free lanthanum ions is low as they bind to phosphate. Jar tests prior to application can be used to ensure proper dosage.	The specific make-up of the blends is proprietary. If alum and lanthanum blend, then the same potential impacts and toxicity prevention approaches.
Permitting	Alum is an approved phosphorus inactivation chemical in the APAM permit.	Lanthanum is an approved phosphorus inactivation chemical in the APAM permit.	Ecology must be allowed to confirm that the chemicals in the product are already approved or an experimental application permit must be obtained.

Table 22 (continued). Comparison of Water Column Phosphorus Inactivation Chemicals.

Water Column Inactivation Method	Alum	Lanthanum	Proprietary Blend
Water Stripping Estimated Cost for 2025 **(including materials + sales tax, permitting, contractor fees, and monitoring; 2024$)**	$85,400 (unbuffered alum)	$84,500 (EutroSORB G) $96,100 (Phoslock)	$86,000 (MetaFloc) $93,900 (EutroSORB WC)
Long-term 20-year Water Stripping Cost	$2.7 million	$2.6 million (EutroSORB G) $2.9 million (PhosLock)	$2.7 million (MetaFloc) $2.9 million (EutroSORB WC)
Sediment Inactivation Estimated Cost for 2025 **(including materials + sales tax, permitting, contractor fees, and monitoring; 2024$)**	$193,000 (buffered alum)	$176,000 (EutroSORB G) $490,000 (Phoslock)	$216,000 (MetaFloc) $430,000 (EutroSORB WC)
Long-term 20-year Sediment Inactivation Cost	$1.0 to $3.6 million	$0.9 to $3.4 million (EutroSORB G) $2.6 to $9.0 million (PhosLock)	$1.1 to $4.0 million (MetaFloc) $2.3 to $7.9 million (EutroSORB WC)
Recent Past Applications	Heart Lake, Anacortes, Washington (2018) Waughop Lake, Lakewood, Washington (2020) Wapato Lake, Tacoma, Washington (2017) Green Lake, Seattle, Washington (2016)	Kitsap Lake, Bremerton, Washington (2020 – [annually]) Lake Lorene, Federal Way, Washington (2012)	No published case studies or management plans

Watershed Management Methods

The following sections summarize feasible watershed management techniques that may be used to reduce external loads to the lake and meet the water quality objectives. Table 15 provides a comparative summary of these techniques. The watershed management techniques that were considered not to be effective are presented in the next section of this plan with rationale for their elimination.

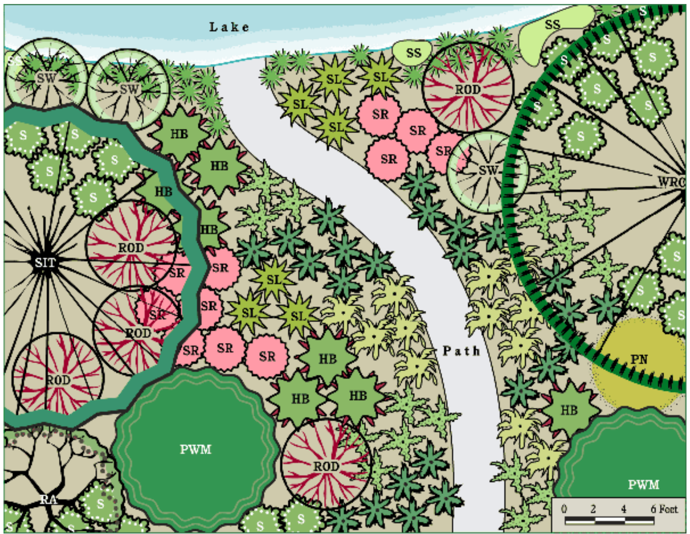
The annual phosphorus budget for Echo Lake indicates that stormwater runoff (55 percent) is the primary source of phosphorus to the lake on an annual basis. A key long-term pathway to preventing cyanobacteria blooms in Echo Lake is to decrease nutrient loading to the lake from its watershed. This involves both source control and treatment of stormwater drainage to the lake from the watershed.

Source Control

Source control is the removal or mitigation of a nutrient or pollution source. A variety of source control actions are available for reducing phosphorus loading to lakes that include: planting healthy lake shorelines to filter runoff and reduce Canada geese habitat, picking up pet waste, inspecting businesses to identify and control stormwater pollution sources, preventing spills or discharges of wastes into the stormwater drainage system; reducing soil erosion from construction sites; controlling sanitary sewer overflows (SSOs), leaks, or cross-connections with storm drains; and educating residents and businesses on stormwater best management practices (BMPs).

Shoreline Management

Best management practices for lake shorelines include healthy shoreline alternatives that use native plants, beaches, and wood to protect houses while improving habitat for fish and wildlife, views, and recreational opportunities. Healthy shoreline alternatives are designed to create a more gradual sloping shoreline and overhanging vegetation to provide protected, shallow water habitat needed by fish and a food source for native birds and wildlife. Healthy shorelines are simply lake edges planted with shrubs, trees, or perennials instead of lawn to the water's edge (Snohomish County 2023 and King County 2024a; see inset example planting plans).



Example Planting Plan (King County 2024a)

These plants have lots of benefits over lawn because they:

- Have deeper roots that trap and filter up to nine times more phosphorus
- Stabilize the shoreline, preventing erosion
- Provide great habitat and food for birds, turtles, frogs and other beneficial aquatic life
- Can add beauty to your shoreline and potentially increase property values
- Need little maintenance once established.

Example Planting Plan (Snohomish County 2023)

Benefits of healthy shorelines for property owners include:

- Reduced lake sediment erosion
- Reduced wave-induced sediment nutrient recycling and cyanobacteria growth
- Reduced Canada geese activity and droppings on property
- Easier access to beach and water
- Shallow gradient shorelines are often favored over steeper designs, especially if you have small children
- More usable shoreline with beach and cove
- Reduced maintenance
- Potential for increased property values.

Populations of resident Canada geese have dramatically increased over the past 25 years, particularly in urban areas where there are few predators, prohibitions on hunting, and a dependable year-round supply of food and water (WDFW 2024c). Canada geese are particularly attracted to mowed lawns around homes, golf courses, parks, and similar areas next to open water. Besides the lawn replacement and the addition of plant barriers, there are other ways to reduce phosphorus loading from Canada geese fecal deposits:

- Educate people to stop feeding geese
- Install fences, other low barriers, wire grids, and netting
- Employ harassment and scare tactics (eyespot balloons, flags, streamers, scarecrows, noisemakers, lasers, dogs, and chemical repellents)
- Lethal control as a last resort (egg addling by permit and euthanasia by the U.S. Department of Agriculture’s Wildlife Services)

Advantages

- Reduces phosphorus loading to the lake in the long-term
- Reduces fecal contamination
- Improves lake habitat quality

Disadvantages

- Expensive, low cost-effectiveness on a large scale
- Does not address immediate algae bloom issues

Suitability for Echo Lake

Plants that grow in and along lake shorelines have an important role in protecting water quality and providing habitat aquatic organisms. Shoreline plants can absorb and slow runoff from upslope lawns and paved surfaces, which reduces nutrient inputs. They are also important for fostering native insects that are food for fish and birds. Bulkheads increase erosion of adjacent lake sediments by reflecting waves and increasing transport of those sediments to deep portions of the lake where their nutrients are released during summer periods of anoxia (loss of oxygen in bottom waters due to high microbial decay rates). Replacing bulkheads and lawns on shorelines with native plants decreases nutrient inputs and cyanobacteria growth in lakes.

Waterfowl droppings are a contributor to phosphorus loading to Echo Lake. They also have a negative aesthetic impact and present a potential health risk to lake users from fecal pathogens. It is important to prevent the migrating populations from becoming resident. Feeding waterfowl discourages natural winter migration; can lead to aggressive behavior; and encourages large resident bird flocks that degrade parks, lawns, and beaches with droppings. Lawns extending to the shoreline can encourage access and help feed Canada geese, while planting native shrubs in its place as a shoreline buffer discourages access by waterfowl, in addition to filtering lawn runoff.

The shoreline of Echo Lake was not surveyed for this project, it appears to be primarily vegetated with a low amount of bulkheads or lawns at the shoreline. One bulkhead is known to be present along about 90 feet of shoreline and is constructed on reused concrete (A. Michel, personal communication, June 5, 2024). Approximately 20 percent of the lake shoreline was estimated to have grass extending to the shoreline. City property at Echo Lake Park is entirely vegetated except for the small sandy beach area. Efforts to establish native plants and control invasive weeds have been made along the south shore and elsewhere at Echo Lake.

Developing a healthy shoreline program to promote and fund replacement of bulkheads and lawns with native plants is a suitable management action to reduce nutrient inputs and cyanobacteria growth in Echo Lake. A good example program to replicate is the Snohomish County LakeWise Program (Snohomish County 2023). Also, the King Conservation District (2024) has the Urban Shorelines & Riparian Habitat Improvement Services that provides free educational tours and workshops and site visits and site-specific vegetation management recommendations to empower landowners with the knowledge and skills needed to better steward their aquatic areas. King Conservation District also offers financial incentives, as well as project design and implementation services to qualified property owners in the City of Shoreline. As part of the Soak It Up Rebate Program, the City's Surface Water Utility offers rebates up to $2,000 for Shoreline home or business owners to install a rain garden or native vegetation landscaping on their property. These features are part of a natural approach to managing rainwater flows and help recreate a forest-like environment in the City by allowing rainwater to soak into the soils and return to groundwater resources and waterways, naturally.

Planning Level Costs

The cost of individual shoreline restoration projects varies from property to property based on existing conditions, slope, and more. The estimated cost of establishing a 10-foot natural shoreland buffer ranges from $50 to $150 per linear foot of shore. The cost of changing existing lawn and landscaping management practices, such as eliminating fertilizer use, is expected to be minimal.

The Spanaway Lake Cyanobacteria Management Plan (Herrera 2023) recommended an annual budget of $35,000 to provide technical assistance for shoreline restoration, waterfowl management, pet waste management, stormwater management, and a lake monitoring program. For Echo Lake, an annual budget of $10,000 is recommended for developing and implementing a healthy shoreline program that is modelled after the Snohomish County's LakeWise Program.

Natural Yard Care

The City's Natural Yard Care outreach works with general public, landowners, and contractors to raise awareness of gardening practices that protect local waterways (Shoreline 2024a). The City's Natural Yard Care web page includes the following instructional videos:

- Growing a Healthy Lawn Naturally
- Fall Prep for a Luscious Lawn
- Honey I Shrunk the Lawn!
- Talking Dirty: Compost, Mulch, Amendments, and More!
- Designing Successful Gardens for the Pacific Northwest
- Fall Prep for a Thriving Garden
- Identifying and Removing Invasive Weeds
- Landscaping with Native Plants of the Pacific Northwest

The "Growing a Healthy Lawn Naturally" video references using phosphorus-free fertilizers and the impact of phosphorus on local waterbodies, but this could be more clearly linked back to the Washington law prohibiting phosphorus in lawn fertilizers and the impact of phosphorus-containing fertilizers on Echo Lake (and other local waterbodies). This video also states that fertilizers should be cleaned up if spilled on a driveway or another hard surface and should not be overapplied. It also describes soil testing options.

Advantages

- Reduces phosphorus loading to the lake in the long-term
- Improves lake habitat quality

Disadvantages

- Does not address immediate algae bloom issues

Suitability for Echo Lake

With a predominantly residential watershed and residences along the shoreline of Echo Lake, targeted education and outreach around natural yard care could be an effective management method.

Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Pet Waste Management

The City's Clean Water – How You Can Help web page includes information on properly disposing of pet waste. Park signage and pet waste stations also encourage the general public and dog owners to pick up their pet waste (Shoreline 2024a). Park signage and educational postcards discourage the general public and park goers from feeding waterfowl to reduce fecal pollution in lakes and ponds (Shoreline 2024a).

Advantages

- Reduces phosphorus loading to the lake in the long-term
- Reduces fecal contamination

Disadvantages

- Does not address immediate algae bloom issues

Suitability for Echo Lake

With a predominantly residential watershed and residences along the shoreline of Echo Lake and public park space at the outlet of the lake, education and outreach around pet waste management is a suitable method.

Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Source Control Program

The City's Source Control Program started in 2023. The City's program currently includes a total of 305 sites, 61 of which will be inspected annually. The Source Control Program focuses on preventing pollution from outdoor activities that could be carried by rain or other water sources into natural waterways, the public stormwater system, or groundwater. The inspections (and associated recommendations) focus on spill prevention (having a spill kit and spill plan), hazardous materials storage, dumpsters, pressure washing, vehicle washing, and other recommendations associated with specific activities conducted at the sites. Implemented recommendations from these inspections can reduce phosphorus loading to Echo Lake and other waterbodies.

In order to address nutrient sources within the Echo Lake watershed, City inspectors should focus on identifying and implementing recommendations to control erosion from landscaped areas and migration of loose material from stockpiles of fertilizer, topsoil, and compost at nurseries, hardware stores, and other businesses that is transported into the City's stormwater drainage system.

Advantages

- Reduces phosphorus loading to the lake in the long-term

Disadvantages

- Does not address immediate algae bloom issues

Suitability for Echo Lake

Illicit discharges have been documented in the watershed in the past 5 years including fuel and/or vehicle related fluids, sediment/soil, paint, and food-related oil/grease. Continued education, outreach, inspection, and enforcement in the lake watershed could reduce pollutants to the lake.

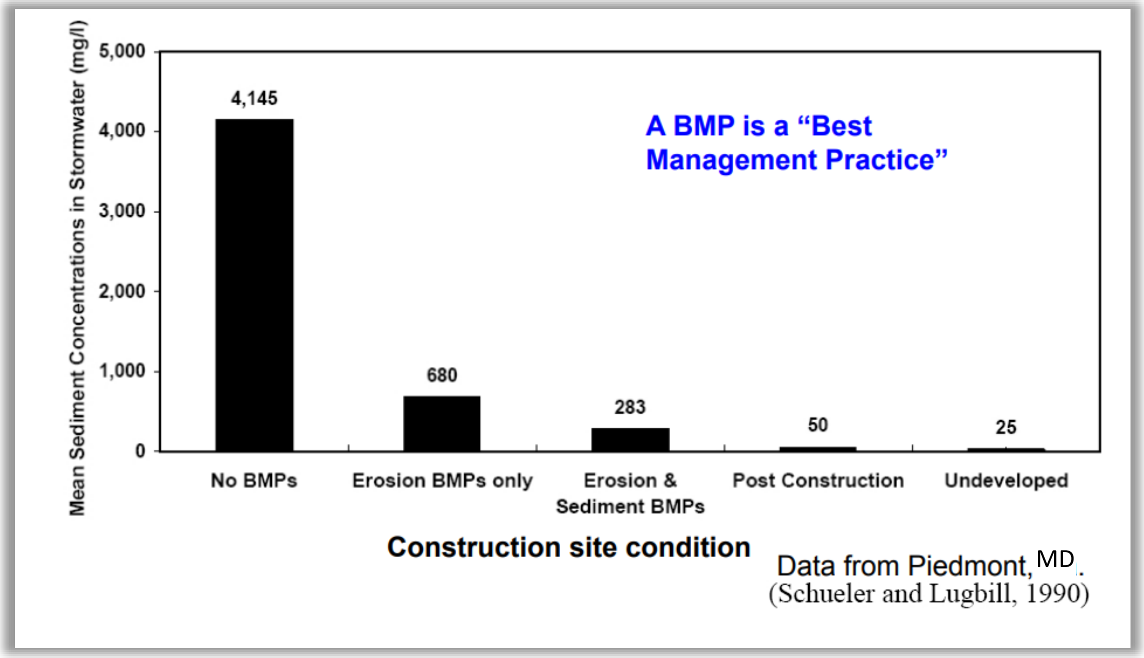
Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Construction Inspection Program

Construction stormwater site inspectors should also focus on proper maintenance of construction BMPs installed at construction sites within the watershed to ensure that construction site erosion is not contributing sediment and nutrients to the City's stormwater drainage system (and eventually ending up in the lake). If not properly controlled, construction site erosion can be the greatest source of nutrients in urban watersheds (Figure 24, Schueler and Lugbill 1990). The portion of the Aurora Corridor within the watershed will likely see continued development in the coming years and decades.

Figure 24. Effect of Erosion and Sediment Controls on Suspended Sediment Concentrations.



Data from Piedmont, MD.
(Schueler and Lugbill, 1990)

Advantages

- Reduces phosphorus loading to the lake in the long-term

Disadvantages

- Does not address immediate algae bloom issues

Suitability for Echo Lake

Illicit discharges have been documented in the watershed in the past five years sediment/soil from construction activities. Continued education, outreach, inspection, and enforcement in the lake watershed could reduce pollutants to the lake.

Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Stormwater Management

Stormwater runoff is an important pathway of nutrients collected from paved and unpaved surfaces to surface water and groundwater. The Echo Lake watershed is 58 percent impervious and most stormwater runoff from impervious surfaces flows into the City's stormwater drainage system in route to the lake, while some runoff drains to private stormwater drainage systems adjacent to the lake. Rainfall on the remaining pervious surfaces generates some runoff but primarily infiltrates and enters subsurface groundwater flow. The hydrologic budget estimated that approximately 50 percent of the annual rainfall reaches the lake through the stormwater drainage systems. Even with an extensive education and source control program, nutrients still contaminate stormwater runoff with phosphorus from construction sites, fertilized areas, domestic animals, and wildlife. Stormwater management seeks to treat or infiltrate runoff from impervious and pollutant-generating surfaces prior to discharge to lake. This can be achieved through management of the stormwater system and stormwater retrofits.

Training, Tracking, and Education of Phosphorus Treatment for New Development and Redevelopment

The City's municipal code does not currently reference the requirement for phosphorus treatment for new and redevelopment in the Echo Lake watershed, but this is addressed in the City's Engineering Development Manual (EDM) (Shoreline 2024b). The EDM states that "phosphorus treatment is required in the McAleer Creek Basin unless the site discharges downstream of Lake Ballinger." The EDM also states that "bioretention with underdrains is not permitted to be installed within one-quarter (0.25)-mile of Echo Lake unless the Ecology-approved high-performance bioretention soil mix, or other suitable mix which reduces potential for phosphorus export as approved by the Director is utilized."

Additional training and documentation to track the implementation of this phosphorus treatment requirement through the plan review process and the contribution towards the overall watershed reduction goal would be useful. The City should provide additional training for plan review staff to ensure that appropriate BMPs that provide phosphorus treatment are selected and designed for implementation for new development and redevelopment projects. Education of developers and designers through a submittal checklist/handout or Pre-Application Meeting on proper treatment system design, operation, and maintenance of selected BMPs would help to ensure the reduction of stormwater phosphorus loading to Echo Lake.

Advantages

- Ensures phosphorus treatment is incorporated into the Echo Lake watershed during future development and redevelopment projects

Disadvantages

- Does not address immediate bloom issues

Suitability for Echo Lake

Continued development is expected within the Echo Lake watershed and along the Aurora Corridor. Additional training and documentation to track the implementation of phosphorus treatment for new development and redevelopment through the plan review process and the contribution towards the overall watershed reduction goal would be useful.

Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Stormwater System Maintenance

The City's Surface Water Utility inspects and maintains the stormwater system, constructs new facilities to address drainage issues and reduce pollution, works with businesses and residents to reduce pollution, monitors the health of the City's streams and lake, and responds to flooding from storm events. Maintenance of the stormwater system includes activities such as cleaning and repairing catch basins, clearing ditches, cleaning stormwater pipes, and maintaining stormwater facilities. Current recommended maintenance frequencies for stormwater facilities in the watershed are annual (or more frequent) for the Filterra® units, which includes removing and replacing the mulch layer with double-shredded, hardwood mulch; annual (or more frequent) for the BPBs; and annual (or more frequent) for the DTS.

Advantages

- Reduces phosphorus loading to the lake in the long term
- Reduces other pollutants (e.g., metals)
- Cost effective

Disadvantages

- None.

Suitability for Echo Lake

Targeted maintenance of the stormwater system in the lake watershed could help reduce nutrient loads from stormwater.

Planning Level Costs

The City of Shoreline already conducts this work under existing programs. No additional costs are expected.

Stormwater Retrofits

Stormwater retrofits include adapting existing stormwater facilities or treatments in order to improve their performance in reducing nutrient concentrations in stormwater and/or reducing peak flows. Stormwater treatment can be done through built and natural infrastructure, such as filtering stormwater through phosphorus adsorbing media.

Existing stormwater system and stormwater treatment facilities in the Echo Lake drainage basin are shown in Figure 4 and are summarized in Table 2 in the *Watershed Characteristics* section of the Background chapter. In 2015 to 2017, King County (2017) monitored treatment performance of four bioretention planter boxes (BPBs), the DTS, and one Filterra® system. These systems and monitoring results are presented in Table 23. Three of the BPBs frequently exported phosphorus and the DTS showed no significant difference between the inlet and outlet TP concentrations. The one Filterra® system that was monitored during five storm events had a 30 to 60 percent reduction in TP concentrations. Filter media has not been replaced in any of the BRBs or Filterra® systems since they were installed 9–13 years ago. The lifecycle of the Filterra® media is estimated to be 10–15 years, but only the top 3 inches of media needs to be replaced at that time. The lifespan of bioretention soil mix (BSM) is unknown, but BSM should be swapped out if there are any observed issues with reduced flow rates or clogging. Similar to the Filterra® system, only the top 3 inches of media may need to be replaced instead of the full BSM depth.

Table 23. Stormwater Treatment Facilities Monitored in the Echo Lake Drainage Basin.

AssetID in GIS	BMP Sampling Location Name(s)	Installation Date	Drainage Area Treated	Monitoring Results (King County 2017)	Stormwater Treatment Design Notes
BR-20	BPB1	2011	1.02 acres total for all BPBs (each BPB treats 0.05–0.13 acres)	Frequent increases in TP concentrations	Currently uses standard BSM which has been shown to export phosphorus
BR-13	BPB2			NA	
BR-10	BPB3			NA	
BR-105	BPB4	2015		Limited sampling at this site	
AU01	FLT1	2011	1.86 acres for all FLT (each FLT treats 0.05–0.23 acres)	30–60% reduction in TP concentrations	Filterra has a GULD for Basic, Enhanced (Metals), Phosphorus, and Oil Treatment
MC12	DTS	2015	125 acres	No significant difference between inlet and outlet TP concentrations	The DTS is not designed to provide phosphorus treatment
11001	Sky Nursery StormFilter Vault	Unknown	Unknown	NA	Currently includes three 18” StormFilter ZPG cartridges that are GULD approved for Basic Treatment, but not Phosphorus Treatment

BPB: bioretention planter box | BR: bioretention | BSM: bioretention soil mix | DTS: detention tank system | FLT: Filterra® system | GULD: General Use Level Designation | TP: Total phosphorus

These existing stormwater treatment systems could be modified or upgraded to provide phosphorus treatment for reducing total phosphorus concentrations by at least 50 percent. Recommendations for the BPB systems include replacing existing BSM with high-performance bioretention soil mix (HPBSM) and a polishing layer, which is designed to remove phosphorus. The Filterra® units could be refreshed by replacing the mulch (recommended annually). Replacement of the top 3 inches of Filterra® media is recommended after 10–15 years only if standing water is observed in the units. The recommended maintenance interval for the StormFilter® is annual and includes removing accumulated sediment from the vault and replacing spent cartridges with recharged cartridges. If clogging and reduced flow rates are observed in the StormFilter®, the maintenance frequency should be adjusted to once every 6 months, or more frequent.

Advantages

- Reduces phosphorus loading to the lake in the long term
- Reduces other pollutants (e.g., metals)

Disadvantages

- Expensive, low cost-effectiveness
- Does not address immediate bloom issues

Suitability for Echo Lake

The Echo Lake watershed is 40 percent residential development and 30 percent commercial use, with a high proportion of impervious surfaces from a combination of roadways, rooftops, and driveways. Even with an extensive education and source control program, phosphorus can make its way into stormwater and therefore treatment would be beneficial. There are many existing stormwater facilities in the watershed that could be retrofit to provide phosphorus treatment.

Planning Level Costs

Stormwater management costs for recommended retrofits are outlined in the *Watershed Phosphorus Management* section below.

Methods Rejected

We rejected several cyanobacteria management methods for Echo Lake due to high cost, low effectiveness, and/or low certainty of success. Rejected methods are described in the sections below and rationale for rejection is summarized in Table 24.

In-Lake Methods

Whole-Lake Mixing

Artificial circulation and mechanical mixers have been successfully used in lakes and reservoirs as physical controls to increase oxygen concentrations in bottom waters and to destratify the water column to remove the optimal habitat for buoyant cyanobacteria. The key objective of lake aeration or mixing technologies is that the circulating or mixing motion of the water is also circulating and mixing algae cells. Most bloom-forming cyanobacteria can regulate their buoyancy to optimize their position in the water column and float to the surface. Mixing promotes growth of preferred algae such as green algae and diatoms because under natural conditions their time in the sunlit photic zone is determined by their sinking rate, so mixing increases their time in the photic zone. Cyanobacteria have air vacuoles that provide buoyancy and allow them to remain within the photic zone for longer periods of time. Aeration or mixing reduces this advantage, although to do so requires that mixing velocities need to be high enough to overcome cyanobacteria buoyancy, which can vary and be difficult to predict.

Table 24. Rejected Cyanobacteria Management Methods for Echo Lake.

Method Type	Management Method	Rationale for Rejection
Lake Physical Methods	Whole-Lake Mixing	Uncertain effectiveness
	Surface Mixing (SolarBees)	Uncertain effectiveness
	Sonification	Uncertain effectiveness
	Lake Dilution	High cost
	Ozone/Microbubble/Nanobubbles	Not effective
	Dredging	Very expensive, difficult to permit
	Shading (Dyes)	Not feasible
	Improve outlet conveyance capacity	Not effective
Lake Chemical Methods	Iron Treatment	Not effective with anoxic hypolimnion
	Calcium Treatment	Not effective with low hardness
Lake Biological Methods	Biomanipulation	Potential for unintended ecological consequences. Low effectiveness.
	Macrophyte Planting	Low effectiveness.
	Barley Straw	Low confidence in success.
Watershed Methods (External)	Stream Phosphorus Inactivation	No streams, stormwater treatment preferred

While cyanobacteria concentrations may be reduced, total algal biomass and chlorophyll-a concentrations may increase and green the water from the decreased settling rates. Whole-lake mixing by aeration disrupts the thermocline and increases nutrient availability by mixing deep waters to the surface. These technologies also introduce oxygen either passively through increased mixing and turbulence of surface waters or more actively through pumping air through the water. These changes in algal community populations and oxygen levels result in other changes in the lake food web.

The two most common types of destratification are air injection and mechanical mixing (Hudson and Kirschner 1997). Air injection is a “bottom-up” approach that quickly pumps air to the bottom of the lake so that it will rise and carry the water from the hypolimnetic layers to the top layer. Mechanical mixing uses a “top-down” approach wherein a rotating propeller in the surface layers pushes the water downward, displacing bottom waters to the surface, where they are reoxygenated by the atmosphere. Popular commercially available models are powered by solar panels. Although artificial circulation is beneficial for oxygen and nutrient redistribution, the ecological effects on plant and animal life of destratifying a lake are not always predictable and could potentially be harmful (Hudson and Kirschner 1997).

Advantages

- Permanent control by both mixing and oxygenation
- Depending upon design may also target sediment derived phosphorus
- Many lake applications for case studies for whole-lake mixing

Disadvantages

- Resuspension of sediment layer nutrients in the water column
- Sedimentation of organic matter
- Installation and operational cost
- Ineffective in shallow lakes/ reservoirs with a large surface area
- May require continuous operation
- Can be ineffective when external nutrients are not controlled
- These need to be carefully designed and engineered. Poorly sized or designed applications can worsen problems.
- Larger mixing systems require shore based electrical supply and long, air supply line.

Suitability for Echo Lake

Whole-lake mixing is not recommended for Echo Lake because of its high uncertainty in its ability control the internal phosphorus load.

Surface Mixing (SolarBees)

The SolarBee is a solar-energy–driven, mixing device that is used to mix either the epilimnion or the entire lake volume. Like other mixing devices it controls algae through mixing them throughout the water column (Hudnell et al. 2010). Although no air is pumped into the water, additional oxygen is added through turbulence and increased contact with air above the lake surface. Surface mixing is theorized to combat cyanobacteria dominance by (1) increasing contact with cyanobacteria pathogens, predators, and bacteria that lyse cyanobacteria; (2) promoting competitor algae; and (3) interfering with the advantages of buoyancy-regulating cyanobacteria (Hudnell et al. 2010).

There are no significant design costs or issues associated with these; they are modular units that are easily scalable depending upon lake surface area. While SolarBees appear to primarily be used in small lakes and ponds, there have been successful applications in larger lakes, reservoirs and drinking water supplies.

Advantages

- SolarBees have no long-term energy costs because they are solar-powered
- Can sink algae to below the photic zone, decreasing productivity
- Mixing systems can mix either epilimnion or entire water column
- Can give advantage to diatoms and other beneficial algae that can't control their buoyancy
- Easily scalable modular units
- Low/no design costs

Disadvantages

- Epilimnetic mixing does not address sediment-derived phosphorus
- Few case studies for epilimnion mixing
- Can increase algae biomass and decrease water clarity by reducing settling rate of non-buoyant algae
- Often insufficient oxidation of sediments to reduce sediment phosphorus release

Suitability for Echo Lake

Surface mixing with a SolarBee unit is not expected be an effective tool to manage cyanobacteria in Echo Lake.

Sonification

Sonication treatment implements high frequency (>20 Khz) ultrasound for the control of cyanobacterial blooms. The ultrasonic waves act as a barrier to upward movement of algal cells into the photic zone. The waves also reduce cyanobacterial growth by causing structural and functional cellular damage. The LG Sonic system continuously monitors cyanobacteria pigments and water quality parameters to systematically transmit ultrasonic waves when conditions warrant. There are few well-studied implementations of sonication systems and reports are largely anecdotal with highly variable results. In a recent review, Luring and Mucci (2020) concluded that low-frequency ultrasound should be avoided, as it is ineffective; high-frequency treatment is more effective, but it is costly due to energy demand, and its effective range is limited.

Advantages

- Permanent control.
- Some devices provide real-time data on lake quality

Disadvantages

- Few lake case studies to confirm effectiveness. Results have been variable
- May cause cell lysis, and increase extracellular cyanotoxin levels
- Benthic blooms may still occur
- Limited by the effective treatment radius
- Requires a permanent contract for monitoring

Suitability for Echo Lake

Sonification treatment in Echo Lake is not recommended due to the low certainty of success.

Ozone, Microbubbles, and Nanobubbles

Ozone is a strong oxidant that is majorly employed in water treatment for pre-oxidation to control natural organic matter to minimize the formation of disinfection by-products. Studies have shown its ability to damage cyanobacteria cells (Coral et al., 2013; Fan et al., 2013; Wert and Rosario-Ortiz 2013) while simultaneously oxidizing cyanotoxins and taste and odor compounds (Meriluoto et al., 2017; Wert et al., 2014). Ozone application for managing blooms at the source may be promising but is limited by structural and safety requirements that make for a complex application. Furthermore, the efficiency of aqueous ozone oxidation is restricted by rapid decay rates.

Microbubbles (diameter 10–50 µm) and nanobubbles (<200 nm) have attracted increasing scientific attention in recent years. Due to their small diameters, these tiny bubbles have low rising velocities in the aqueous phase, high internal pressures, and rapid mass transfer rates that can significantly improve gas solubility (Atkinson et al., 2019; Hu and Xia, 2018; Li et al., 2014).

Nanobubble aeration uses compressed gas (e.g., air, ozone, carbon dioxide) to produce nanobubbles (bubbles 2,000 times smaller than a grain of salt) to aerate the water column. The key advantage of using nanobubbles versus traditional aeration technologies is that the very small bubbles move both vertically and horizontally, spreading out evenly and remaining in the water column for long periods of time (versus floating to the surface and dispersing), and therefore this technology greatly increases oxygen transfer. Another advantage is that the bubbles are too small to cause water currents and disrupt a stable thermocline. Bubbles are typically injected near the sediment surface, thus reducing phosphorus release from the sediments without physically disturbing the sediments, which can occur from traditional aeration systems. The high oxygen transfer rate and resultant oxidation (through creation of ozone and other oxidative compounds) has been shown to break down algae cells and degrade toxins.

Advantages

- Very small bubbles spread out evenly and remain in the water column for long periods of time (versus floating to the surface and mixing water column)
- Greatly increases oxygen transfer and benefits aquatic life uses
- Reduces phosphorus release from sediments
- Breaks down algae cells and degrades toxins
- Easily scalable modular units
- Low/no design costs

Disadvantages

- Requires supply of compressed gas (e.g., air, ozone, carbon dioxide)
- Few case studies to evaluate effectiveness and duration of treatments with some recent reports of ineffective systems
- New technology with many companies, specifications and costs vary

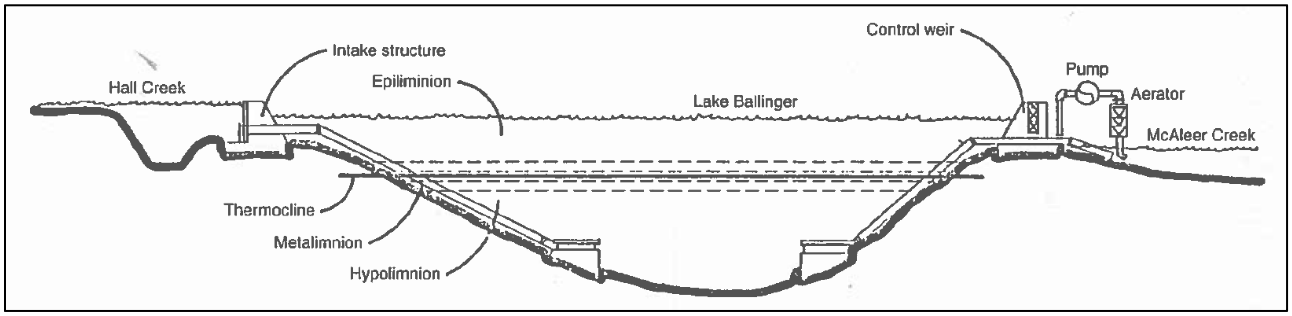
Suitability for Echo Lake

Ozone, microbubbles, or nanobubble are not recommended for Echo Lake due to the limited information on effectiveness and the initial investment cost.

Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves using a specialized pump system or deepwater dam intake to withdraw water from the hypolimnion and release it into the surrounding watershed. By removing nutrient-rich water from the hypolimnion, hypolimnetic withdrawal can reduce the amount of phosphorus available to support algal growth in the lake. To be effective and to avoid disrupting the natural balance of the lake ecosystem, hypolimnetic withdrawal must be carefully designed and managed. The process should be timed to coincide with the natural stratification and mixing patterns of the lake. The rate of withdrawal should be adjusted to minimize the risk of causing sudden changes in temperature or water chemistry. As a control strategy, hypolimnetic withdrawal from stratified systems is most effective in systems where internal nutrient loads are the primary cause of the algal blooms and external nutrient loads are declining or low. A recognized disadvantage of hypolimnetic withdrawal is its impact on downstream waters, including eutrophication, temperature increase, oxygen depletion, and odor development (Nurnberg 2009).

A local example of a hypolimnetic withdrawal system is Lake Ballinger, just downstream of Echo Lake. In 1982, inflowing Hall Creek waters were injected into the hypolimnion. The hypolimnion was pumped from an intake structure on the lake bottom and discharged to the lake outlet on McAleer Creek (Cooke et al. 2005). The system substantially reduced hypolimnetic phosphorus concentrations (from 400–900 to 100–150 µg/L) and internal loading (70 percent reduction) during the first 3 years of operation. However, the lake was treated with alum in 1993 due to increasing external loading from development and intermittent system operation. Operations were curtailed because of odors from the discharge and high iron bacteria growth in McAleer Creek. Ecology ordered termination of system discharge in 2008 due to water quality impacts to McAleer Creek. They would require treatment of the discharge prior to future operation. Installation of the Lake Ballinger system cost $420,000 in 2002 dollars (Cooke et al. 2005).



Advantages

- No waste or by-products generated
- Readily available equipment
- Reported water quality and ecological benefits
- Minimal aesthetic impact to the lake

Disadvantages

- Can be disruptive to the lake ecosystem, particularly if withdrawal rates are too high or the process is not carefully managed; can cause the lake to destratify (mix upper warm and lower cold layers) and lead to changes in water chemistry, temperature, and oxygen levels that can harm fish and other aquatic life
- Infrastructure needs (electricity, piping), if no deep-water outlets are in the water body
- Potential downstream discharge issues, including water quality, smell, fueling downstream blooms, and delivery of algae blooms and cyanotoxins during flushing events
- Likely to require an NPDES permit and end-of-pipe treatment for discharge to downstream receiving waters
- Costly installation, maintenance, and monitoring of infrastructure or pumps; difficulty permitting

Suitability for Echo Lake

A hypolimnetic withdrawal system is not feasible for Echo Lake. There are not adequate summertime surface water flows in the watershed to offset the loss of water by pumping out the hypolimnion. Other sources of water, like pumping groundwater or using drinking water, would be prohibitively expensive. Furthermore, a discharge treatment system would be needed to discharge hypolimnetic water to Ballinger Lake.

Iron Treatment

Iron treatment is a relatively inexpensive control strategy (Matthijs et al., 2016) added to aquatic systems within the water column or sediment surface in the form of chloride and sulfate salts, such as $FeCl_3$, $FeCl_2$, and $Fe(SO_4)_3$, or as zero valent iron (ZVI). Iron used to coagulate dissolved phosphorus is sensitive to potential redox changes, in that ferric iron (Fe^{3+}) freely precipitates phosphorus in oxygenated conditions. In anoxic conditions, however, ferric iron is reduced to ferrous iron (Fe^{2+}), and the binding capacity with orthophosphate declines. This results in release into the aqueous phase. As a result, iron applications are often done in combination with hypolimnetic oxygenation methods.

ZVI is a form of iron typically used in soil and groundwater remediation efforts to bind chemical contaminants by transferring an electron to a contaminant compound. Contaminants in groundwater that have been inactivated by ZVI include petroleum hydrocarbons, pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and nitrates.

ZVI has also been added experimentally to rural wastewater treatment systems where sewage strength was low. In these systems, ZVI additions helped enrich bacteria biofilms and prevent blooms of filamentous cyanobacteria, even under conditions without additional aeration treatments (Wang and Li 2022). However, primary sewage treatment requires at least basic oxygenation. This suggests that ZVI is ineffective under anoxic conditions. ZVI could become effective, if applied in combination with hypolimnetic oxygenation methods, or if ZVI was applied as a modified clay composite like bentonite (Sarkar et al. 2019). Lake Lorene in Federal Way, Washington, is frequently treated with algaecide followed by ZVI applications to inactivate soluble phosphorus released by dead algae.

Under the Aquatic Plant and Algae Management General Permit, a jar test must be completed prior to treatment to identify proper dosing levels.

Advantages

- Removes soluble reactive phosphorus from water column and from shallow sediments in the epilimnion (and deep sediments if hypolimnion remains oxygenated)
- Not expected to have environmental impacts at anticipated dosage

Disadvantages

- Phosphorus bound to iron in lakes and reservoirs can be resuspended due to dissolution in anoxic conditions
- Limited effectiveness when watershed load is dominant

Suitability for Echo Lake

Echo Lake's hypolimnion becomes anoxic during the summer. The application of iron to sequester water column phosphorus is therefore not expected to be effective, because much of the phosphorus bound to iron would settle to the hypolimnion and be released during the summertime anoxic period. Furthermore, iron-bound phosphorus can release from shallow sediments. This occurs due to high pH caused by algae blooms, or due to anoxic conditions developing immediately below the sediment surface. Such anoxic conditions develop by microbial decomposition of high organic matter content or under dense aquatic plant canopies. Additionally, there are relatively minor amounts of dissolved phosphorus in the water column, meaning that the applied iron would only remove a minor fraction of the phosphorus in the water column.

The Aquatic Pesticide and Algae Management Permit issued by the Washington Statement Department of Ecology specifically states, regarding iron:

> *Do not apply where anoxic conditions (zero percent dissolved oxygen) may occur, including anoxic conditions created by applications of herbicide and algaecide.*

Potentially, if a hypolimnetic oxygenation strategy is also employed, iron application could be a useful tool to increase binding sites for phosphorus in the sediments and to strip bioavailable phosphorus from the water column. Such a treatment would not be suitable until a hypolimnetic oxygenation system is in operation, as noted above.

Assuming there is approximately 60 µg/L of soluble phosphorus to remove from the water column, a ZVI stripping dose would cost approximately $105,017 (Table 25). The material cost ($3,345) is notably lower than other phosphorus inactivation projects and may be a cost-effective tool for water column stripping and sediment inactivation following hypolimnetic oxygenation.

Table 25. Zero-Valent Iron Application Dose and Cost Estimate for Water Column Stripping.

Assumption	Value
ZVI to P Adsorption Ratio (125 µm ZVI) (mass-based)	44 ZVI : 1 P
Available P Mass in Water Column (assume 30.3 ppb)	63 kg
ZVI Dose	2,764 kg
ZVI Cost ($1.21 per kg)	$3,345
Shipping Fee	$1,672
Permitting, Monitoring, and Planning Cost	$50,000
Applicator Fee	$50,000
Total Cost	**$105,017**

Similar to other in-lake management actions, accessing the lake with the necessary equipment (e.g., a boat) to the lake may pose a challenge due to no road access or boat launch on the lake.

Calcium Treatment

Calcium is applied to lakes in the form of lime (CaO, $CaCO_3$, $Ca(OH)_2$) or calcite ($CaCO_3$). Lime addition mimics natural calcite ($CaCO_3$) precipitation in hard water lakes that strips phosphorus from the water column. CaO and $Ca(OH)_2$ addition in water increases aqueous pH and facilitates the formation of $CaCO_3$. Direct addition of $CaCO_3$ is deemed beneficial, since it precipitates and then reacts with dissolved orthophosphate in the water column. Calcium applications are generally not effective in soft water lakes present in western Washington. There is so little background calcium that the applied amount is not sufficient to precipitate phosphorus as was demonstrated in Lake Steilacoom (Herrera 2009).

Under the Aquatic Plant and Algae Management General Permit, a jar test must be completed prior to treatment to identify proper dosing levels. This jar test needs to be conducted at least over a 24-hour period to ensure that the pH response is at equilibrium with water chemistry. Furthermore, monitoring under S6.B of the permit is required. This includes:

1. The Permittee must measure pH once on the day before treatment, once in the morning prior to treatment and once in the afternoon after treatment has stopped for the day, for the duration of the treatment and for 24 hours following treatment. If the pH is above 9.0 due to the effects of the treatment (rather than through photosynthesis), the Permittee must stop treatment.
2. For continuous injection systems, the Permittee must measure pH at a minimum once every 2 weeks during the first month of continuous injection and thereafter once a month for the duration of the injection process. The Permittee must ensure that pH measurements represent waterbody-wide conditions, unless the injection system is in an isolated area in relation to the main waterbody (e.g., in a bay with a narrow channel to the main waterbody). For isolated areas of waterbodies, the Permittee must measure pH at the end of the bay and in the main waterbody.

Advantages

- Short-term removal of available phosphorus from water column

Disadvantages

- Possible limitation to provide only short-term improvements due to the redissolution of precipitating CaCO3 as it settles in deep waters
- Potential to cause high pH in the water column
- Limited effectiveness in soft water lakes
- Limited effectiveness when watershed load is dominant

Suitability for Echo Lake

While calcium treatments would likely provide limited short-term improvements in Echo Lake, alternative phosphorus inactivation treatments are more effective due to the lake's soft water and low calcium content. Similar to other in-lake management actions, accessing the lake with the necessary equipment (e.g., a boat) to the lake may pose a challenge due to no road access or boat launch on the lake.

Dredging

Dredging is a technique that can be used to control phosphorus levels in lakes. The process involves removing sediment and organic material from the bottom of the lake, which can contain significant amounts of phosphorus that have accumulated over time. By removing this material, the amount of phosphorus in the lake can be reduced, which can help to prevent the growth of harmful algal blooms and promote better water quality.

Dredging can be a complex and costly process that requires specialized equipment and expertise. The process typically involves the use of a dredge, which is a machine that is designed to scoop up sediment and other material from the bottom of the lake. The material is then transported to a disposal site, where it can be treated or stored for later use. Dredging is very expensive primarily due to costs associated with dewatering and disposal of the material. Alum may be used to settle suspended sediment and associated phosphorus suspended by dredging and to inactivate phosphorus in remaining sediments.

Advantages

- Removal of sediment as a phosphorus source
- Increased lake depth, causing reduced aquatic weed entanglement risk and improving recreational uses

Disadvantages

- Difficulty to permit
- Prohibitive expense ($ millions)
- Impacts to aquatic life
- Temporary increased turbidity
- Temporary public use disturbance

Suitability for Echo Lake

Dredging is not suitable for Echo Lake due to its high cost.

Biomanipulation

This method involves increasing the pressure on phytoplankton communities by reducing or removing planktivorous fish (Shapiro, 1990; Shapiro and Wright, 1984) or by increasing grazers and zooplankton populations (Ger et al., 2014; Kâ et al., 2012). By increasing pressure on phytoplankton, the goal is to reduce their populations through increased consumption by other feeders. Biomanipulation can also involve removal of common carp or other benthivorous fish to reduce phosphorus loading from sediment disturbance and fish excretion. Removal of zooplanktivorous and benthivorous fish and the addition of piscivores are the most frequently applied biomanipulation methods.

Some species of cyanobacteria are more resistant to grazing pressures from zooplankton. Cell/colony/filament size, toxicity, and poor nutritional value are defense mechanisms against grazing (Moustaka-Gouni and Sommer 2020). Grazers may fail to feed if cyanobacterial species, especially filamentous species, can surpass the optimal size range for food based on grazer body size.

Advantages

- Potential for long-term benefits
- No chemical residuals

Disadvantages

- Uncertainty of success
- Does not address nutrient issues
- May remove desirable fish species (e.g., trout)

Suitability for Echo Lake

Biomanipulation is not recommended for Echo Lake because of the uncertainty of success.

Macrophytes

Submerged macrophytes can control cyanobacteria through three main processes: (1) macrophytes compete with phytoplankton for nutrients, taking up nutrients from the sediments, and can prevent resuspension of sediments during rainfall and wind events; (2) macrophyte coverage provides habitat for zooplankton grazers of cyanobacteria; and (3) some macrophytes secrete allelochemicals that are inhibitory to phytoplankton.

Advantages

- Potential for long-term benefits
- No chemical residuals
- Increased fish habitat

Disadvantages

- Uncertainty in ideal macrophyte coverage
- Relatively minor nutrient control
- Does not address external nutrient loads
- Macrophytes may not be desired by shoreline homeowners

Suitability for Echo Lake

Macrophytes are not a suitable technique to manage cyanobacteria blooms in Echo Lake. The steep sloping characteristic of the lake provide a very limited area for macrophyte growth. Ongoing surveillance and management of noxious aquatic plants is recommended.

Straw

Applying straws such as barley and rice straws in lake systems is considered an alternative cyanobacterial control strategy. The mode of action of barley straws for cyanobacteria control is not entirely understood and has been a subject of much debate. However, various researchers have indicated that the release of allelopathic compounds during the aerobic decay of straws is a potential mechanism for controlling algae. Barley straws do not provide immediate improvements in water quality. The decomposition of straws may create an oxygen demand in the water column. Therefore, successful application may require oxygen-rich systems as low oxygen levels can slow or hinder the straws from releasing algal inhibitory substances.

Advantages

- No chemical residuals
- Rotting straw may provide habitat for invertebrates
- Low cost

Disadvantages

- Do not provide immediate relief
- Inhibitory action is not understood
- May reduce lake oxygen levels due to decomposition
- May be a visual or boating nuisance
- Does not address nutrient issues

Suitability for Echo Lake

The use of straws is not recommended for Echo Lake due to the low certainty in success.

Watershed Management Methods

Stream Phosphorus Inactivation

Phosphorus inactivation products can be applied at the mouth of streams or stormwater outfalls entering a lake to inactivate phosphorus prior to it becoming available for lake algae. Systems that pump aluminum-based inactivating compounds into an inflow pipe, ditch, or stream have become more widespread (Pilgrim and Brezonik 2005, Wagner et al. 2017). In some cases, a retention pond is provided to capture aluminum floc before it enters the lake, whereas in others the floc is allowed to enter the lake and settle onto target sediments where further P inactivation can occur. Due to high installation and operating costs, alum injection is most effective for large volumes of water that a system either conveys from a large drainage area or stores in a large basin (EPA 2021).

An alum injection system could be designed for lake inlet(s) that injects low doses of alum through tubing from onshore storage tanks to an aeration or circulator system mounted in the stream bed for through mixing of the alum with stream waters. A flow-weighted dosing system would be used that adjusts the dose with stream flow and may be integrated with a water quality monitoring system to measure pH or other parameters to terminate treatment exceeded programmed thresholds. A buffer such as sodium hydroxide or aluminate can be added but is not likely needed for low doses, mixed systems, and pH feedback mechanisms.

Alternatively, lanthanum-modified clay or zero valent iron can be used to inactivate stream phosphorus in lake inlet(s). Porous bags can be filled with either product and placed in the bottom of the stream channel and may require installation of a hard substrate to prevent them from sinking in soft stream sediment. The bags are turned on one occasion before they are replaced when they are expected to become ineffective based on the phosphorus loading rate relative to the amount of inactivation product.

Advantages

- Reduces phosphorus loading to the lake long-term

Disadvantages

- Alum could impact aquatic biota from aluminum toxicity if the pH is outside 6.5–8.5.
- Ecology may not permit alum injection in a stream without containment and removal of the alum floc
- Requires routine O&M and has an annual operating cost

Suitability for Echo Lake

Stream phosphorus inactivation with an alum injection system is not suitable for Echo Lake because placement and operation at the lake inlet would be difficult, presents a risk for aluminum toxicity to aquatic organisms under extreme pH conditions (less than 6 or greater than 8.5), and may not be allowed by Ecology without a floc retention system. Stream phosphorus inactivation with filter bags of lanthanum-modified clay or zero valent iron is not suitable for Echo Lake because the bag replacement would be labor intensive and difficult to predict. Use of state-approved Phosphorus Treatment of stormwater is more feasible and preferred over stormwater phosphorus inactivation.

Recommended Cyanobacteria Management Plan

This chapter describes the recommended management approach for controlling cyanobacteria in Echo Lake. These are recommendations by Herrera that need to be further evaluated by the City and considered against other priority watersheds and available funds. We recommend an adaptive management approach that provides long-term cyanobacteria bloom prevention through internal load reduction and watershed phosphorus control. We recommend OST for internal phosphorus control and a combination of source control and stormwater treatment for watershed phosphorus control. Ongoing monitoring should be used to monitor achievement of water quality objectives and to inform adjustments to management techniques.

LCMP recommendations are summarized in Table 26 and described separately below for in-lake phosphorus management and watershed phosphorus management. The total cost of LCMP implementation is estimated at $765 thousand for the first 3 years (in 2024 dollars) and $3.2 million to 5.8 million for the following 20 years (including 3.5 percent/year inflation).

In-Lake Phosphorus Management

Sediment release is the primary source of phosphorus to cyanobacteria in the lake. While controlling watershed inputs is critical to preventing accumulation of additional phosphorus in the sediments, managing the existing reservoir of phosphorus in the lake is recommended to manage phosphorus and algae abundance in the lake. For long-term management, we recommend three alternatives:

1. Installation of a hypolimnetic oxygenation system, specifically an oxygen saturation technology (OST) system, to oxygenate the deep waters of the lake, reduce internal phosphorus loading, improve fish habitat, and reduce phosphorus export to Lake Ballinger.
2. Annual phosphorus water column stripping with a low dose of either unbuffered alum or EutroSorb G (lanthanum).
3. Phosphorus sediment inactivation with high doses of either buffered alum every 5 to 10 years or EutroSorb G (lanthanum) every 2 to 5 years.

These alternatives are compared in Table 214.

Table 26. Recommended Cyanobacteria Plan Implementation Cost Summary.

Plan Element	First Three years (2025 to 2027) Description	First Three years (2025 to 2027) Cost (2024$)	Next 20 years (2028 to 2047) Description	Next 20 years (2028 to 2047) Cost ($)
Oxygen Saturation Technology (OST)	Permit and install an OST in 2026.	$377K	Ongoing maintenance and electricity costs (base cost: $9K/year)	$0.26M[a]
Watershed Source Control Education/Outreach (Waterfowl, Septic, Shoreline, and Land Stewardship)	Leverage existing Lake Stewardship program from King County to encourage and install best management practices.	$0	Ongoing	$0
New Development and Redevelopment	Improve training, tracking, and education of phosphorus treatment for new and redevelopment.	$0	Ongoing	$0
Stormwater Retrofit Evaluation	Evaluate potential stormwater retrofit locations.	$100K	Implement high-value, multi-benefit stormwater retrofits	$0.8-3.5M
Monitoring and Reporting	Routine/supplemental lake monitoring, bloom and fecal surveillance, stormwater monitoring, sediment monitoring, and reporting (base cost: $34K/year)	$110K	Routine/supplemental lake monitoring, bloom and fecal surveillance, stormwater monitoring, sediment monitoring, and reporting (base cost: $34K/year)	$1.1M[a]
Lake Management Administration	Finance and grant tracking. Adaptive management. Coordination with consultants and contractors. Implementation of management plan (base cost: $60K/year)	$190K	Finance and grant tracking. Adaptive management. Coordination with consultants and contractors. Implementation of management plan. (base cost: $60K/year)	$1.0M[a]
	Total (first three years)	**$777K**	**Total (next 20 years)**	**$3.2-5.8M**

[a] 20-year cost assumes cost escalation of 3.5 percent each year in consideration of wage, utility, and material cost increases.

If installing the OST system, we anticipate it will take 2–3 years to design the system and obtain the necessary permits. The near- and long-term costs for sediment inactivation are dependent on the longevity of each treatment and the selected inactivation chemical. Overall, for a 23-year period from 2025 to 2047, OST is the lowest cost option at $0.6 million, followed by sediment inactivation at $1.1 to $1.9 million, and water column stripping at $3.0 million. Due to the lower costs and potential ecological benefit of increasing fish habitat, OST is the preferred option (Table 16).

An OST system functions by transporting approximately 95 percent pure oxygen from an onshore facility to an in-lake device where the water is supersaturated with oxygen. The water is then injected back into deep areas of the lake where it disperses over the sediment surface. The oxygenated water can coat and penetrate the sediments, preventing the release of phosphorus from iron-phosphate complexes and allowing the oxidized iron to bind to phosphate released by microbial decay of organic matter. The onshore facility consists of a compressor and an oxygen generator. There is no storage of oxygen on premises.

It is anticipated that attaining permits and securing funding for the OST will take several years. Environmental permits required by the State Environmental Policy Act (SEPA) and Shoreline Management Act (SMA) will be obtained through submittal of a Joint Aquatic Resources Permit Application for the following:

- Washington Department of Fish and Wildlife (WDFW) Hydraulic Project Approval (HPA)
- Washington Department of Natural Resources (DNR) Aquatic Use Authorizations for State-Owned Aquatic Land
- City of Shoreline Critical Areas Special Use Permit (for public agencies and utilities)
- City of Shoreline Building Permit for the oxygenation system on shore.

An OST system is expected to cost $165 to $205 thousand for the system and installation. Ongoing operation and maintenance are estimated at approximately $6,800 per year, with an estimated 3.5 percent escalation each year. Given this high upfront cost, we recommend pursuing funding in tandem with attaining permits. Viable funding sources are described in the *Funding Strategy* section below.

Available sediment data indicates that the amount of iron in the sediment is currently sufficient to sequester the total amount of phosphorus in the sediments. The measured iron-to-phosphorus ratio in the deep portion of Echo Lake was 15.9:1, and a ratio of at least 15:1 is expected to provide complete control in oxygenated sediments (Jensen et al. 1992). The declining effectiveness of the hypolimnetic oxygenation system at Lake Stevens, located in Snohomish County, was partially attributed to decreased availability of iron in the sediments (TetraTech 2009). The sequestration capacity of Echo Lake may diminish over the years as the reservoir of iron is used. This is of particular risk due to ongoing inputs of phosphorus from the watershed. If Echo Lake no longer meets water quality objectives, then iron salts or zero-valent iron (ZVI) may be applied in the lake to augment the iron supply for phosphorus sequestration. These materials are relatively low cost compared to alum, lanthanum, or other phosphorus inactivation chemicals. However, the hypolimnion must remain well-oxygenated because the iron-phosphorus complexes are sensitive to low-oxygen conditions.

Alternative: Phosphorus Inactivation

Alum, lanthanum, or proprietary chemicals may be applied in lakes to inactivate phosphorus in the water column and the sediments. These phosphorus inactivation methods are described, and costs are compared above in *Cyanobacteria Management Methods Considered*. Table 20 compares 20-year costs and Table 21 describes the attributes of these methods for use in Echo Lake. Alternative inactivation approaches using iron (without oxygenation) or calcium were deemed to not be suitable for Echo Lake because of the lake’s low oxygen and hardness, respectively.

Phosphorus inactivation can be conducted annually to strip phosphorus from the water column and settle it to the sediments, or larger treatments may be conducted to both remove phosphorus from the water column and inactivate phosphorus in the sediments ("sediment reset"). Figure 25 presents pictures of buffered alum treatments in Green Lake (Seattle) for sediment inactivation in 1991, 2004, and 2016.

Figure 25. Buffered Alum Treatments in 1991, 2004, and 2016 (left to right) for Sediment Phosphorus Inactivation in Green Lake, Seattle.

Water column stripping with alum often does not need a buffer because of the low dose and acidity (relative to the lake buffering capacity). Sediment inactivation with alum needs to use sodium aluminate as a buffer to the high dose of acidic alum (aluminum sulfate) in the soft waters of Echo Lake, and unit product costs are higher than just alum for a stripping treatment because sodium aluminate is much more expensive than alum. Lanthanum products (EutroSORB G or Phoslock) are neutral and do not require a buffer for either water column stripping or higher doses for sediment inactivation. Either alum or lanthanum by water column stripping or sediment inactivation would be suitable phosphorus control approaches for Echo Lake.

Over the long-term, annual water column stripping applications are expected to cost more than sediment inactivation applications every 5 to 10 years due to mobilization costs (see Table 15). The longevity of sediment inactivation treatments is dependent on the control of external loading and stability of the bonds between the inactivation chemical and sediment phosphorus. Given the relatively high amount of watershed phosphorus loading to Echo Lake, a long-term sediment inactivation treatment is predicted to last 5 years at a cost of approximately $1.5 to $1.7 million for four treatments in 20 years. This cost is greater than the 23-year cost for OST at approximately $0.6 million. Additionally, average annual costs should be lower for OST past 20 years and alum treatments do not have the fish habitat benefit of oxygenation.

Watershed Phosphorus Management

Surface inflows from the watershed are the primary source of phosphorus to Echo Lake. A key long-term pathway to preventing cyanobacteria blooms in Echo Lake is to decrease nutrient loading to the lake from its watershed. This involves both source control and stormwater management to reduce phosphorus inputs to the lake from the watershed.

Source Control

The City has implemented stormwater education and outreach programs focused on natural yard care, pet waste management, and pollution prevention for businesses and construction sites. These are described in the *Watershed Management Methods* section above. It is recommended that these activities and programs continue, including:

- Shoreline Management. The existing King County and Snohomish County Lake Stewardship programs can be leveraged to encourage lake property owners to implement shoreline management BMPs. A recommended management action is to develop the Echo Lake Healthy Shoreline Program for to promote and fund replacement of bulkheads and lawns. where feasible, with native plants to reduce nutrient inputs and cyanobacteria growth in the lake.
- Natural Yard Care and Soak It Up Rebate Programs. It is recommended the City continue educating residents in the watershed about natural yard care and providing rebates for installing rain gardens or planting native vegetation.
- Pet Waste Management. It is recommended the City continue educating residents in the watershed to properly manage pet waste to reduce nutrient and fecal bacteria inputs to the lake.
- Business Pollution Inspection Program. The City should continue inspecting and educating businesses in the watershed to reduce nutrient pollution from illicit discharges to the storm drain system and require phosphorus treatment of ongoing sources.
- Construction Inspection Program. The City should continue inspecting and educating businesses in the watershed to reduce nutrient pollution from illicit discharges to the storm drain system and require phosphorus treatment of ongoing sources.

An annual budget of $10,000 is recommended for developing and implementing the Echo Lake Healthy Shoreline Program modelled after the Snohomish County's LakeWise Health Shoreline Program. No additional costs are anticipated for continuing ongoing source control operations by the City of Shoreline.

Stormwater Management

Stormwater runoff is an important pathway of nutrients collected from paved and unpaved surfaces to surface water and groundwater. The Echo Lake watershed is highly impervious and most stormwater runoff flows into the City's stormwater drainage system. The rest of the stormwater runoff infiltrates and enters subsurface groundwater flow. Approximately 50 percent of the annual rainfall reaches the lake through the stormwater drainage system. Even with an extensive education and source control program, nutrients still contaminate stormwater runoff with phosphorus from construction sites, fertilized areas, domestic animals, and wildlife. Stormwater management methods described above in the *Watershed Management Methods* section are recommended to reduce phosphorus loading and control toxic cyanobacteria blooms in Echo Lake:

- Improve Training, Tracking, and Education of Phosphorus Treatment for New Development and Redevelopment. This LCMP has established that Echo Lake is sensitive to phosphorus inputs and the need for new development and redevelopment to install stormwater treatment systems that are specifically designed to remove phosphorus using Ecology-approved technologies. The City's EDM should continue to require Phosphorus Treatment in the Echo Lake watershed. The City should provide additional training for plan review staff to ensure that appropriate BMPs that provide phosphorus treatment are selected and designed for implementation for new development and redevelopment projects. Education of developers and designers through a submittal checklist/handout or Pre-Application Meeting on proper treatment system design, operation, and maintenance of selected BMPs would help to ensure the reduction stormwater phosphorus loading to Echo Lake.
- Stormwater System Maintenance. The City's Surface Water Utility should continue maintenance of the stormwater system including cleaning and repairing catch basins, clearing ditches, cleaning stormwater pipes, and maintaining stormwater facilities. Of particular importance is to maintain existing stormwater treatment systems by clearing debris, removing sediment, and replacing filter media with phosphorus absorbing media on a regular basis to insure they properly function as designed.
- Stormwater Retrofits. The City should evaluate, design, and construct stormwater system retrofits to reduce phosphorus concentrations in stormwater drainage to Echo Lake. Three high priority projects identified for stormwater retrofits in the basin include:
    - Detention Tank System (DTS) Phosphorus-Optimized Stormwater Treatment (POST) Retrofit
    - Bioretention Soil Mix Replacement

Each of these high priority projects and approximate planning level costs associated with each are described in the following subsections.

Detention Tank System POST Retrofit

The current detention tank system (DTS) was not designed to provide phosphorus treatment. Since a large volume of water is already routed to this location, conversion to a phosphorus treatment facility could be one of the most cost-effective stormwater treatment retrofits for this watershed.

One example of a regional stormwater treatment facility designed for phosphorus treatment is the Park Place Water Quality Facility (PPWQF) located in the Lake Whatcom Watershed. The PPWQF was redesigned to provide phosphorus treatment with a new non-proprietary media blend. The new technology was named the Phosphorus Optimized Stormwater Treatment (POST) system and consists of either a one- or two-chamber rectangular vault designed as a three-stage vertical filtration media bed. Stage 1 is a mulch prefilter, Stage 2 is a primary treatment media bed that may be planted, and Stage 3 is a polishing media bed. The stages can be stacked with all three stages on top of each other (Figure 26) or unstacked with stages located next to each other (

Figure 27).

The POST system received General Use Level Designation (GULD) approval from Ecology in 2022 (Ecology 2022b). The redesign of the Park Place Stormwater Treatment provides phosphorus treatment for approximately 168 acres of residential land use draining to Lake Whatcom. The mean total phosphorus reduction during the Technology Assessment Protocol – Ecology (TAPE) monitoring in Bellingham was 61.5 percent (Ecology 2022b). Approximate planning level costs for the redesign of the DTS are summarized in Table 27.

Figure 26. Example Cross Section of the POST System, Stacked-Stage Configuration.

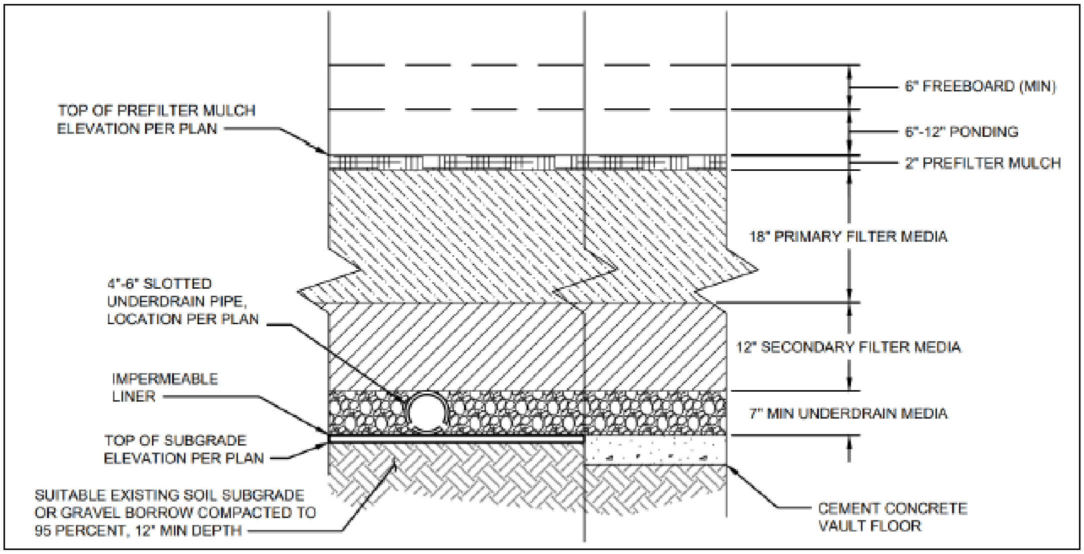


Figure 27. Example Cross Section of the POST System, Unstacked Configuration.

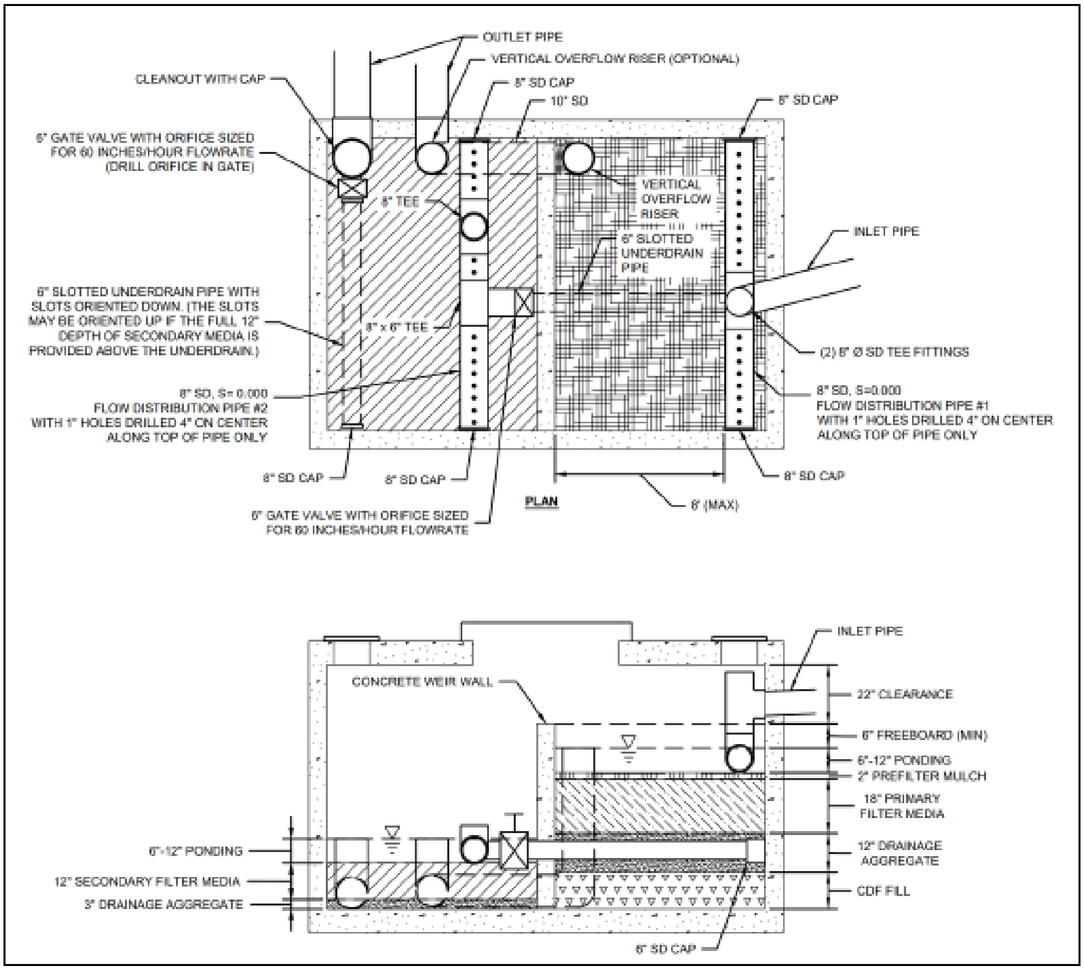


Table 27. Planning Level Cost Estimate for DTS to POST Conversion.

Cost Element	Quantity	Planning Level Cost
Planning, Design, and Permitting	20% of Construction	$400,000
Construction	--	$2,000,000
Construction Management	15% of Construction	$300,000
Subtotal		**$2,700,000**
Contingency	30% of Subtotal	$800,000
Total		**$3,500,000**

The following maintenance activities are recommended for the POST system on an annual basis (Herrera 2022b):

- Inspection of the unit housing structure and media
- Removal and disposal of trash, silt, and debris from the prefilter surface
- Removal and replacement of the prefilter mulch layer
- Raking of the media to discourage surface occlusion
- Pruning of vegetation (if present)
- Replacement of vegetation (if vegetation is dead or in poor health)
- Replacement of prefilter, primary, and/or secondary media bed to an appropriate depth if a non-stormwater liquid spill (e.g., oil or paint) has entered the system

Semi-annual inspections (every 6 months) are also recommended to determine if the prefilter mulch requires replacement. Replacement of the primary and polishing media beds is generally not required until media exhaustion. Annual maintenance costs are expected to be similar to other stormwater treatment systems, such as bioretention systems, unless replacement of the prefilter, primary, and/or secondary media bed is necessary.

Bioretention Soil Mix Replacement

A total of 11 bioretention systems were installed in the watershed in 2011 and 2015. These systems include the standard BSM, which has been shown to export phosphorus due to the large amount of compost included in the mix. Standard BSM is not recommended for use in phosphorus-sensitive watersheds within 1/4 mile of a lake.

Herrera assisted with the development of a HPBSM which is designed to meet phosphorus treatment requirements when installed in a bioretention system at an 18-inch depth underlain by a 12-inch polishing layer. The current bioretention systems installed in the Echo Lake watershed, primarily along the Aurora Corridor have a 2-foot BSM depth. Retrofit options without extensive replumbing of the conveyance system include either installing an 18-inch HPBSM layer underlain by a 6-inch polishing layer or a 12-inch HPBSM layer underlain by a 12-inch polishing layer. Another option may be to use the full 18-inch HPBSM and have a shallower (6-inch) polishing layer on top of the underdrain pipe backfill gravel but extend to the full 12-inch polishing layer in areas not directly above the underdrain pipe gravel backfill. A pre-design feasibility assessment is recommended prior to moving forward with any retrofit recommendations to ensure that the proposed media depths will be feasible and will be accepted by Ecology.

The cost of upgrading BSM to HPBSM will involve removing the existing BSM, installing the polishing layer and HPBSM, and revegetating the bioretention cells and is summarized in Table 30. The full 18-inch HPBSM and 12-inch polishing layer are included in these costs for a total of 11 bioretention systems installed in the watershed in 2011 and 2015: BR-9, BR-10, BR-11, BR-12, BR-13, BR-20, BR-21, BR-104, BR-105, BR-107, and BR-108.

The upgrade to HPBSM may not be needed if the DTS POST retrofit is pursued. Due to the high cost of the DTS POST retrofit, it may be helpful to proceed with the lower cost media replacement first, while exploring grant and financing options for the larger DTS POST retrofit.

Table 30. Planning Level Cost Estimate for Bioretention Soil Media Replacement.

Cost Element	Estimated Quantity	Unit	Unit Price	Planning Level Cost
Mobilization	10%	NA		$44,000
Excavation and disposal	700	CY	$20	$14,000
HPBSM	400	CY	$400	$160,000
Polishing layer	300	CY	$750	$225,000
Revegetation	7,000	SF	$10	$70,000
Subtotal				*$516,000*
Pre-design feasibility	1	L.S.	$40,000	$40,000
Construction Management	15%	NA		$78,000
Contingency	40%	NA		$207,000
Total				**$841,000**

In addition to the BSM replacement, the City should continue to inspect the 25 City-owned Filterra® units and replace the mulch in at least annually. Mulch should be a double-shredded, hardwood variety and should be replaced every 12 months at a minimum, or more frequently at heavy-use sites. Replacement of Filterra® media is not recommended by the manufacturer unless water is not draining through the media properly (T. Williams, personal communication, April 30, 2024). If ponding or standing water is observed in any of the Filterra® units, then the top 3 inches of media could be replaced to restore the original system flow rate (Contech 2023). Since the mulch replacement cost should be included in the City’s annual maintenance budget, it is not included in this Plan.

Other Potential Stormwater Treatment Systems

Other potential stormwater treatment retrofits in the Echo Lake watershed include coordination with private property owners to upgrade stormwater treatment systems or install new stormwater treatment retrofits within the public right-of-way. Two private bioretention systems at 19237 Aurora Ave N could also benefit from an upgrade to HPBSM similar to what is described in the Bioretention Soil Mix Replacement section. A pre-design feasibility assessment is also recommended prior to moving forward with any retrofit recommendations to ensure that the proposed media depths will be feasible.

Future Monitoring and Adaptive Management

To further the long-term water quality and lake use goals for Echo Lake, this plan includes the following adaptive lake management framework to regularly reassess and amend LCMP strategies or goals as part of ongoing, adaptive lake management, pursuant to future lake needs, stakeholder values, and funding. This section describes (1) the decision-making process and adaptation framework by which the LCMP shall be modified, (2) the current knowledge gaps and the recommended monitoring plan for continued effectiveness evaluation, and (3) potential future LCMP adaptations to begin considering.

Framework and Procedures

Adaptive management is a structured process that promotes flexible decision making; it can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. This form of management can improve clarity of key plan elements, focus decision-makers' attention on the *what*, *why*, and *how* of action implementation, and emphasizes accountability and explicitness in decision making (Williams et al. 2009). This is particularly important for resource management, which often entails multiple management objectives, constrained authorities and abilities, dynamic resource systems, and uncertainty in the responses to management actions. According to the Technical Guide for Adaptive Management Plans by the U.S. Department of the Interior (Williams et al. 2009), activities comprising this structural decision-making approach should include:

- Engaging stakeholders in the decision-making process
- Identifying the problem(s) to be addressed
- Specifying the objectives and tradeoffs that capture stakeholder values
- Characterizing assumptions about resource structures and functions
- Predicting the consequences of alternative actions
- Identifying key uncertainties
- Measuring risk tolerance for potential consequences of decisions
- Anticipating future impacts of present decisions
- Accounting for legal guidelines and constraints

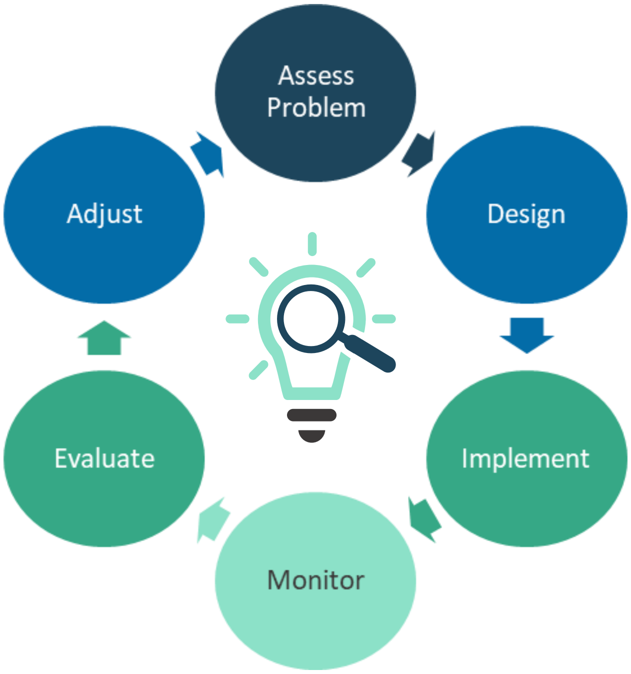
This LCMP recommends that the City form a Community Advisory Board, potentially in partnership with King County, FOEL, and ELNA, to continue informing management through a formal, science-based adaptive management program. This adaptive management program shall provide science-based recommendations and technical information to assist in the determination of if and when it is necessary or advisable to adjust the goals, objectives, management actions, and/or measures of evaluation set forth in previous versions of the LCMP. Additional LCMP adaptive management participants may include those staff members defined by the City, County, or Board, independent reviewers, and policy makers.

The following generalized procedure may be used for LCMP adaptive management and decision making (see inset graphic):

Assessing the Problem

The City, County, Community Advisory Board, and other stakeholders shall provide observations of the system function and identify issues.

Designing a Solution. The City's lake management leader, with consultation from the Community Advisory Board and King County, should establish key questions, and define and prioritize resource objectives. Lake resource objectives may consist of functional objectives, which are broad statements regarding potentially affected major functions, and performance targets, which are measurable criteria defining specific and attainable conditions and processes.



Adaptive Management Cycle. Adapted from Williams et al. (2009)

Implementation. Adaptive management proposals should be submitted to the City lake management leader by the Community Advisory Board and/or other relevant participants, or by the general public at public/board meetings. Proposals should demonstrate how future impacts will address key questions and lake resource objectives/issues. Proposal approval and prioritization will be determined by the City. Approved projects are then implemented and/or delegated at the City's discretion.

Monitoring. Monitoring is a key component of adaptive management. A basic monitoring program at Echo Lake should be conducted by trained staff and/or volunteers and should consist of the minimum elements described in the *Recommended Monitoring* section. Independent scientific review may be conducted at identified points of implementation, pursuant to study goals, City/County/Board direction, and/or funding resources.

Effectiveness Evaluation. Using monitoring data and observations, project performance and management effectiveness will be evaluated. An evaluation report should outline recommended actions, data gaps, and next steps for City, County, and Community Advisory Board review. Relevant reports or petitions for rulemaking shall be shared with the public.

Adjust. Based on the recommendations established in the evaluation report and those provided by technical advisors, and the values of the community and general public, the City is responsible for all final decisions regarding LCMP adaptations/adjustments.

Lake Management Objectives

We acknowledge there is inherent uncertainty to the success of the recommended management actions. Therefore, it is critical to set measurable objectives, maintain monitoring of those objectives, and adjust the management plan if those objectives are not being met.

For each recommended management activity, we recommend the following measurable objectives and adaptive management actions for when objectives are not met (Table 28):

Table 28. Measurable Echo Lake Management Objectives.

Activity	Objective	Potential Adaptive Management Action
Hypolimnetic Oxygenation	Hypolimnetic oxygen levels are at least 4 mg/L through the summer. Internal loads via hypolimnetic phosphorus release are reduced by maintaining a summertime average total phosphorus concentration of less than 24 µg/L.	Work with manufacturer to adjust equipment to meet target oxygen levels. If ongoing internal loading is observed, evaluate alternative sediment phosphorus sequestration options, such as iron supplementation.
Alternative - Sediment Phosphorus Inactivation	Reduce summertime phosphorus available for algae to average concentrations less than 24 µg/L in the water column.	Continue lake monitoring to track effectiveness of inactivation. Adjust dosage or chemical used.
Beach Cyanotoxin Monitoring	Cyanotoxin samples are collected when a bloom is present and additional samples are collected following state protocol. Warning signs should be posted when there is an exceedance of state recreational and removed after two weeks without an exceedance. Beach closures should occur no more than twice in a five-year period, lasting no longer than three weeks.	If weekly samples are not collected or immediate public notification of exceedances is not completed, audit program to understand challenges. If beach closure objective is not achieved, re-evaluate cause(s) of cyanobacteria blooms in consideration of changes in internal and external loads resulting from management actions.
Stormwater Management	Reduce stormwater phosphorus loading to Echo Lake by at least 25 percent (i.e., <47 kg/year.	Evaluate effectiveness of retrofit projects. Secure additional funding for future retrofits if needed.

Data Gaps

Key data gaps identified for the continued characterization of water quality in Echo Lake, can be considered to inform cyanobacteria and adaptive lake management, include:

- Regular lake water quality measurements (physical, chemical, biological) during the winter months (November–April)
- Measurements of orthophosphate, ammonia, and nitrate + nitrite at the lake surface and bottom, more frequently than twice per year (e.g., increase to monthly in summer)
- Regular (e.g., weekly May–October) cyanotoxin testing and/or phytoplankton analysis to capture community dynamics between reported blooms. Testing is currently conducted only when volunteers report a visible algae bloom.

- Phytoplankton and zooplankton taxonomic composition and biomass data.
- Long-term comparative analysis of cyanotoxin concentrations and phytoplankton (cyanobacteria) compositions.
- Year-round lake inflow water quality monitoring, including but not limited to discharge and total phosphorus at the lake inlet and selected stormwater outfalls to the lake that have not been monitored.
- Regular assessments (e.g., twice annually) of groundwater flow and nutrient concentrations.

Recommended Monitoring

No matter the management objectives or management strategy employed, ongoing monitoring is necessary to evaluate success and allow adaptive management. The adaptive management approach for Echo Lake includes short-term and long-term monitoring. Short-term monitoring is focused on key data gaps and will provide the information needed to confirm and refine the selected measures and develop more accurate cost estimates. Long-term monitoring will provide the information needed to evaluate progress toward achieving management goals and to adjust or augment the lake management measures.

As outlined in Table 29, we recommend developing a monitoring plan which builds on current water quality and lake level monitoring programs to include:

- Additional routine lake monitoring
- Cyanobacteria bloom and fecal bacteria surveillance
- Stormwater treatment performance and inlet monitoring
- Sediment phosphorus monitoring

Estimated costs for each monitoring element are also presented in Table 29 and includes a 20 percent contingency for a total annual cost of $33,660.

If conducting a phosphorus inactivation treatment, additional monitoring will be required by the Aquatic Plant and Algae Management General Permit (see the *Alum Treatment* subsection in *Cyanobacteria Management Methods* for a summary of monitoring requirements).

Table 29. Future Monitoring and Adaptive Management.

Monitoring Component	Description	Reporting/Activity	Estimated Additional Cost
Lake water quality	Continue with King County VLMP and expand twice monthly summer monitoring to add: ● Total phosphorus in deep sample (1 m above bottom) twice monthly. ● Three surface (1 m) samples per year analyzed for phytoplankton species biovolume.	Continue annual reporting on monitoring activities, water quality, evaluating trends, emerging issues, and recommendations.	$15,000 per year for routine Volunteer Lake Monitoring Program $1,000 per year for additional lake management plan monitoring Assumes lake monitoring is performed by volunteers.
Lake level	Continue monitoring lake level gauge by King County.	Include lake level summary and trend evaluation in annual report.	$0 (included in lake water quality cost)
Surveillance for Cyanobacteria Blooms	Expand existing surveillance program for identifying and sampling cyanobacteria blooms to year-round to encompass potential wintertime or early spring algae blooms.	If a bloom is detected, collect a sample to analyze through the Northwest Toxic Algae Program or King County Laboratory if outside program period. Compare results to state recreation criteria to issue beach closures. Include activities, advisory decisions, and results (including non-detects) in annual report.	$2,000 per year Assumes 5 cyanotoxin sample analyses/year by King County at $175/sample Assumes16 hours staff time/year at $75/hour.
Sediment Monitoring	Collect 2 sediment cores every 5 years for phosphorus fractionation, iron, and bulk density analysis in 5 sediment layers each. Collect additional cores pre-/post- phosphorus inactivation treatments as necessary.	Evaluate trends in concentrations and annual loads, assess for efficacy and/or dosage of phosphorus inactivation treatments, if applicable, and provide recommendations in reports.	$2,100 per year (20-year average) Assumes lab cost = $3,000 per event, every 5 years Assumes 50 hours consultant staff time per event at $150/hour.
Stormwater/ Inlet Monitoring	Monitor performance of stormwater treatment facilities (TP for 6 storm events/year) at 2 lake inlets and 2 treatment facilities each year	Evaluate phosphorus removal by treatment facility and long-term trends at 2 lake inlets.	$3,300 per year (20-year average) Assumes 24 TP samples/year at $25/sample lab cost Assumes 6 hours/event and 36 hours/year staff time at $75/hour.
Data QA and management	Input laboratory and field data into database, perform data QA/QC.	Qualify data and modify procedures as necessary. Include QA results in annual report.	$750 per year for stormwater data Assumes 10 hours extra City staff time at $75/hour.
Annual Reporting	Summary of Monitoring Data, Management Effectiveness (if applicable), and Adaptive Management Recommendations	–	$3,000 per year Assumes 40 extra hours City staff time per year at $75/year
Project Management	Coordination	–	$900 per year Assumes 12 extra hours/year City staff time at $75/hour.
		Subtotal Cost	$28,050
		Contingency at 20%	$5,610
		Average Annual Cost	**$33,660**

Future Adaptations to Consider

We expect that the OST system will reduce internal phosphorus loading but it alone will not sufficiently reduce in-lake total phosphorus concentrations enough to meet the management objective for total phosphorus. Watershed source control efforts are necessary to reduce phosphorus loading by at least 25 percent (i.e., <47 kg/year) and phosphorus concentrations to 24 µg/L or less. This total phosphorus concentration objective is the boundary between mesotrophic (moderate productivity) and eutrophic (high productivity) classifications that is also expected to meet the other established objectives for water clarity (Secchi depth), algae biomass (chlorophyll-a) and toxic cyanobacteria blooms (cyanotoxins) (see *Lake Management Objectives*).

If the OST alone does not appear to be adequately reducing the hypolimnetic phosphorus, then modification of the management strategies is needed. Modifications may include, in order of priority:

1. **Increase in the oxygen input amount and/or extend the duration of oxygen input to the hypolimnion from the OST system.**
2. **Increase the amount of iron in the lake sediments to bind phosphate under oxygenated conditions by applying zero valent iron to either the entire lake or just the hypolimnion area.**
3. **Plan and initiate a phosphorus inactivation treatment of the lake using alum or lanthanum.**

Once the hypolimnion is sufficiently oxygenated, iron may be used as a lower-cost phosphorus inactivation chemical and can be applied either as zero-valent iron or an iron salt. The hypolimnion must be well-oxygenated because the iron-phosphorus complexes are sensitive to low-oxygen conditions.

Funding Strategy

The recommended set of management strategies is estimated to cost approximately $0.6 million in the first 3 years and about $5.1 million over the next 20 years. Additional funding sources will be necessary to implement the recommend elements of this plan to supplement available City and County funds. A, Flood Control Special Use District or Lake Management District could be formed to raise funds from lake or watershed residents. Additional funds could be obtained through state legislative budget allocations and various grants, and/or loans to fully implement this LCMP. We recommend considering the sources provided in Table 30. Additional supplementary grants and programs which may provide limited or specialized benefit are summarized in Appendix D.

Table 30. Funding Sources for Lake Management Actions.

Funding Source	Description	Applicable Activities
Flood Control Special Use District Dues	A flood control special use district is formed following steps in RCW 85.38 and RCW 86.09. The establishment of a special district may be initiated by either petition of the owners of property located within the proposed special district, or by resolution of the county legislative authority or authorities within which the proposed special district is located. After County processing, the district formation and assessment rates are decided by a majority vote of property owners within the proposed district boundaries. Both private- and publicly owned lakefront property and upland/watershed lots are commonly included. The district assessments are collected by the County Treasurer for district disbursement. Flood control districts are not restricted to a time frame unless specified.	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • In-lake management • Outreach and Education
Lake Management District (LMD) Dues	A LMD is formed with property owners from within the proposed district voting by mail, each granted one vote for each dollar they would be assessed under the proposed LMD. Both the County Council and affected property owners must approve the district formation, and revenues are then collected by the treasurer as a specific item on the annual property tax statement (Chapter 36.61, Revised Code of Washington). A LMD is established for a specific time frame, up to 10 years. Both private- and publicly owned lakefront property and upland lots are commonly included. It may be possible to include the entire watershed in a LMD	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • In-lake management • Outreach and Education
City of Shoreline Public Works Fund	The City of Shoreline Public Works Department maintains the stormwater system in the incorporated areas draining to Echo Lake.	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • In-lake management • Outreach and Education

Table 34 (continued). Funding Sources for Lake Management Actions.

Funding Source	Description	Applicable Activities
King County Department of Natural Resources and Parks (DNRP) Funds	The mission of the DNRP is "to protect and restore the natural environment for the people, fish, and wildlife of King County, promoting more resilient, sustainable, equitable communities." DNRP's Stormwater and Surface Water (SWM) Management team leads the volunteer-based monitoring program at Echo Lake in partnership with the City, and supports lake residents to support and improve lake health through programs like RainWise. SWM activities are funded in part through a per parcel surface water management fee for parcels in unincorporated King County.	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • In-lake management • Outreach and Education
King County Waterworks Grants	The WaterWorks Grant Program provides a total of approximately $5 million in funding every 2 years to organizations carrying out projects which improve water quality within or demonstrate water quality benefits are related to King County's Wastewater Treatment Division service area. Proposals for the council-allocated application track are selected by King County Council. Proposals may also be submitted through the competitive application track. Nonprofits, schools and educational institutions, cities, counties, tribes, and special purpose districts are all eligible to apply. WaterWorks staff administer all grants after they are awarded, and all grants have the same reporting requirements.	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • Outreach and Education • Community Engagement and Stewardship • Riparian Area Restoration • Scientific Research and Technology Development • Project Planning and/or Design
King County Flood Reduction Grants	King County Flood Control District's Flood Reduction Grant Program targets medium and local flood reduction projects in King County. Annual awards are not capped and range from $10,000 to $1.5 million and must be used within 36 months of signing the grant agreement. There are four grant categories: original flood reduction, urban streams, coastal erosion/flooding, and culvert replacement/fish passage. Nonprofits, cities and towns within King County, King County agencies, tribes, and special purpose districts are all eligible to apply for any category grant. Homeowner associations and schools are eligible for the Original Flood Reduction Grant category only.	• Watershed management • Planning/design, permitting, and/or construction of projects which reduce flooding impacts on safety, water quality, or infrastructure
State Legislature Budget Allocation	State funding of some lake management measures may be appropriate, providing sufficient political support can be generated in the State Legislature for selected lake management efforts. Legislative budget allocations may be particularly well suited to one-time capital expenditures as opposed to ongoing activities requiring stable, long-term funding sources.	• Water quality monitoring • Watershed management • Onsite septic repair and replacement • In-lake management • Outreach and Education

Table 34 (continued). Funding Sources for Lake Management Actions.

Funding Source	Description	Applicable Activities
Freshwater Algae Control Grants	The Washington State Freshwater Algae Program has an annual funding cycle for projects to manage toxic algae (cyanobacteria) blooms. The grant funds up to $50,000 and requires a 25 percent in-kind match (which may be eliminated in 2024). In-lake treatments, such as OST, alum, or lanthanum, *are* eligible for this grant, provided the waterbody has an approved Lake Cyanobacteria Management Plan.	● Water quality monitoring ● Watershed management ● Onsite septic repair and replacement ● In-lake management ● Outreach and Education
Clean Water State Revolving Fund Loans	The CWSRF program is funded via an annual U.S. Environmental Protection Agency (EPA) capitalization grant, state matching funds, and principal and interest repayments on past CWSRF loans. This program provides low-interest and forgivable principal loan funding for wastewater treatment construction projects, eligible nonpoint source pollution control projects, and eligible green projects. In-lake treatments, such as phosphorus inactivation and oxygenation, *are* eligible for these loans.	● Water quality monitoring ● Watershed management ● Onsite septic repair and replacement ● In-lake treatments ● Outreach and Education
Centennial Clean Water Grants	The Centennial Clean Water Fund is a Washington State-funded grant program administered by Ecology. Local governments, special purpose districts, conservation districts, and federally recognized Tribes are eligible for these funds applicable to water quality infrastructure (e.g., wastewater treatment facilities) and nonpoint source pollution projects to improve and protect water quality. In-lake treatments, including phosphorus inactivation and oxygenation *are not* eligible for these grants.	● Water quality monitoring ● Watershed management ● Onsite septic repair and replacement ● Outreach and Education
Section 319(h) Clean Water	EPA provides “Section 319(h)” grant funds to Washington State where the State is required to provide a 40 percent match in funding. The Section 319(h) program provides grants to eligible nonpoint source pollution control projects, similar to the state Centennial Clean Water Fund. Eligible projects include lake water quality planning, riparian and wetlands habitat restoration and enhancement, and other water quality improvement efforts. Non-profit organizations are also eligible for these funds. A 25 percent match is required, and grants may be limited to $250,000 or $500,000, depending on the match type. In-lake treatments, including phosphorus inactivation and oxygenation *are not* eligible for these grants.	● Water quality monitoring ● Watershed management ● Onsite septic repair and replacement ● Outreach and Education

Roles and Responsibilities

Projects and partnerships succeed when participants share a common understanding of roles and responsibilities. It is important to establish clarity regarding those roles, responsibilities, and expectations for each participating entity at the outset, to ensure the best chance at achieving the project's vision, mission, goals, and objectives. When roles and responsibilities are clearly defined, productivity, respect, communication, value for individual contributions, and shared ownership for success is enhanced throughout the team.

The relevant entities to fulfill the required roles and responsibilities of organizing, governing, and executing the decisions of an example lake management structure as a primary mechanism for decision-making, funding acquisition, and implementation of management activities for Echo Lake, have been defined below in Table 31.

Table 31. Roles and Responsibilities.

Agency/Group	Role	Responsibilities
City of Shoreline Public Works	Lead Entity	Administer the Lake Cyanobacteria Management Plan. Develop an annual workplan for approval by City Council. Lead for loan application through CWSRF. Procure and manage contracts for lake improvement services. Additional training, tracking, and education of phosphorus treatment. Retrofit of existing stormwater infrastructure. Stormwater monitoring. Lead toxic algae monitoring program.
King County Surface Water Management	Administer Lake Water Monitoring and Data Management	Water quality and level monitoring of Echo Lake through the Lake Stewardship Program. Supplement public education program. Provide supplemental funding through SWM fee.
Seattle - King County Health Department	Management and Monitoring Support	Oversight and assistance with cyanotoxin and E. coli monitoring.
Friends of Echo Lake & Echo Lake Neighborhood Association	Monitoring Support and Community Engagement	Assist King County in lake monitoring and surveillance for toxic algae bloom. Outreach to elected officials to seek budget allocations through King County Council and Washington State Legislature. Outreach and engagement to advertise lake stewardship.

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Appendix A

Lake and Watershed Monitoring Report

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Appendix B

Field Sheets

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Appendix C

Lab Reports

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Appendix D

Supplementary Grants and Programs

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