Spanaway Lake Management Plan

December 2016

Pierce County
Public Works and Utilities
Surface Water Management

Made possible by funding from the Washington State Legislature

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Executive Summary

In 2013, Pierce County Public Works and Utilities (County) received $400,000 from Washington State Legislature to research and develop a management plan for Spanaway Lake. The County selected Brown and Caldwell (BC) to help develop a Lake Management Plan (LMP). BC retained Geosyntec Consultants (Geosyntec) and Applied Ecology Consulting as subconsultants to provide technical support for the planning effort. County staff performed most of the monitoring. The County's contract laboratory, Spectra Laboratories (in Tacoma, Washington), analyzed the surface water, groundwater, and sediment samples for all parameters except phytoplankton and zooplankton, which were analyzed by Water Management Laboratories, Inc. (in Tacoma, Washington).

The County, along with Pierce County Parks and Recreation, Tacoma-Pierce County Health Department (TPCHD), Pierce County Sewer Utility, Pierce Conservation District, U.S. Geological Survey (USGS), and Spanaway Lake Advisory Group (Advisory Group) members will use this information to develop recommendations for the LMP.

The objective of the LMP is to develop strategies to improve and protect the lake uses. The LMP was developed in two phases. Phase 1 involved characterizing Spanaway Lake water quality and identifying and quantifying nutrient and bacteria sources that are affecting the lake. Phase 2 involved evaluating potential management measures based on the Phase 1 findings. This LMP summarizes the results of phases 1 and 2 of the project.

Lake Features

Spanaway Lake is a large, natural kettle lake in central Pierce County, Washington. An area of approximately 17 square miles drains into Spanaway Lake, which has a surface area of 272 acres. The average and maximum lake depth are approximately 16 and 28 feet, respectively. The largest source of water to the lake is groundwater, which contributes approximately 65 percent of the inflow to the lake. The main surface water source to the lake is a wetland system that feeds into Coffee Creek on the south end of the lake. Water discharges from the lake at the north end into Spanaway Creek. The lake supports a variety of uses including boating, fishing, swimming, and wildlife habitat. More than 170 single-family homes and 160 multi-family residences have direct access to the lakeshore. The County operates a large, regional park on the northeast shore of the lake that allows public access. The park receives approximately 500,000 visitors per year.

Water Quality Problems

A Quality Assurance Project Plan (QAPP) was developed to guide the collection of field data. County staff collected data following the procedures outlined in the QAPP between October 2014 and December 2015. Data collection included monitoring flow, lake water quality, surface water quality, and groundwater quality to develop a nutrient budget for the lake, identify key nutrient sources, and support evaluation of lake management measures.

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Identified water quality concerns for Spanaway Lake include excessive nutrients, low dissolved oxygen (DO), and elevated fecal indicator bacteria. Elevated nutrient concentrations in the lake water increase the growth of cyanobacteria (also known as blue-green algae), which can produce substances that are toxic to people, pets, and wildlife. The number of days per year during which TPCHD has issued advisories on the lake for toxic algae during the past 10 years has ranged from 64 days in 2011 to 318 days in 2015.

Elevated nutrient concentrations can also contribute to the excessive growth of rooted aquatic plants. Although rooted plants get most of their required nutrients from the sediment, nutrients are also obtained to a lesser degree from the lake water. High nutrient concentrations in lake water also provide the long-term basis for nutrient-rich sediments, as microscopic plant algae die, settle to the lake bottom, and decompose to become part of the organic sediment layer.

The primary nutrient of concern in Spanaway Lake is total phosphorus (TP), which fuels both algal blooms and the growth of rooted aquatic plants. Excessive growth of algae and rooted plants can cause large swings in DO concentrations. Dead algae and plant materials settle to the lake bottom, where they decompose and reduce DO in the lake water. Low DO levels are harmful to fish and other aquatic life.

Thermal stratification plays an important role in the phosphorus cycle of the lake. From approximately April through October, water in the bottom of the lake is too cold and dense to mix with the warmer, well-oxygenated surface water. The deep water becomes anoxic (i.e., no oxygen) because of the decomposition of dead plants and other organic matter on the lake bottom. As the lake bottom sediments become anoxic, phosphorus is released into the lake water. When the weather cools in the fall, the temperature throughout the lake becomes uniform and the phosphorus-rich bottom water can mix with the rest of the lake and trigger additional algal blooms.

Based on the monitoring results from October 2014 through December 2015, the TP load to the lake is about 1,000 kilograms (kg) or 2,200 pounds (lbs) per year. As shown on Figure ES-1, roughly 55 percent of the TP load comes from the lake bottom sediments, while groundwater and Coffee Creek contribute about 29 percent and 12 percent, respectively. The current TP loading from the watershed is estimated to be about 35 percent higher than the watershed loading rate that would result in more pristine or oligotrophic lake conditions. The TP load from groundwater is predicted to slowly increase over time.

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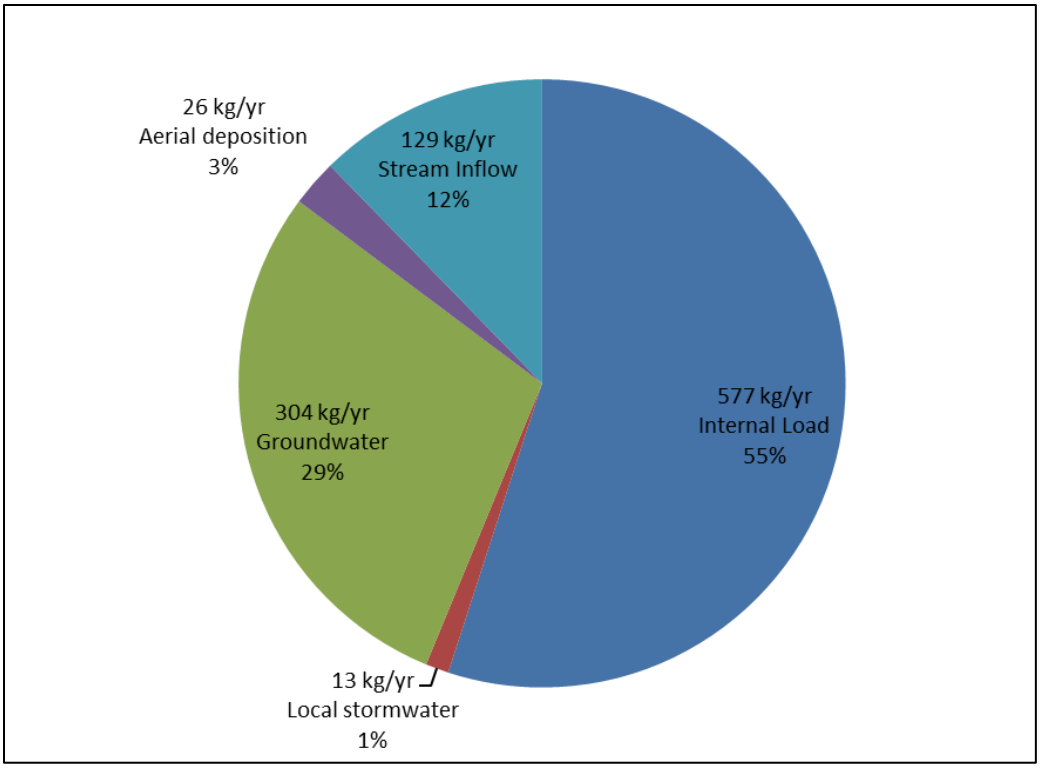

Figure ES-1. Estimated annual TP loading to Spanaway Lake

Fecal coliform and E. coli bacteria are indicators of potential fecal contamination. Elevated concentrations of these bacteria indicate that potentially harmful bacteria, viruses, or parasites may be present. In Spanaway Lake, elevated fecal indicator concentrations have been observed in samples collected near the swimming areas by TPCHD.

Other Problems

The Advisory Group identified two other lake management problems in addition to harmful algae blooms and fecal contamination:

- Dense aquatic plant growth in some areas
- Inundation of docks and shoreline areas

Pollutant Sources

The lake characterization study identified the following primary pollutant sources:

Lake Sediment. The lake bottom sediment contains a large amount of phosphorus. Higher concentrations are found in the finer-grained sediments in the deeper parts of the lake. The sediment can release phosphorus to the water column when the lake water becomes anoxic and also when lake water pH is high.

Septic Systems. There are nearly 4,000 onsite sewage disposal systems (OSDS) located upgradient of Spanaway Lake. Surface failures are rare because of the very permeable soils, but TP from OSDS can slowly move through the soil and reach the lake through groundwater flow. Septic systems installed in shallow groundwater areas close to the lake have the potential to contribute fecal coliform bacteria to the lake via groundwater transport. Model estimates indicate that OSDS currently contribute on the order of 53 kg to 89 kg of phosphorus to the lake each year, which is about 17 to 20 percent of the current groundwater load to the lake. Because groundwater and the associated TP tend to move very slowly in the subsurface, the model predicts that the number of OSDS that affect the lake and OSDS TP loads will slowly increase over time.

Waterfowl. Droppings from waterfowl have the potential to contribute both phosphorus and fecal coliform to the lake. Limited information is available regarding waterfowl use of Spanaway Lake. The available data suggest that waterfowl are not a major source of TP, but may be an important source of fecal contamination. The impacts of waterfowl on Spanaway Lake are less understood due to the lack of data related to waterfowl use of the lake.

Stormwater. Direct stormwater runoff appears to be a minor source of TP and bacteria to Spanaway Lake. Only a small area around the lake contributes runoff directly into the lake. Because of the very permeable soils and numerous infiltration facilities, most stormwater in the watershed is infiltrated and does not reach the lake as surface runoff.

Identification of Potential Lake Management Measures

The project team (BC, Geosyntec, Applied Ecology Consulting, and County staff) developed a preliminary list of more than 25 potential measures to improve water quality in Spanaway Lake based on the characterization results. The list included in-lake as well as watershed measures. The Advisory Group reviewed and amended the initial list of potential measures.

The potential measures were discussed during several Advisory Group meetings held during September through November 2016. Based on the screening evaluations and Advisory Group input, the following management measures were selected for additional evaluation:

- Hypolimnetic oxygenation
- Hypolimnetic siphon
- Hypolimnetic withdrawal for golf course irrigation
- Phosphorus inactivation: whole lake treatment or alum emitter
- Improve conveyance capacity of lake outlet
- Aquatic plant management
- Waterfowl management
- Hypolimnetic oxygenation with an alum injector

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The project team performed additional evaluations and developed planning-level cost estimates for the measures listed above. Discussions with County Parks staff revealed that Parks recently began inspecting the lake outlet and has the permits needed to remove vegetation and debris when necessary.

The project team and Advisory Group also discussed the need for monitoring to fill key data gaps (e.g., aquatic plant distribution) and to evaluate lake water quality over time to assess progress and support refinements in management measures.

Table ES-1 summarizes the recommended measures for Spanaway Lake. These recommendations are based on the Lake Characterization monitoring data, technical evaluations, and input from the Advisory Group.

Because these recommendations are based on limited data, additional data collection and evaluation should be performed to address key data gaps, confirm the viability of the concepts and support design of the hypolimnetic oxygenation system, and to develop an environmentally sound aquatic plant management plan. The watershed and groundwater models the County is developing for the Spanaway Watershed-scale Stormwater Plan should be used to improve understanding of pollutant sources and support refinement of management measures if needed. Long-term monitoring is recommended to track progress and support adaptive management.

Full implementation of the Spanaway LMP will likely require funding from multiple sources. For example, capital costs could be funded by state grants, budget allocations, and/or a State Revolving Fund (SRF) loan, while long-term O&M costs and SRF loan payments could be funded by revenues from special benefit districts such as a Lake Management District (LMD), Flood Control Zone District (FCZD) (with Pierce County FCZD approval), or—more likely—a combination of ongoing dedicated funds. Implementing the Spanaway LMP will likely require a local funding source to help pay for ongoing lake management activities. To gain approval, the local funding source would need to be tailored to local conditions and community preferences and perceived as equitable by potential rate payers.

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Table ES-1: Recommended Measures for Spanaway Lake

Measure	Description	Anticipated Water Quality Benefits	Estimated Costs	
			Initial	Ongoing
Hypolimnetic oxygenation system with alum injector	Inject oxygen near lake bottom to minimize phosphorus release from sediment under anoxic conditions. Add alum at key times to increase phosphorus removal.	Reduced internal phosphorus load, increased DO, more fish habitat.	$2,000,000	$81,000
Aquatic plant management	Perform aquatic plant survey. Develop aquatic plant management plan tailored to Spanaway Lake. Routine monitoring by volunteers. Perform targeted plant removal when necessary, in accordance with LMP.	Reduced risk of invasive plants, improved recreation, small reduction in sediment phosphorus.	$12,000 for plant survey, plan, field guide.	$16,500 assumes removal of aquatic plants from 5 acres/year (yr) at average cost of $3,500/acre.
Waterfowl management	Initial survey to characterize bird use of lake. Use landscaping/physical barriers, deterrence measures and education to help manage waterfowl.	Reduced fecal loads to lake, less fecal matter on docks, beaches, and lawns.	$5,000 to support initial survey[a]	TBD[a]
Public education and outreach	Support lake committee. Adapt LakeWise program to encourage lake-friendly landscaping, septic system maintenance, pet waste cleanup, and responsible boating.	Reduced phosphorus from shoreline landscapes and septic systems, reduced bacteria loads from waterfowl and pets, public support for LMP activities.	$30,000[b]	$23,000[c]
Focused monitoring	Bathymetric survey, equipment acquisition, grab sampling and profiling at several deep locations in the lake, limited sediment sampling.	Fill key data gaps to confirm and refine selected measures and cost estimates.	$26,000[d]	None
Long-term monitoring	Monthly monitoring from early spring through late fall throughout the lake water column, sampling in Coffee Creek, deep hole sampling, algae sampling.	Evaluate LMP progress and support adaptive management.	None	$33,000[d]

Notes:

a. Assumes program would be implemented primarily by private property owners and volunteers with limited support from County staff.

b. Includes one-time activities such as audience research, LakeWise signage, pet waste stations, and printing.

c. Staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.

d. Assumes program would be implemented primarily by volunteers, with some support from County staff. Focused monitoring cost includes $2,000 for equipment that could also be used for long-term monitoring.

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List of Abbreviations

AACE	Association for the Advancement of Cost Engineering
Advisory Group	Spanaway Lake Advisory Group
BC	Brown and Caldwell
CDFI	Community Development Financial Institution
cfs	cubic foot/feet per second
cfu	colony-forming unit
cm	centimeter(s)
County	Pierce County Public Works and Utilities
CWSRF	Clean Water State Revolving Fund
DASH	diver-assisted suction harvesting
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EMC	event mean concentration
EPA	U.S. Environmental Protection Agency
FACT-LITE	Financing Alternatives Comparison Tool
FCZD	Flood Control Zone District
Fe	iron
FTE	full time employee
Geosyntec	Geosyntec Consultants
GROSS	Grants of Regional or Statewide Significance
HOS	Hypolimnetic Oxygenation System
HPA	Hydraulic Project Approval
HSPF	Hydrological Simulation Program-Fortran
ID	identifier
JBLM	Joint Base Lewis-McChord
kg	kilogram(s)
km	kilometer(s)
lb(s)	pound(s)
LID	low-impact development
LMD	Lake Management District
LMP	Lake Management Plan
ln	natural logarithm
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mg/L	milligram(s) per liter
mg/L-N	milligram(s) of nitrogen per liter
mgd	million gallons per day
mL	milliliter(s)
mS	SI unit of conductivity, siemens per meter
N	nitrogen
N/A	not applicable
N:P	nitrogen to phosphorus mass ratio
NALMS	North American Lake Management Society
ND	non-detect
NH_4	Ammonium
NO_3	nitrate
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance
OSDS	onsite sewage disposal system
OSS	onsite sewage systems
ppb	part(s) per billion
QAPP	Quality Assurance Project Plan
REHAB	Regional Evaluation of Harmful Algal Blooms
RSS	Report of System Status
S.U.	standard units.
SFAP	Stormwater Financial Assistance Program
SWM	Pierce County Surface Water Management
TBD	To Be Determined
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TPCHD	Tacoma-Pierce County Health Department
TSI	Trophic State Index
TSS	total suspended solids
UCL	upper confidence limit
ULID	Utility Local Improvement District
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WSP	Spanaway Watershed-Scale Stormwater Management Plan
yr	year(s)
µg/L	microgram(s) per liter

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Section 1: Introduction

Spanaway Lake is a large natural lake in central Pierce County, Washington (see Figure 1), at the terminus of the watershed. The lake supports a variety of beneficial uses including boating, fishing, swimming, and wildlife habitat. More than 170 single-family homes and 160 multi-family residences are located along the lake shoreline. Spanaway Lake Park has swimming beaches, a fishing pier, a boat ramp, and other amenities that attract visitors from throughout the region.

Spanaway Lake has a history of cyanobacteria (i.e., blue-green algae) blooms that have the potential to release toxic substances harmful to people, pets, and wildlife. The Tacoma-Pierce County Health Department (TPCHD) issues health advisories when potentially toxic blooms are observed. TPCHD algae advisories have been common for Spanaway Lake during the past 10 years (see Table 1).

Table 1: Algae Advisory Days by Year

Year	Days with advisory	% time with advisory over the year
2006	144	39.5
2007	136	37.3
2008	245	67.1
2009	217	59.5
2010	84	23.0
2011	64	17.5
2012	282	77.3
2013	143	39.2
2014	164	44.9
2015	318	87.1
2016	172	47.1

Spanaway Lake samples had some of the highest concentrations of the algal toxin microcystin of the 30 lakes sampled during 2007–08 for the Washington State Department of Ecology (Ecology) Freshwater Algae Control Program (Hamel 2009). Thirty-eight of 60 water samples collected from Spanaway Lake from September 12, 2007, to June 1, 2016, exceeded 6 micrograms per liter (µg/L), the state recreation guideline value for microcystin (Washington State 2016).

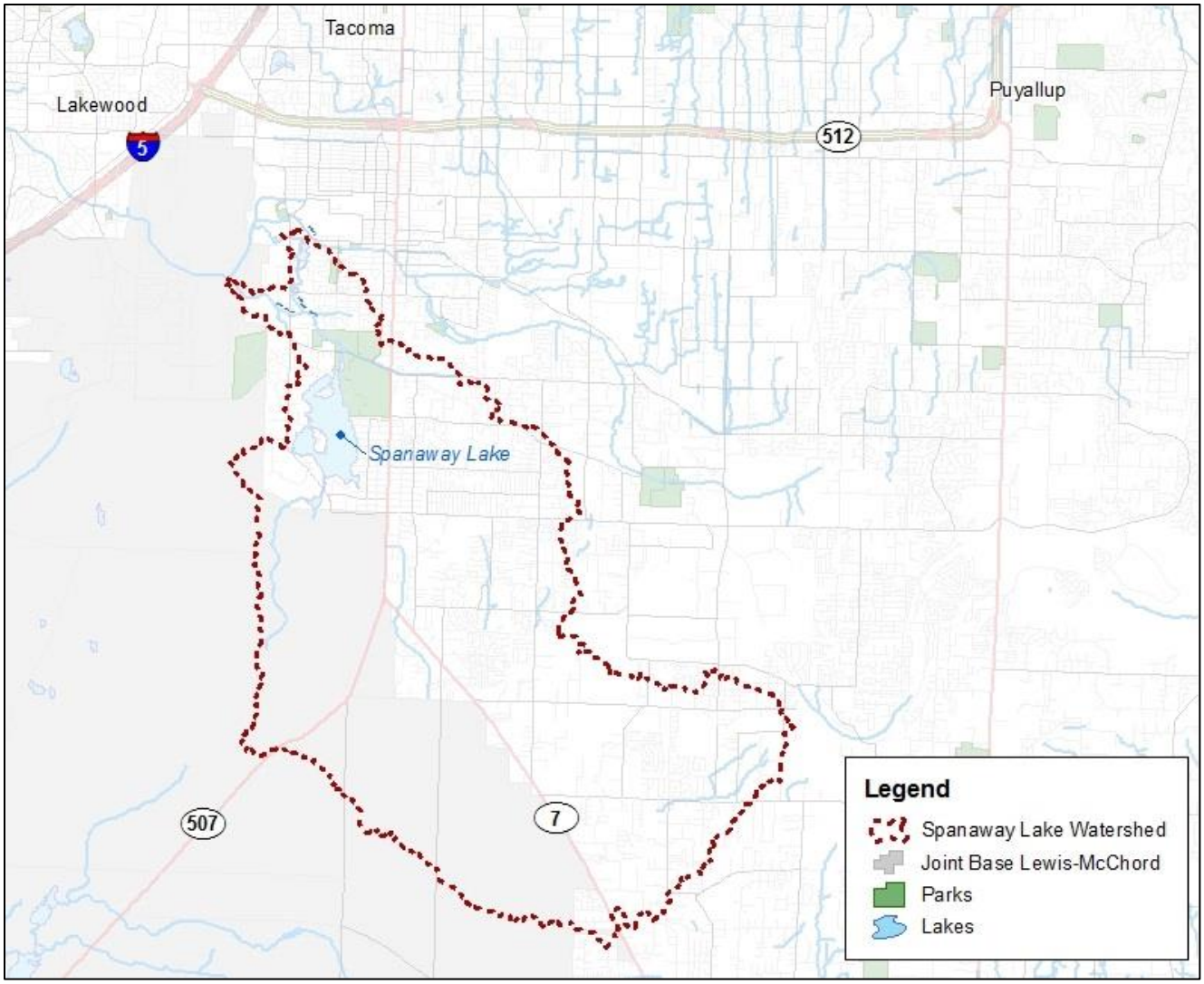

Figure 1. Spanaway Lake

In addition to producing toxic substances, cyanobacteria blooms can harm aquatic life by increasing water pH and reducing dissolved oxygen (DO) concentrations in the lake water. The blooms can also degrade lake aesthetics.

Cyanobacteria blooms in surface waters are typically associated with elevated nutrient concentrations and loadings. Phosphorus is typically the nutrient that limits cyanobacteria growth in western Washington lakes. Ecology's 2015 *Water Quality Assessment* 305(b) Report and 303(d) list identifies Spanaway Lake as a "water of concern" for total phosphorus (TP) (Ecology 2015).

Fecal contamination is also a concern for Spanaway Lake. Ecology's 2015 *Water Quality Assessment* report lists Spanaway Lake as "impaired" based on elevated fecal coliform concentrations in samples collected during 2003–10 (Ecology 2015).

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1.1 Natural Setting

Most of the Spanaway Lake watershed is covered by highly permeable glacial outwash soils (see Figure 2). Approximately 80 percent of the watershed soils are in hydrologic soil group A, which are typically deep, well-drained sands and gravels with high infiltration rates. These permeable soils produce little surface runoff and as a result, there are few surface water channels in the watershed.

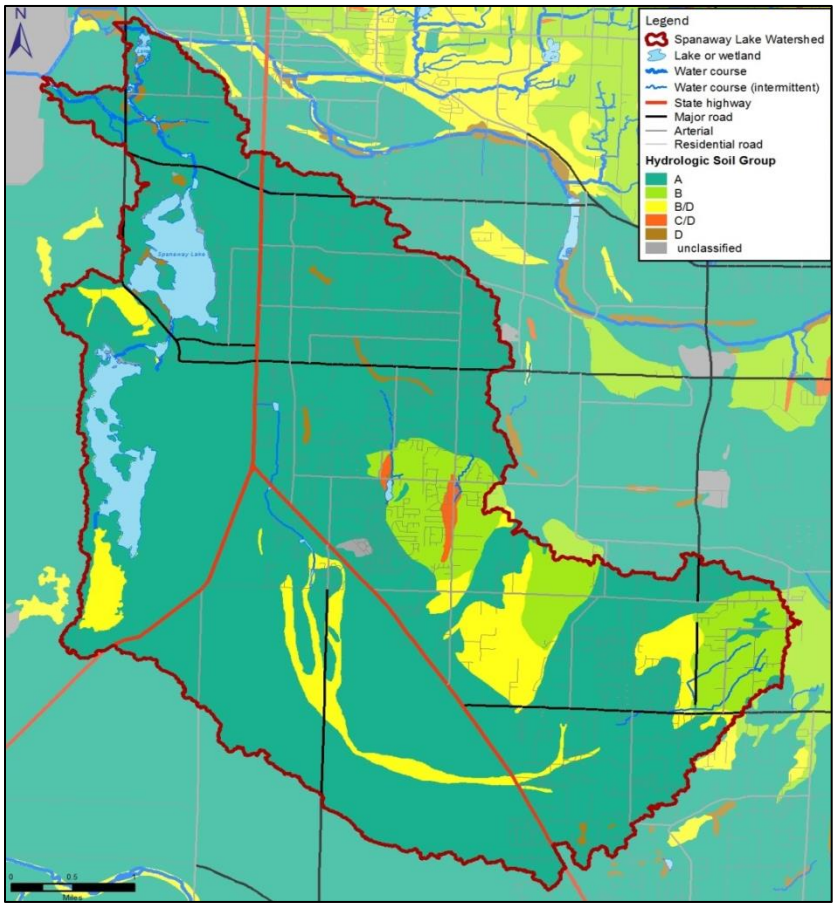

Figure 2. Soils in the Spanaway Lake watershed

Spanaway Lake is a “kettle” lake that formed in a depression left behind after a partially buried block of glacial ice melted. The lake appears to be in direct contact with a surficial groundwater aquifer composed of permeable glacial outwash material. Previous studies and observations from shoreline residents indicate that groundwater is an important source of inflow to Spanaway Lake.

The only significant surface water source to Spanaway Lake is Coffee Creek, which originates at the outlet to a large wetland system on Joint Base Lewis-McChord (JBLM) and flows into the south end of the lake. Visual observations suggest that Coffee Creek gains flow from surficial groundwater before discharging into the lake.

Spanaway Lake discharges into Spanaway Creek at the north end of the lake. Spanaway Creek splits into two channels, Morey Creek and Spanaway Creek, about 0.75 mile downstream of the lake. Both channels ultimately flow into Clover Creek.

1.2 Built Environment

Figure 3 shows the current land uses in the Spanaway Lake watershed. About one-third of the watershed lies within JBLM. The remainder is under Pierce County Public Works and Utilities (County) jurisdiction. Residential land uses occupy most of the County's portion of the watershed. Commercial land uses are concentrated along State Highway 7. Other common land uses include parks, open spaces, and resource lands.

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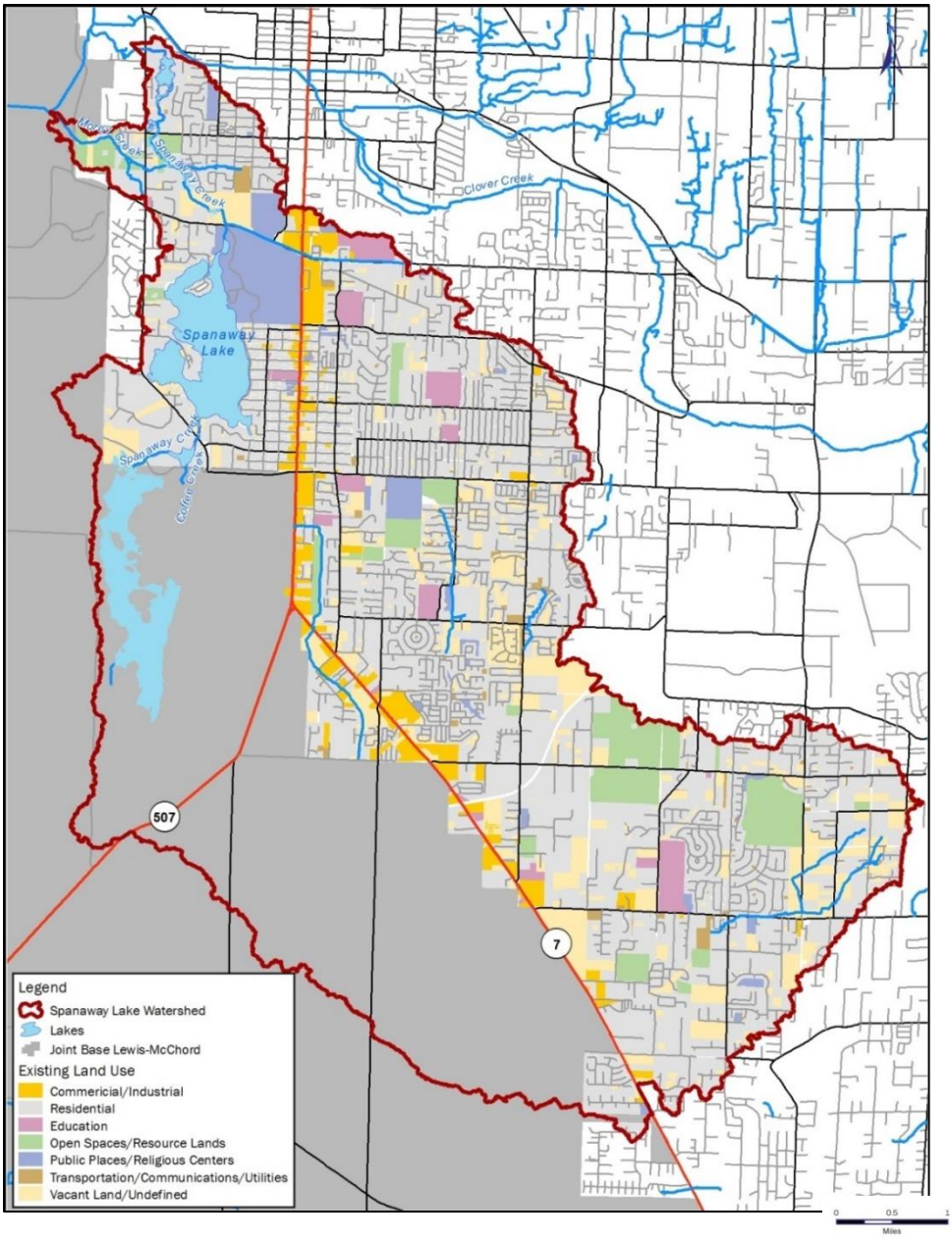

Figure 3. Land uses in Spanaway Lake watershed

The JBLM portion of the watershed is mostly prairie and forest land with little apparent infrastructure aside from roads and fences (see Figure 4). There is a large wetland system that flows into Coffee Creek at the JBLM boundary.

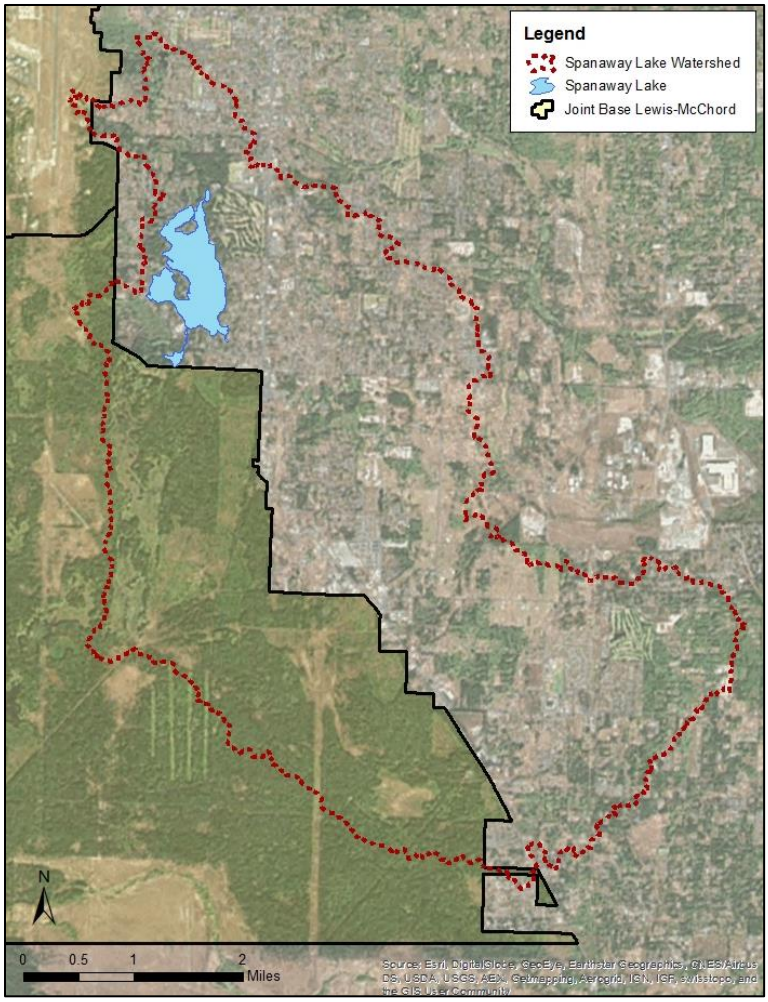

Figure 4. Satellite imagery of Spanaway Lake watershed

As noted above, most of the Spanaway Lake watershed is covered by very permeable soils. Pervious areas (i.e., areas that are not covered by pavement, buildings, or other hard surfaces) in this watershed do not generally produce much surface stormwater runoff. Nearly all of the runoff from impervious areas is infiltrated through drywells, infiltration basins, ditches, or adjacent pervious areas. Figure 5 below shows the locations of more than 1,000 stormwater infiltration facilities. Stormwater runoff from a small area (i.e., less than 250 acres) along the shoreline can discharge via overland flow directly into the lake.

Most of the watershed uses onsite septic systems to treat and infiltrate wastewater. There are more than 4,000 septic systems in the watershed. A small portion of the watershed, including Spanaway Lake Park, is connected to the County sewer system.

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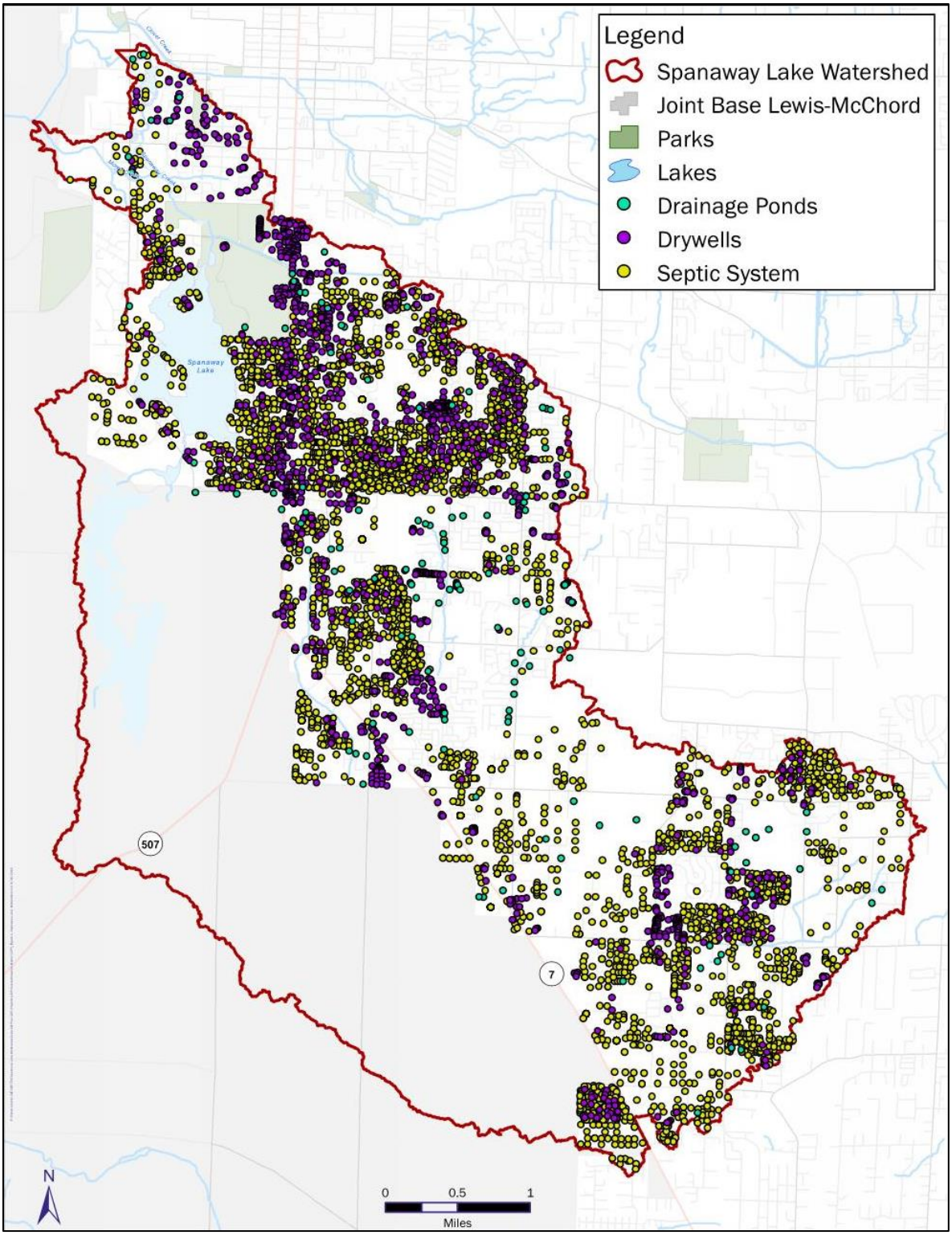

Figure 5. Stormwater infiltration systems and septic systems in Spanaway Lake watershed

1.3 Previous Water Quality Studies

Ecology performed a trophic state assessment of Spanaway Lake in 1998. (Note: Section 3 of this report contains a detailed discussion of lake trophic status.) Lake water clarity and water quality depth profiles were measured on 16 occasions from May to October. Lake water samples were collected two to four times from three locations from June to September 1998. The samples were analyzed for TP, total nitrogen (TN), chlorophyll-a, and a subset was analyzed for fecal coliform. The mean TP concentration was 0.0166 milligram per liter (mg/L). Based on the monitoring results Ecology assigned an overall assessment of mesotrophic condition. Ecology also conducted a lake user survey, which showed that most respondents believed water clarity was deteriorating (Ecology 2000).

In 2012, Spanaway Lake was monitored as part of the Regional Evaluation of Harmful Algal Blooms (REHAB) program. Lake water quality samples were collected from 1-, 4-, and 8-meter (m) depths every 2 weeks from June through October. Chlorophyll-a ranged from 2.2 to 15.6 µg/L (average = 5.9 µg/L) in the shallow (1 m) samples. TP ranged from 0.008 to 0.037 mg/L in the shallow (1 m) samples and from 0.034 to 1.170 mg/L in the deep (8 m) samples. Average TP concentrations for the 1-, 4-, and 8 m samples were 0.016, 0.063, and 0.520 mg/L, respectively (personal communication with Hanowell, R. of TPCHD on March 25, 2014).

A sediment core was collected from the deepest part of Spanaway Lake in 2004 (Longfellow and Holt 2004). The core was analyzed for metals and total organic carbon (TOC) concentrations. The 49.5-centimeter (cm) core was estimated to represent about 99 years of sediment accumulation, with an average sediment accumulation rate of about 0.5 centimeter per year (cm/yr). However, the study did not include radioisotope dating so the timelines and accumulation rates are rough estimates. The researchers noted a spike in copper and TOC about 29 cm below the top of the sediment core and hypothesized that it may have been caused by a large copper sulfate treatment to remove algae (Longfellow and Holt 2004). This suggests that Spanaway Lake has a long history of nuisance algae blooms.

1.4 Lake Management Plan

The County's Surface Water Management (SWM) group has made protection of Spanaway Lake a top priority. In 2011, SWM initiated the "Raise the Grade" program to improve water quality in Spanaway Lake and two other key Pierce County water bodies. SWM installed bioretention facilities to treat stormwater runoff in Spanaway Lake Park and retrofitted stormwater drywells around the lake. SWM also published newsletters to educate lakeshore residents about phosphorus and bacteria sources such as septic systems, pets, fertilizer use, and stormwater runoff.

In 2013, the County received a state budget allocation to prepare the Lake Management Plan (LMP), that would lead to a long-term improvement in water quality and protection of beneficial uses in Spanaway Lake. The goal of the LMP is to develop strategies to improve and protect the lake uses rather than attain specific numeric water quality targets.

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The County selected Brown and Caldwell (BC) to help develop the LMP. BC retained Geosyntec Consultants (Geosyntec) and Dr. Mark Sytsma (Applied Ecology Consulting) as subconsultants to provide technical support for the planning effort. County staff performed most of the monitoring. The County's contract laboratory, Spectra Laboratories (in Tacoma, Washington), analyzed the surface water, groundwater, and sediment samples for all parameters except phytoplankton and zooplankton, which were analyzed by Water Management Laboratories, Inc. (in Tacoma, Washington).

This LMP provides a summary of the monitoring activities that were conducted and a characterization of Spanaway Lake water quality, and then identifies and quantifies the nutrient sources affecting the lake. The LMP also identifies management measures toward achieving the County's goals for the lake including recommendations for appropriate source control and/or treatment measures, including an implementation strategy.

Section 2 summarizes the results of the monitoring program. Section 3 discusses the current trophic status of the lake. Sections 4 and 5 summarize the lake water and nutrient budgets, respectively. Section 6 describes the potential phosphorus and fecal contamination sources identified based on the monitoring data. Section 7 describes the management measures and Section 8 discusses how the County may implement the measures.

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Section 2: Phase 1 Monitoring Results

BC and Geosyntec prepared a Quality Assurance Project Plan (QAPP) to guide collection of the field data needed to develop the Spanaway LMP. The QAPP called for a streamlined monitoring program to fill key data gaps while keeping within the limited budget allocated for monitoring and modeling. The overall goal was to obtain a broad understanding of the watershed processes and lake water and nutrient budgets, as well as the lake management measures that could be effective. The QAPP noted that additional monitoring and modeling may be needed to support the design and implementation of specific lake management measures (BC and Geosyntec 2014). Ecology reviewed and approved the QAPP in October 2014.

2.1 Water Quality Monitoring Activities

County staff collected field data for the Spanaway LMP from October 2014 through December 2015. Field data collection included:

- Nineteen rounds of lake water quality vertical profiling
- Nineteen rounds of water sampling at three locations in the lake
- Sixteen rounds of routine water sampling and six rounds of storm event sampling from Coffee Creek and Spanaway Creek
- Three to four rounds of groundwater sampling in six monitoring wells installed around the lake
- One round of lake-bed sediment sampling at five locations

Figure 6 below shows the monitoring locations. Tables 2 and 3, respectively, list the LMP monitoring parameters and frequencies. Table 4 lists the minimum, average, and maximum observed values for key sample parameters. Appendix A provides copies of the field sheets and laboratory results. Appendix B provides copies of the monitoring well logs.

In addition to the LMP monitoring, the County collected flow data from Coffee Creek (SW-2) and Spanaway Creek (SW-1) to develop a hydrologic model for the Spanaway Watershed-Scale Stormwater Management Plan (WSP). The County is developing the WSP to meet the requirements of the National Pollutant Discharge Elimination System (NPDES) Phase 1 municipal stormwater permit.

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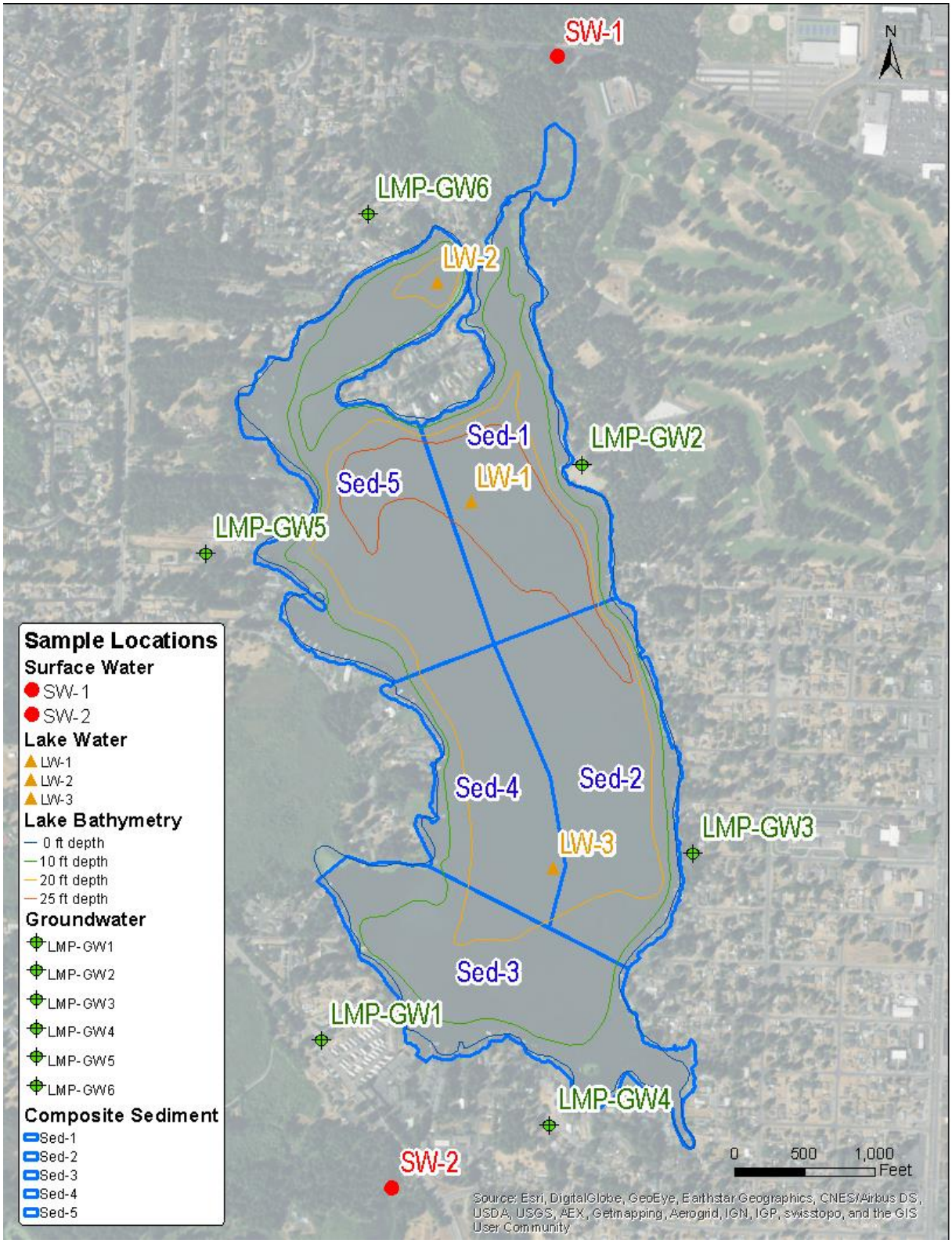

Figure 6. Spanaway LMP monitoring locations

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Table 2: Sampling Locations and Constituents

Sample type	Site ID	TP	SRP	NH4	TKN	NO3	Alkalinity	Fe	TSS	Fecal coliform	Phyto-plankton	Zoo-plankton	Chlorophyll-a	Temperature	pH	DO	Electrical conductivity	Transparency (Secchi depth)	% Solids	Particle size	TOC
Lake water	LW-1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
	LW-2	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓			
	LW-3	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓			
Creek water	SW-1	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓							
	SW-2	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓							
Groundwater	LMP-GW1	✓	✓	✓		✓			✓	✓				✓	✓		✓				
	LMP-GW2	✓	✓	✓		✓			✓	✓				✓	✓		✓				
	LMP-GW3	✓	✓	✓		✓			✓	✓				✓	✓		✓				
	LMP-GW4	✓	✓	✓		✓			✓	✓				✓	✓		✓				
	LMP-GW5	✓	✓	✓		✓			✓	✓				✓	✓		✓				
	LMP-GW6	✓	✓	✓		✓			✓	✓				✓	✓		✓				
Lake-bed sediment	Sed-1	✓			✓			✓											✓	✓	✓
	Sed-2	✓			✓			✓											✓	✓	✓
	Sed-3	✓			✓			✓											✓	✓	✓
	Sed-4	✓			✓			✓											✓	✓	✓
	Sed-5	✓			✓			✓											✓	✓	✓
	Sed-6	✓			✓			✓											✓	✓	✓

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Table 3: Spanaway LMP Monitoring Locations and Frequencies			
Media	**Sampling location**	**Methods**	**Frequency**
Spanaway Lake Water	**LW-1: South of Enchanted Island, deepest part of lake**	• **In-situ vertical (depth) profiling using datasonde** • **Grab sampling from mid-depth when not stratified** • **Grab sampling from epilimnion and hypolimnion when stratified**	• **Twice per month when stratified** • **Monthly when lake was not stratified**
	LW-2: Embayment north of Enchanted Island	• **Grab sampling from mid-depth when not stratified** • **Grab sampling from epilimnion when stratified**	
	LW-3: Southern part of lake	• **Grab sampling from mid-depth when not stratified** • **Grab sampling from epilimnion when stratified**	
Creek water	**SW-2: Coffee Creek upstream of lake**	• **Grab sampling** • **Storm event sampling**	• **Monthly** • **Six storm events, three samples at 12-hour intervals during each event**
	SW-1: Spanaway Creek downstream of lake		
Groundwater	**Six shoreline monitoring wells (LMP-GW1, LMP-GW2, LMP-GW3, LMP-GW4, LMP-GW5, and LMP-GW6)**	**Purge then collect grab sample using pump**	**Quarterly**
Lake-bed sediment	**Five locations throughout lake (Sed-1 through Sed-5)**	**Use clamshell sampler to collect one composite sample from each area**	**Once during summer**

2.2 Lake Water Quality Vertical Profiling Results

Lake water quality vertical profiling involved in-situ water quality measurements at 0.5 m intervals from the lake surface to the bottom in the deepest part of the lake (LW-1, just south of Enchanted Island). Lake water samples were collected at LW-1, LW-2 (bay north of Enchanted Island), and LW-3 (southern portion of lake). When the lake was not stratified, a sample was collected from mid-depth at each location. When the lake profile data showed that the lake was stratified, samples were collected from the epilimnion at all three locations and from the hypolimnion at LW-1. Hypolimnion samples were also collected from LW-2 and LW-3 on two occasions.

Figure 7 below shows the lake water temperature profiles that were measured at the deepest part of the lake (LW-1). As shown in Figure 7, Spanaway Lake undergoes summer thermal stratification typical for a lake of its size and depth. Stratification began in late April and ended in early October 2015.

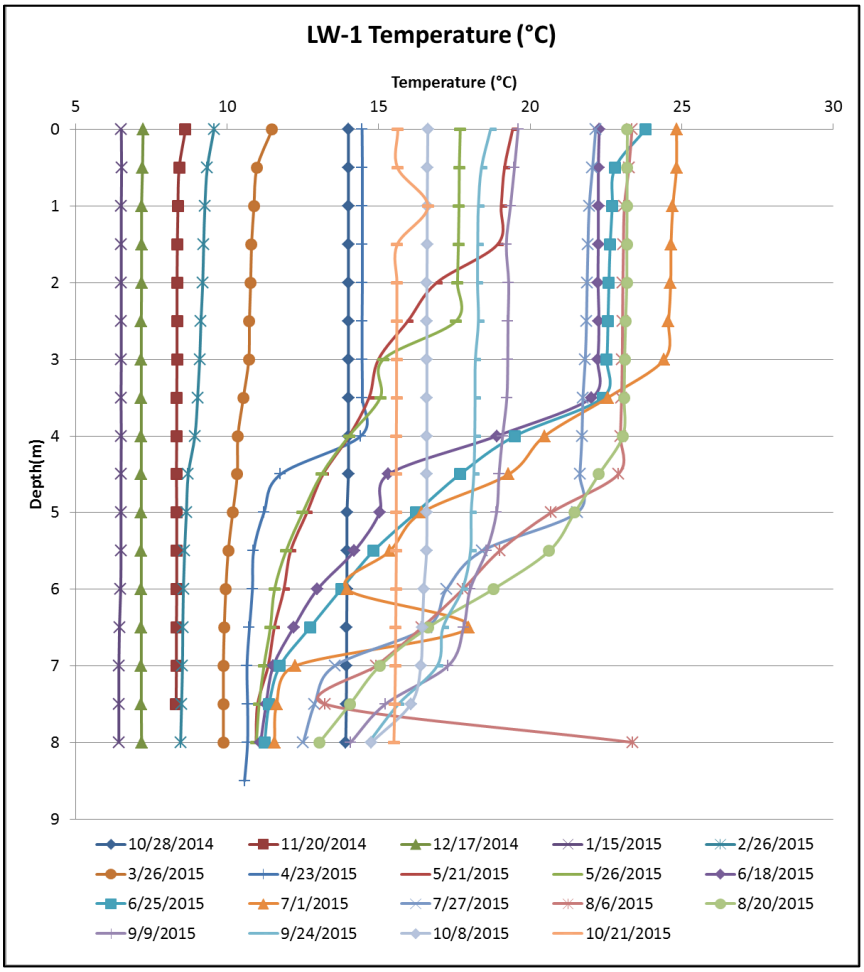

Figure 7. Spanaway Lake water temperature vertical profiles at monitoring site LW-1

During stratification cooler, denser water in the bottom of the lake (hypolimnion) is prevented from mixing with the warmer, well-oxygenated surface water (epilimnion) by an abrupt temperature and water density transition (thermocline). DO concentration within the hypolimnion becomes progressively depleted because of decomposition of organic material in the sediment and the lack of re-aeration. By October, cooler surface temperatures eliminate this mixing barrier, allowing the lake waters to fully mix and reintroduce DO into the hypolimnion.

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Figure 8 below shows the DO concentration vertical profiles for Spanaway Lake during the 2015 summer stratification period. These profiles show a clear progression of anoxia (i.e., DO less than 1 mg/L) developing in the hypolimnion during the summer, with anoxic conditions frequently observed at depths greater than 6 m. Also notable was a distinct increase in DO concentrations observed in the metalimnion during May and June, possibly caused by abundant phytoplankton settling and collecting above the denser waters of the hypolimnion and releasing oxygen through photosynthesis. Low DO concentrations in the hypolimnion can create conditions that allow release of soluble phosphorus from the lake-bed sediment into the water column—further degrading water quality.

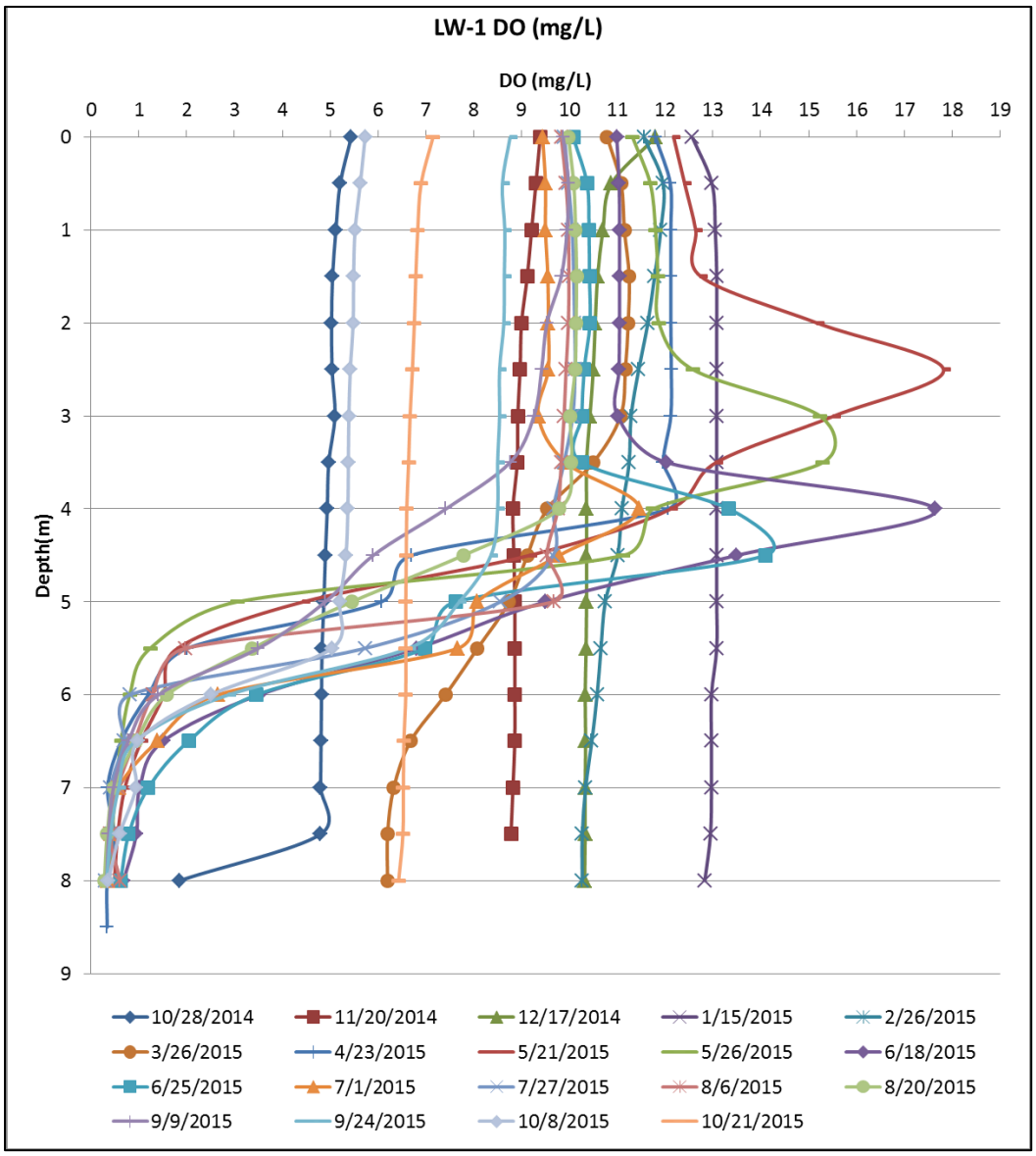

Figure 8. Spanaway Lake DO concentration vertical profiles at monitoring site LW-1

Figure 9 shows the electrical conductivity vertical profiles for the lake. Water conductivity increases as the concentrations of dissolved salts or ions increase. Figure 9 shows that conductivity increased in the lake water below 6 m after Spanaway Lake became thermally stratified. This pattern of increased conductance in the hypolimnion is common in lakes, and is typically due to: (1) ionic loading to the hypolimnetic water that is thermally separated from mixing, and (2) decomposition of algae and other organic detritus by bacteria. This decomposition releases carbon dioxide into the water, which then forms carbonic acid (H_2CO_3), bicarbonate ions (HCO_3^-), and carbonate ions (CO_3^-) at a ratio determined by the pH of the water. These newly created ions increase the conductivity of the hypolimnion.

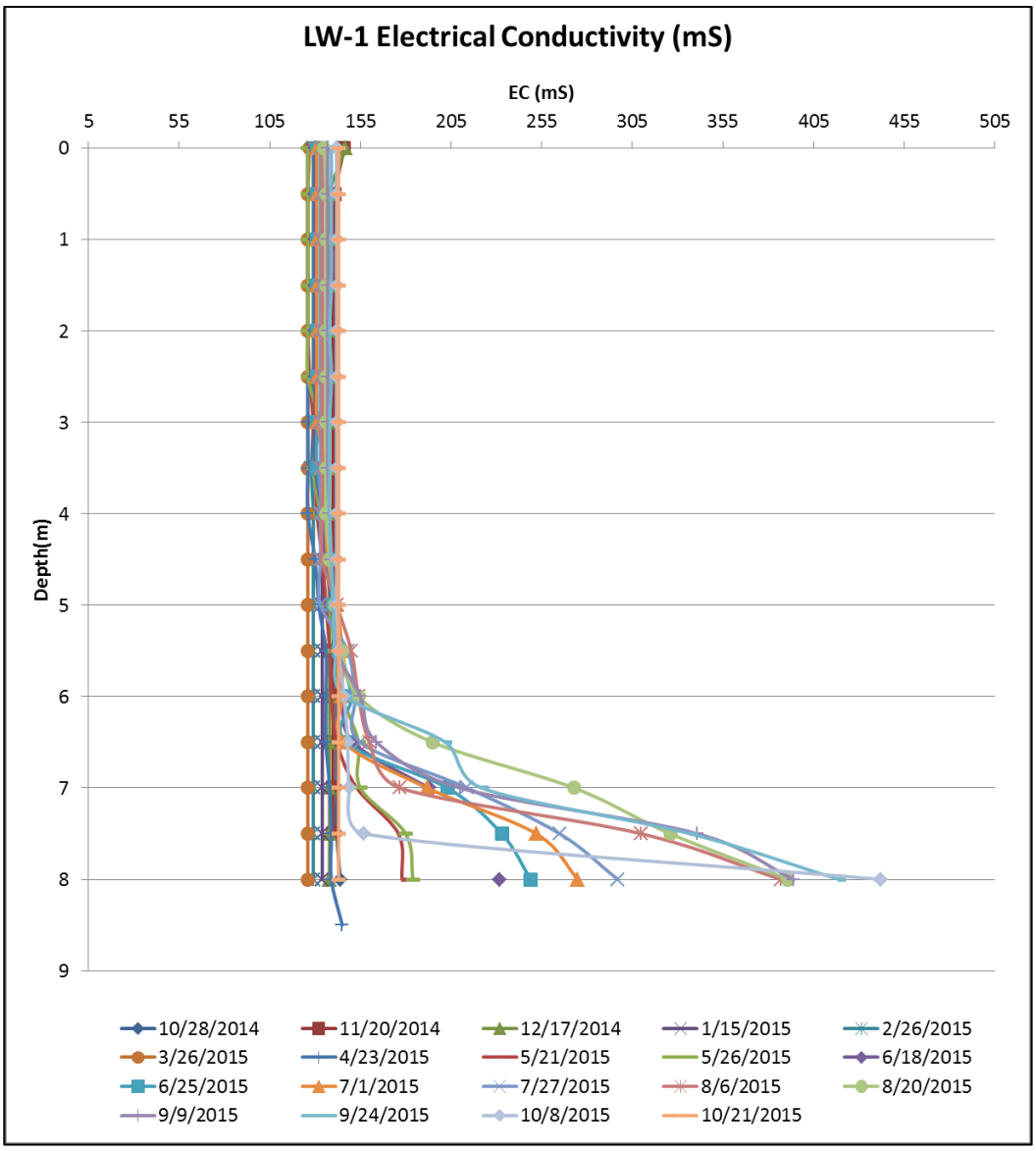

Figure 9. Spanaway Lake conductivity vertical profiles at monitoring site LW-1

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Figure 10 shows the pH profiles that were observed in Spanaway Lake. The highest pH values were observed in the epilimnion during the stratification period. These relatively high pH values are likely because of algal uptake of dissolved carbon dioxide during photosynthesis. During intense photosynthesis, carbon dioxide and its dissociation product, carbonic acid, become less abundant, resulting in higher pH values. The lowest pH levels were observed in the hypolimnion, likely because of decomposition, carbon dioxide production, and lack of vertical mixing. The lake water pH was occasionally outside of the state water quality criteria range of 6.5 to 8.5 S.U.

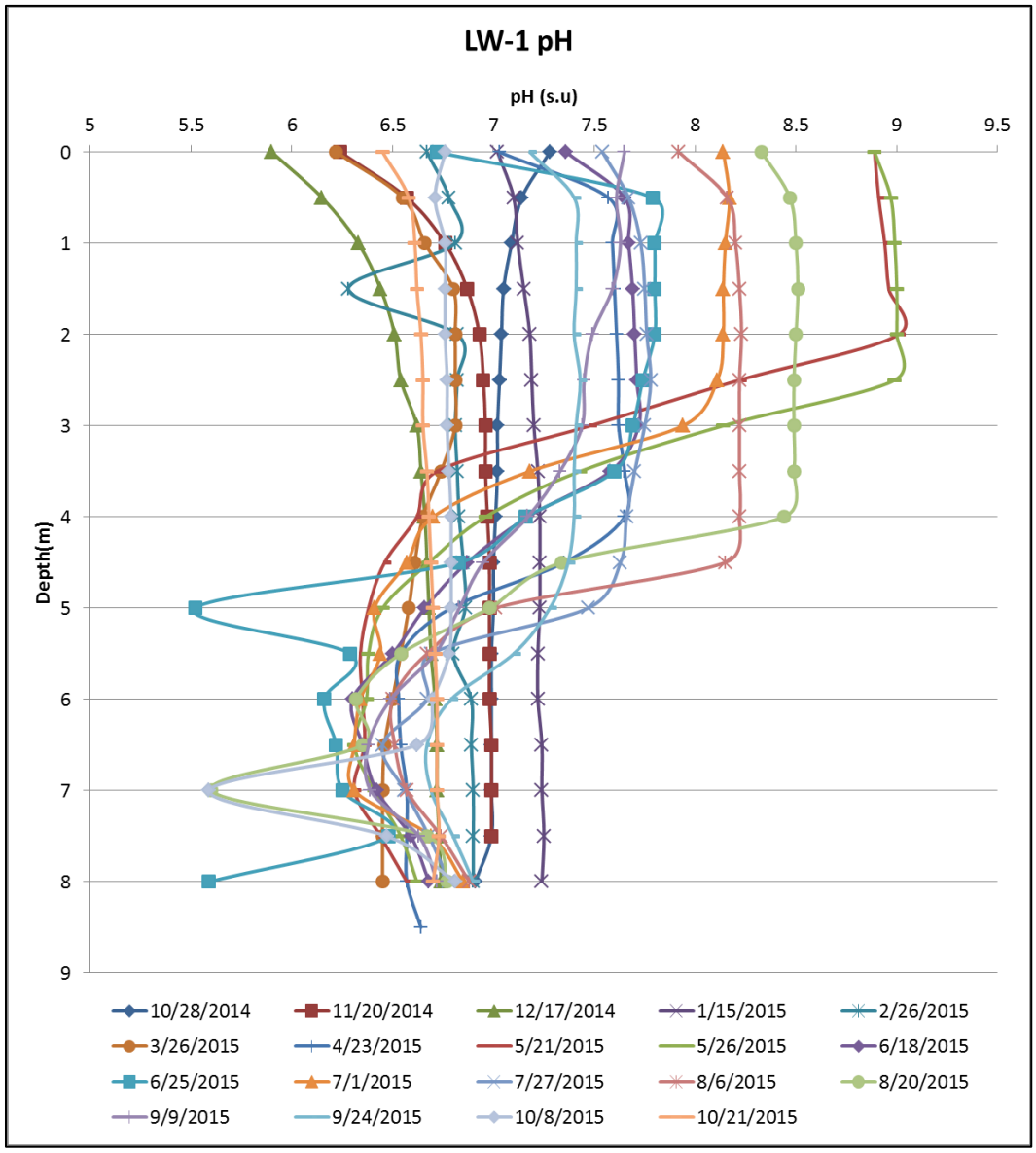

Figure 10. Spanaway Lake pH vertical profiles from LW-1

2.3 Lake Water Sample Results

Lake water samples were collected from three locations in the lake 19 times from October 2014–15. When the lake vertical profiling indicated that the lake was not stratified, a grab simple was collected at mid-depth from each location. In general, when the lake was stratified, a grab simple was collected from the epilimnion and hypolimnion at LW-1, and from the epilimnion at LW-2 and LW-3. During two rounds, hypolimnion samples were also collected from LW-2 and LW-3. A Kemmerer sampler was used to collect the lake water samples from a specific water depth.

Table 4 below lists the minimum, average, and maximum observed values for key parameters in the lake samples. As noted in Table 4, TP concentrations in lake water samples ranged from 0.005 to 0.250 mg/L. Figures 11, 12, and 13 below show the laboratory results for LW-1, LW-2, and LW-3, respectively. The hypolimnion samples collected at LW-1 contained higher TP concentrations than the epilimnion samples. Epilimnion samples collected at LW-2 were typically higher than the epilimnion samples collected at LW-1 or LW-3. The higher epilimnion concentrations at LW-2 could be related to its location in a narrow embayment with developed areas on both sides or because of circulation and use patterns near the monitoring site. In addition, the monitoring is near a relatively deep location where anoxic conditions may be contributing to higher phosphorus concentrations locally in the lake.

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Table 4: Spanaway Lake Water Quality Results for Key Parameters

Sample type	Location	TP (mg/L)			TN (mg/L-N)			N:P ratio[a]			Chlorophyll-a (mg/m^3)			Secchi depth (m)			Fecal coliform (cfu/100 mL)		
		Min	Average[b]	Max	Min	Average[b]	Max	Min	Average[b]	Max	Min	Average[b]	Max	Min	Average[b]	Max	Min	Geomean[c]	Max
Lake water	LW-1	0.016	0.021	0.030	0.50	1.69	2.70	31	79	135	7	21	49	1.10	2.30	4.10	ND	0.02	80
	LW-1E	0.005	0.017	0.035	0.25	0.75	1.60	14	62	160	ND	10	28	N/A	N/A	N/A	ND	0.009	10
	LW-1H	0.005	0.070	0.250	0.61	1.52	3.20	7	38	100	9	54	241	N/A	N/A	N/A	ND	0.004	10
	LW-2	0.014	0.036	0.130	1.28	2.12	4.40	18	105	314	7	13	22	1.20	2.37	4.30	ND	ND	ND
	LW-2E	0.005	0.029	0.120	0.25	0.86	1.40	8	58	140	ND	9	22	N/A	N/A	N/A	ND	0.017	20
	LW-2H	0.020	0.025	0.030	0.25	0.68	1.10	25	31	37	ND	ND	ND	N/A	N/A	N/A	ND	ND	ND
	LW-3	0.020	0.023	0.030	1.37	1.89	2.90	47	85	145	9	14	21	1.20	2.35	4.50	ND	0.013	10
	LW-3E	0.005	0.018	0.034	0.25	0.82	1.40	15	58	130	ND	9	22	N/A	N/A	N/A	ND	0.006	10
	LW-3H	0.020	0.020	0.020	0.60	0.95	1.30	30	48	65	3	4	5	N/A	N/A	N/A	ND	ND	ND
Creek water	SW-1 Routine	0.010	0.029	0.047	0.25	1.20	2.80	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	22	250
	SW-1 Storm	0.005	0.030	0.040	0.50	1.64	3.40	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	62	1675
	SW-2 Routine	0.020	0.026	0.033	0.25	0.75	1.60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5.000	29	220
	SW-2 Storm	0.005	0.028	0.044	0.25	0.91	2.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	12	395
Groundwater	LMP-GW1	0.010	0.019	0.030	1.10	2.65	6.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	N/A	ND
	LMP-GW2	0.010	0.040	0.077	4.90	5.33	6.00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	1.26	100
	LMP-GW3	0.020	0.029	0.043	0.72	4.32	6.20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	0.003	10
	LMP-GW4	0.016	0.020	0.028	3.10	3.38	3.90	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	ND	ND
	LMP-GW5	0.010	0.025	0.044	0.25	0.32	0.53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	0.018	115
	LMP-GW6	0.024	0.031	0.040	0.51	0.66	0.78	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ND	ND	ND

a. The mass values of TN and TP were used to calculate the N:P ratios.

b. Average values were calculated using half of the reporting limit for any sample results below the reporting limit.

c. Fecal coliform geomean values calculated by modifying ND values to 0.001.

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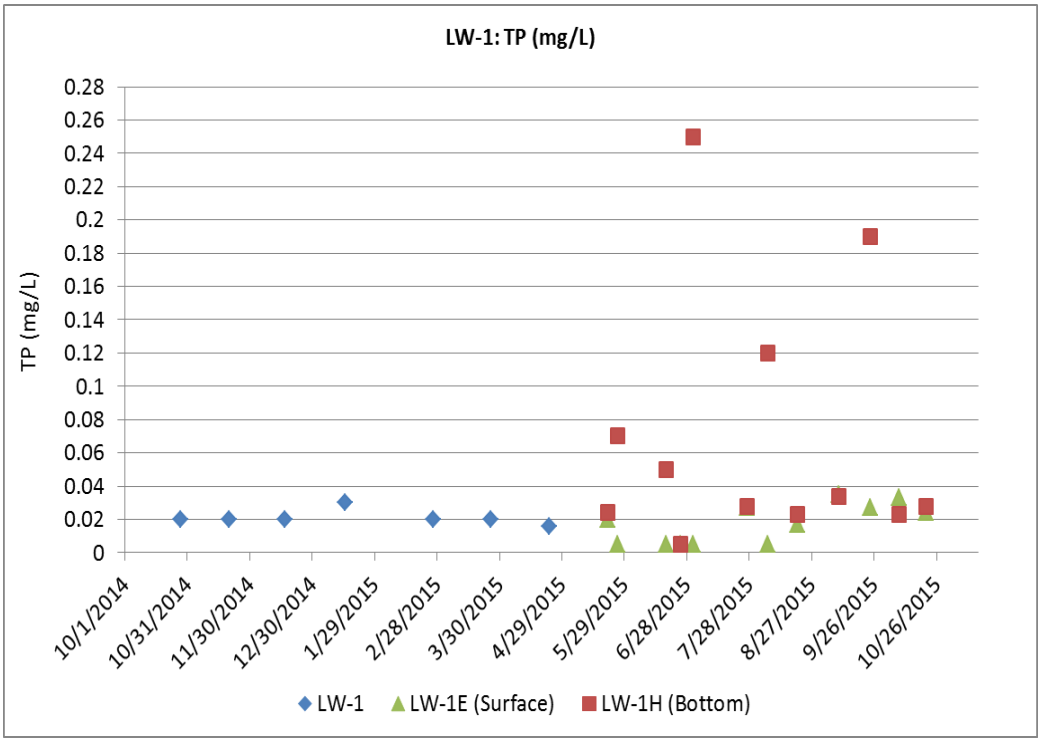

Figure 11. TP concentrations in Spanaway Lake water samples collected at LW-1

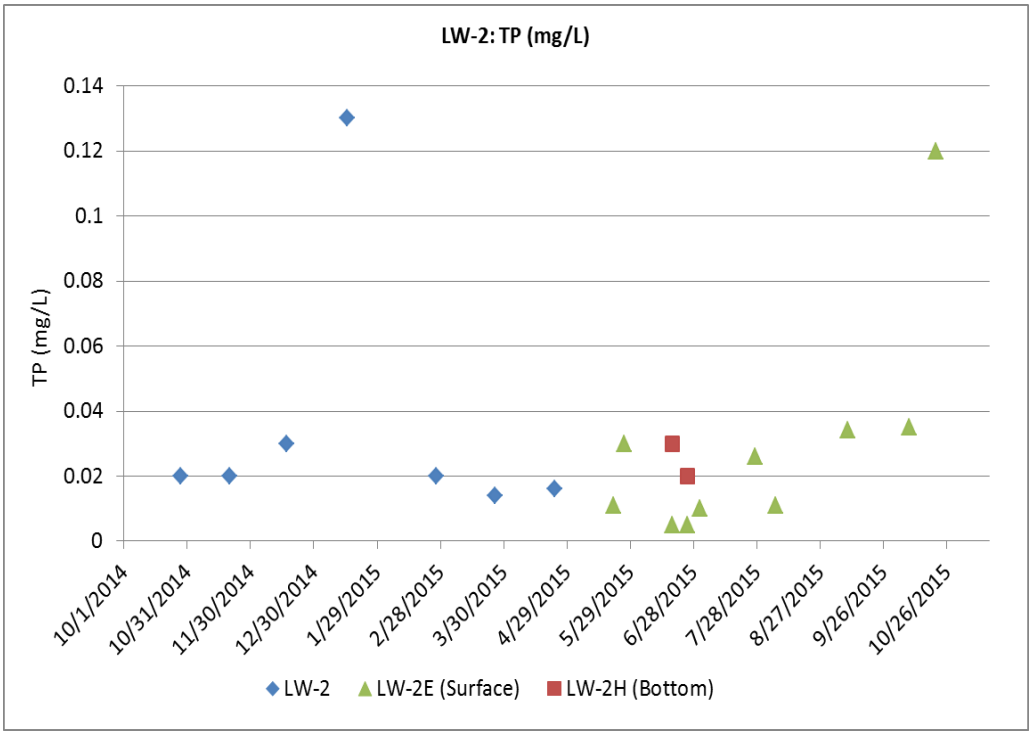

Figure 12. TP concentrations in Spanaway Lake water samples collected at LW-2

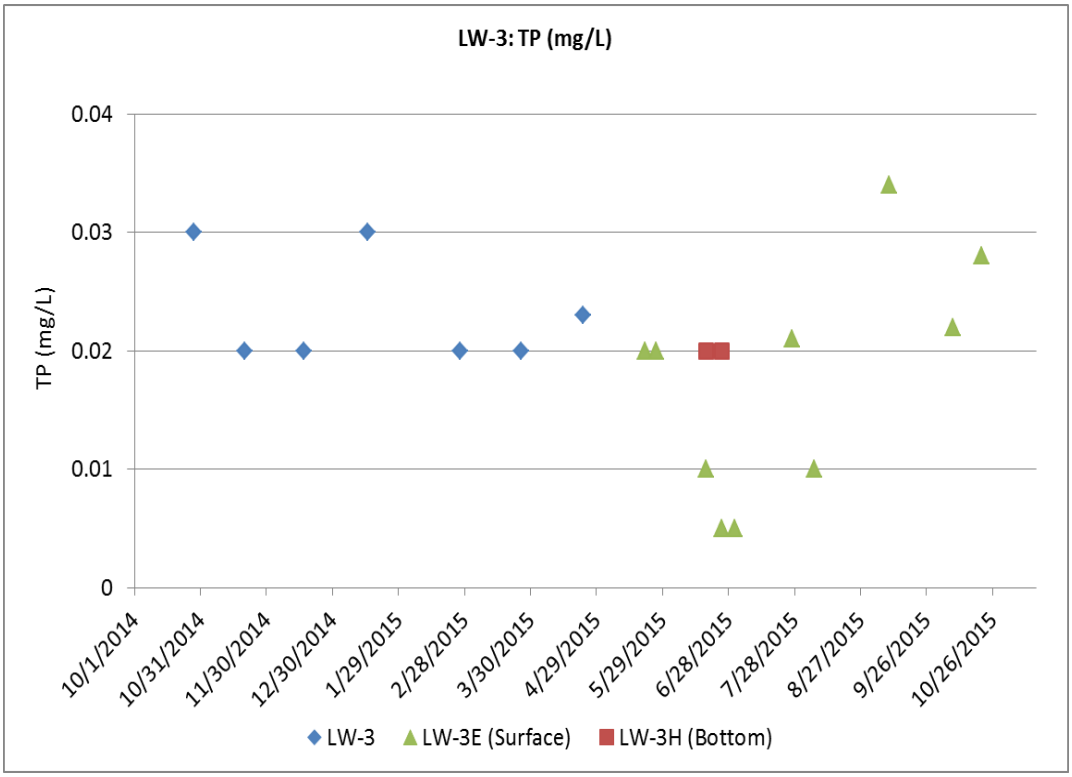

Figure 13. TP concentrations in Spanaway Lake water samples collected at LW-3

The lake TP concentrations measured during this study were similar to the concentrations measured by Ecology during summer 1998. The LW-1 epilimnion and hypolimnion samples ranged from 0.005 to 0.035 mg/L and 0.005 to 0.250 mg/L, respectively. The 1998 epilimnion and hypolimnion samples from the same general location ranged from 0.013 to 0.029 mg/L and 0.015 to 0.340 mg/L, respectively (Ecology 2000). The TP concentrations measured at LW-1 hypolimnion from October 2014–15 were similar to the epilimnion concentrations but lower than the hypolimnion concentrations measured during 2012 for the REHAB program. The 2012 samples ranged from 0.008 to 0.037 mg/L in the shallow (1 m) samples and from 0.034 to 1.170 mg/L in the deep (8 m) samples. These differences suggest that TP concentrations in the hypolimnion may vary considerably.

As shown in Table 4, TN concentrations ranged from 0.25 to 4.40 mg/L. The average TN concentration at LW-2 was higher than the averages at LW-1 and LW-3. The mass of TN to TP (N:P) ratios ranged from 7 to 314. Average N:P ratios ranged from 31 to 105. The observed N:P ratios indicate that phosphorus is the main nutrient that is limiting algal growth in the lake.

Chlorophyll-a concentrations ranged from less than 2 milligrams per cubic meter (mg/m^3) to 241 mg/m^3. The highest chlorophyll-a concentrations were found in LW-1 hypolimnion samples (see Figure 14, below). This is likely related to elevated TP concentrations and the potential proximity of algal blooms to the metalimnion interface.

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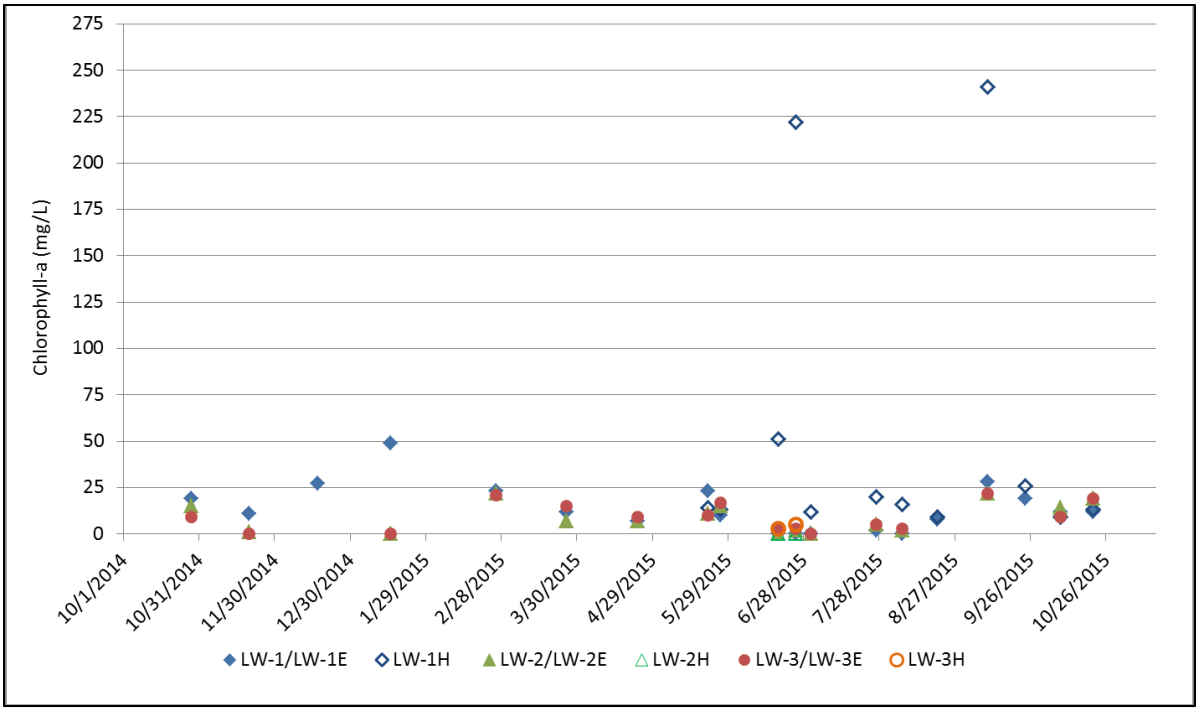

Figure 14. Chlorophyll-a concentrations in Spanaway Lake water samples

Figure 15 below shows the phytoplankton sampling results for LW-1. Overall, cyanobacteria species comprised about 90 percent of the phytoplankton in the lake samples. After the lake stratified, cyanobacteria count in the hypolimnion were often higher than in the epilimnion samples. This may be due the depth of the algal productivity and the nature of the grab samples for the epilimnion versus hypolimnion.

A Secchi disk was used to estimate lake water transparency during each sampling round, and ranged from 1.1 to 4.5 m.

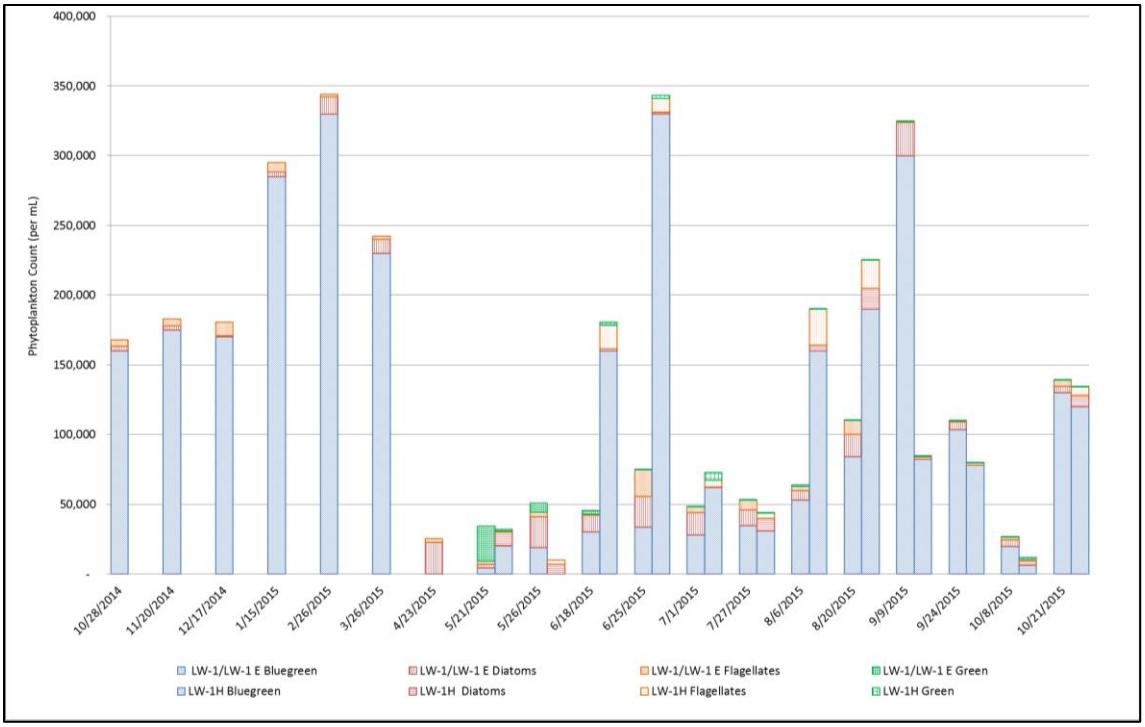

Figure 15. Phytoplankton in Spanaway Lake water samples

As shown in Table 4 above, fecal coliform concentrations in the lake water samples ranged from non-detect (ND) to 80 colony-forming units per 100 milliliters (cfu/100 mL). The highest concentration was in a sample collected from mid-depth at LW-1 on November 20, 2014. Fecal coliform concentrations at all three lake locations were below the state surface water quality criteria (geomean less than 50 cfu/100 mL, no more than 10 percent of samples above 100 cfu/100 mL). The lake water samples had lower fecal coliform concentrations than Coffee Creek upstream of the lake and Spanaway Creek just downstream of the lake.

It should be noted that the lake water samples were collected below the water surface in the middle of the lake, away from potential source areas like swimming beaches, waterfowl feeding areas, shoreline septic systems, and stormwater outfalls. Several samples collected by TPCHD at North Beach and Main Beach during 2015 had elevated concentrations of E. coli, a type of fecal coliform bacteria. For example, a sample collected near North Beach on June 8, 2015, contained 801 cfu/100 mL, while a sample collected from Main Beach on August 10, 2015, contained 540 cfu/100 mL. The TPCHD data suggest that fecal bacteria are a concern in the shoreline areas.

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2.4 Creek Sample Results

Grab samples of baseflow water were collected monthly from Coffee Creek just upstream of the lake, and from Spanaway Creek just downstream of the lake. In addition, samples were collected during six storm events. During each storm event, three grab samples were collected at 12-hour intervals from each creek.

Figures 16 and 17 show the TP concentrations measured in baseflow and storm event samples collected from Coffee Creek (SW-2) upstream of the lake and Spanaway Creek (SW-1) downstream of the lake. The median TP concentration in Spanaway Creek just downstream of the lake was slightly higher than in Coffee Creek upstream of the lake (Figure 16). At both SW-1 and SW-2, the median TP concentrations were slightly higher in storm samples as compared to routine samples.

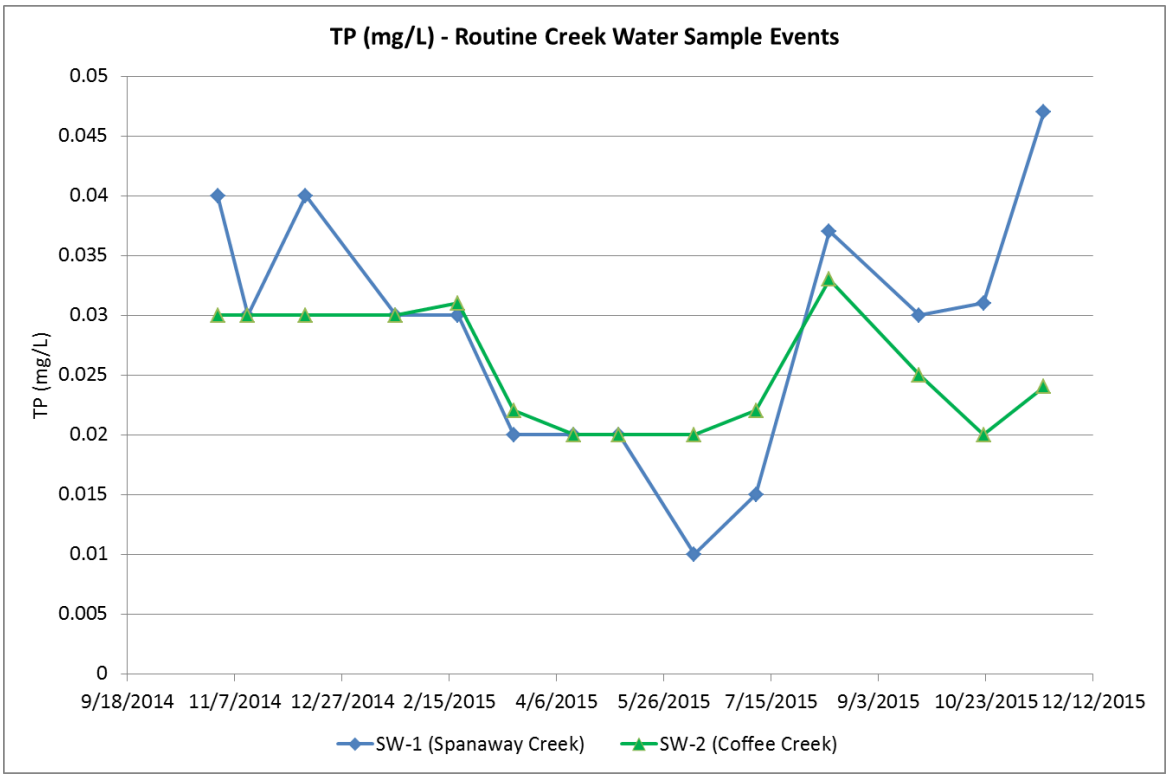

Figure 16. TP concentrations in routine (non-storm) creek samples

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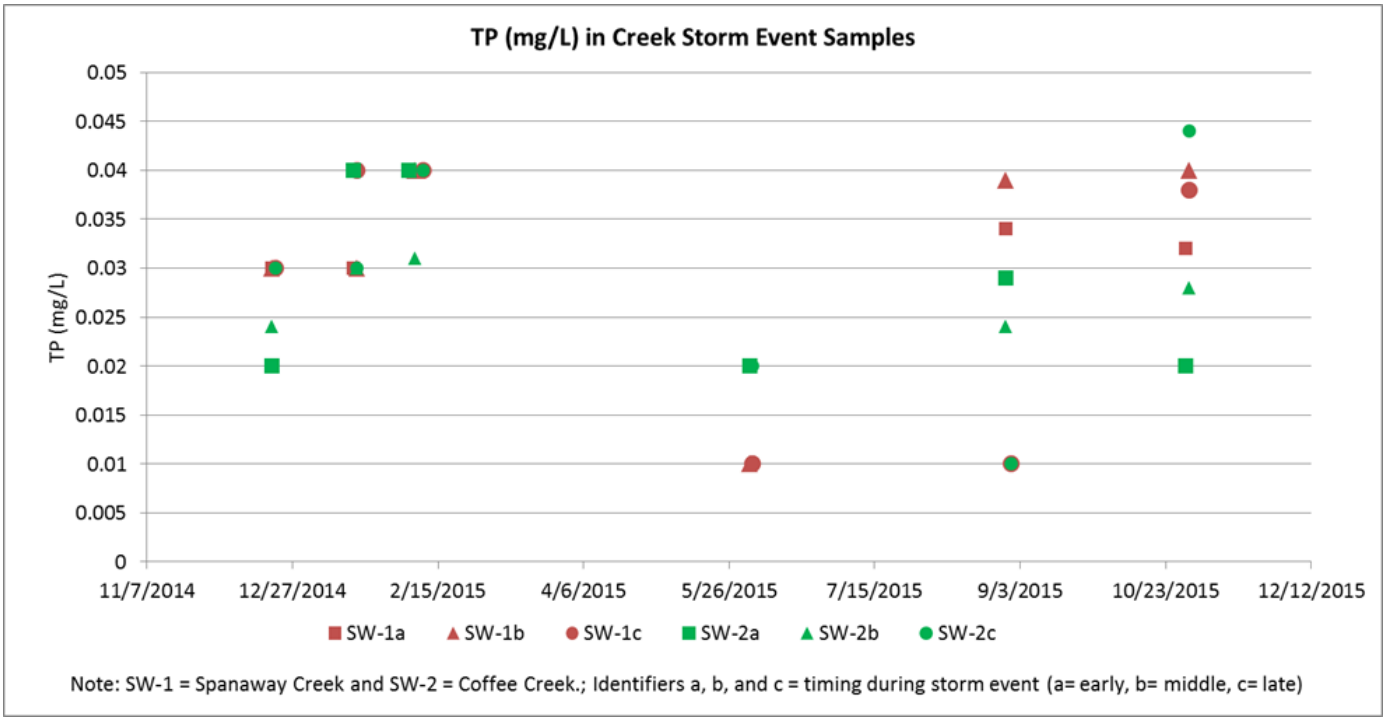

Figure 17. TP in creek samples collected during storm events

TN concentrations followed a different pattern from TP concentrations. Spanaway Creek had higher TN concentrations than Coffee Creek, and storm event samples were higher than the baseflow samples (see Table 4, above).

Fecal coliform in Coffee Creek ranged from 5 to 220 cfu/100 mL in the baseflow samples and 5 to 395 cfu/100 mL in the storm event samples (see Table 4). In Spanaway Creek, fecal coliform concentrations ranged from 2 to 250 cfu/100 mL in the baseflow samples and 10 to 1,675 cfu/100 mL in the storm event samples. Fecal coliform concentrations in the creek samples were considerably higher than the lake samples (see Figure 18). The Coffee Creek samples and the baseflow monthly Spanaway Creek samples met the geometric mean criterion, but more than 10 percent of the monthly and storm event samples from Coffee and Spanaway creeks exceeded 100 cfu/100 mL. The lake water samples met both fecal coliform criteria. In general, the creek fecal coliform concentrations were more variable than the fecal coliform concentrations in the lake.

Figure 19 summarizes the total suspended solids (TSS) concentrations in the creek samples. TSS concentrations ranged from 1 to 4 mg/L in Coffee Creek just upstream of the lake, and from 1 to 10 mg/L in Spanaway Creek just downstream of the lake.

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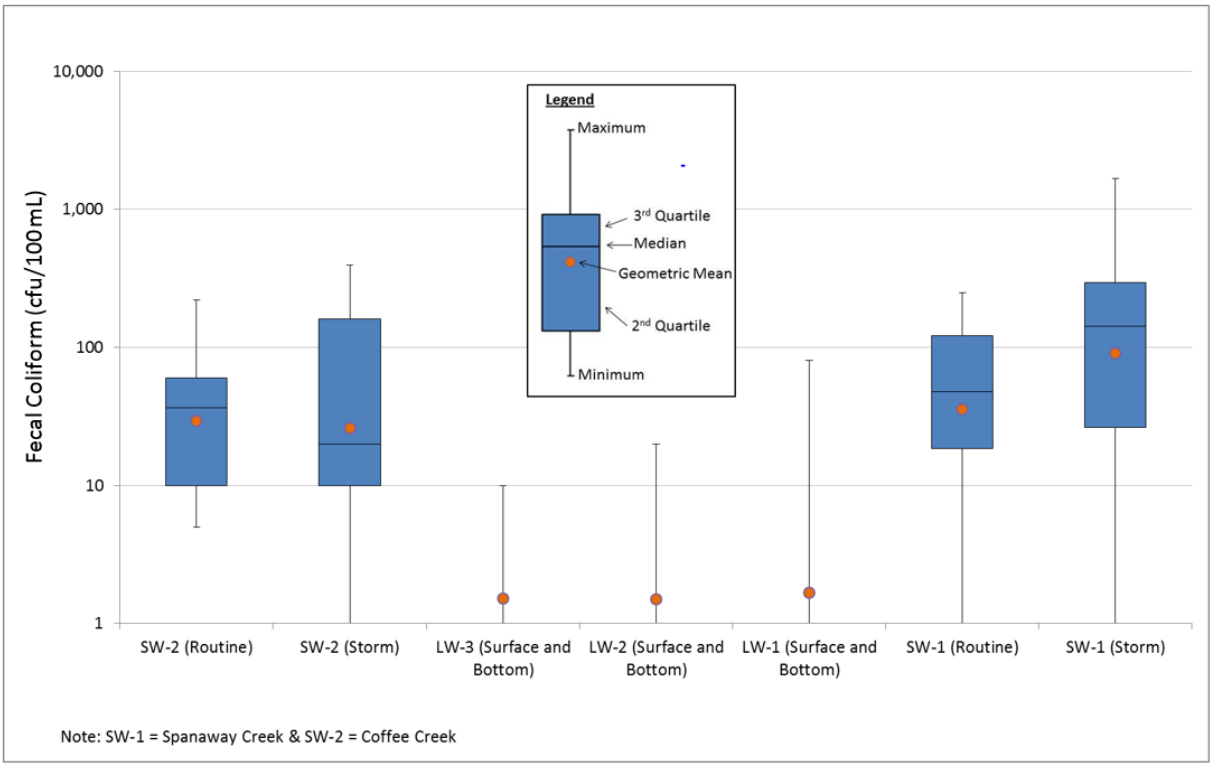

Figure 18. Fecal coliform concentrations in creek and lake samples

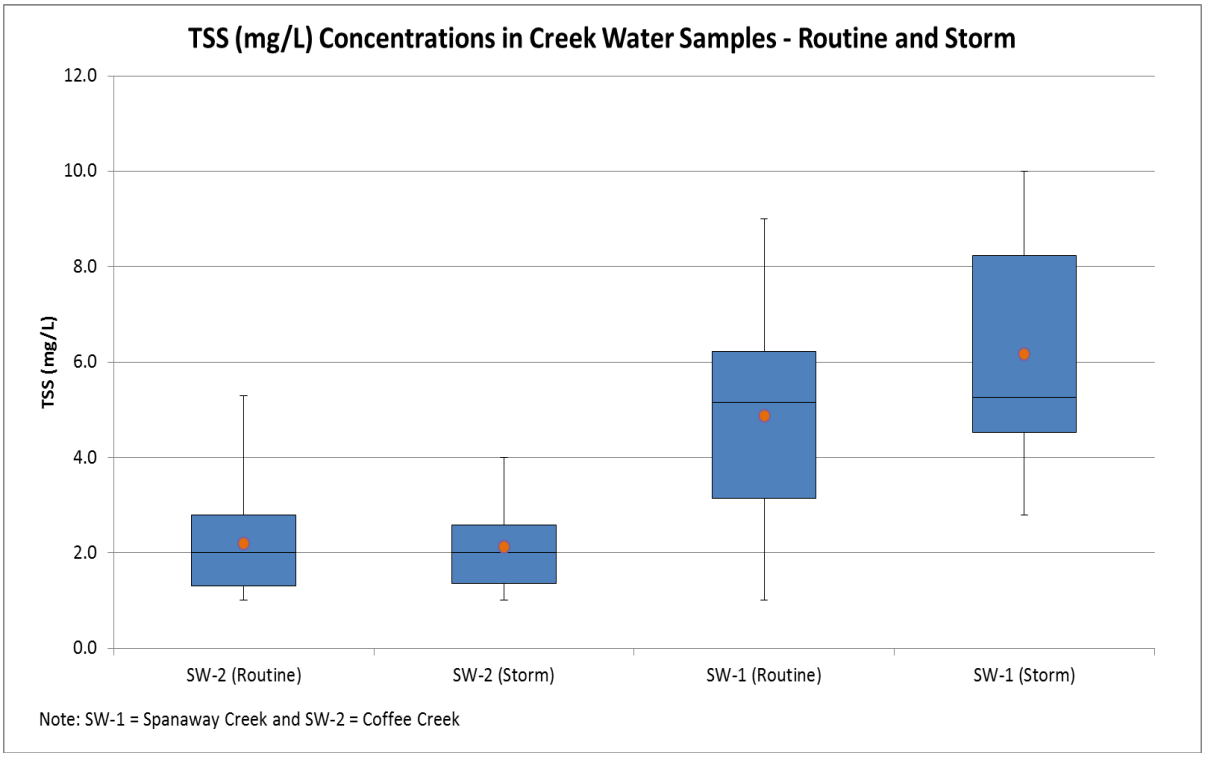

Figure 19. TSS concentrations in creek water samples

2.5 Groundwater Sample Results

Six shallow groundwater monitoring wells were installed around the lake (see Figure 5 above). Each groundwater well was sampled three to four times between March and December 2015. The average TP concentrations in the shoreline area groundwater monitoring wells ranged from 0.019 to 0.040 mg/L as shown in Table 4 above. The average TP concentration for the four wells south and east of the lake was 0.026 mg/L. The average TP concentration for all six groundwater wells combined was 0.027 mg/L. Figure 20 below shows the TP concentrations that were measured in each monitoring well.

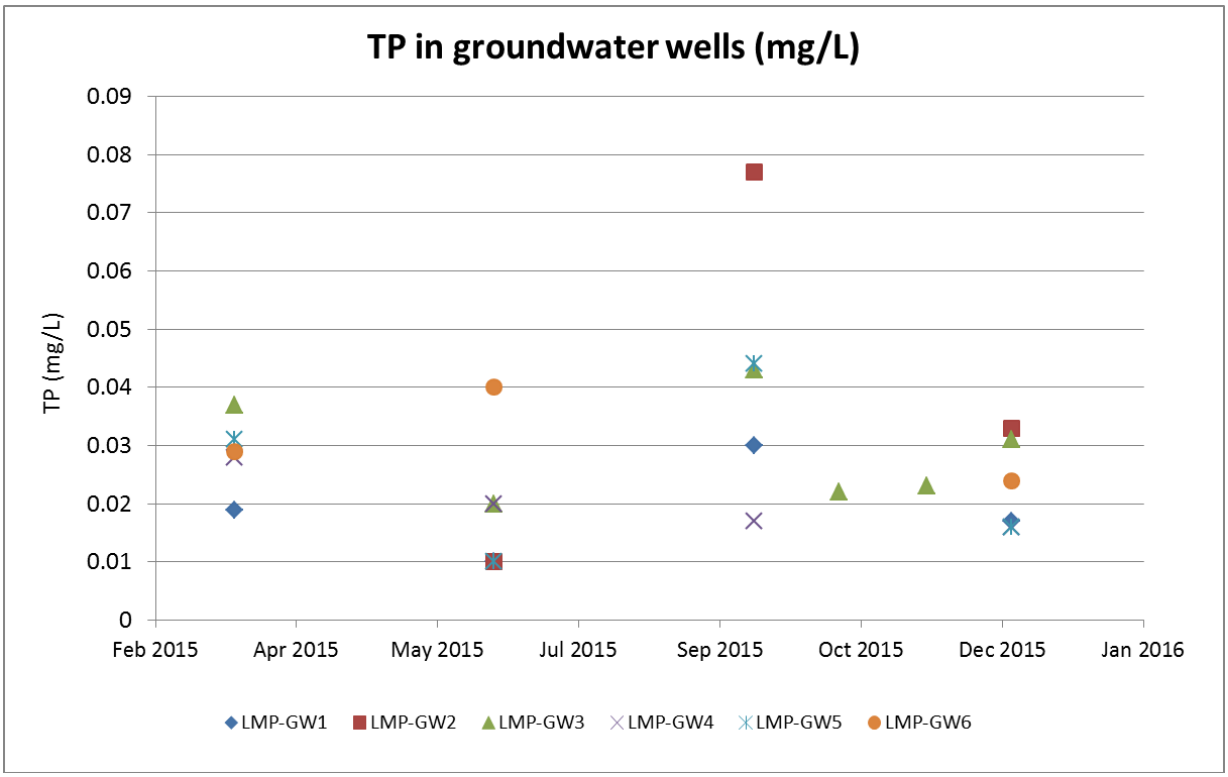

Figure 20. TP in groundwater samples collected near Spanaway Lake

Average TN concentrations in the groundwater monitoring well samples ranged from 0.5 to 5.3 mg/L. The average TN concentrations for the six wells combined was 3.17 mg/L. Most of the TN was in the form of nitrate, with a combined average of 3 mg/L. Ammonia was detected only at LMP-GW6, where several samples contained low concentrations (less than 0.3 mg/L).

Fecal coliform concentrations ranged from ND to 115 cfu/100 mL in the groundwater monitoring wells. The highest concentrations were observed in groundwater samples from LMP-GW2 and LMP-GW5. As shown in Figure 21 below, the groundwater samples generally had lower fecal coliform concentrations than samples collected from Coffee Creek or Spanaway

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Creek. Nevertheless, elevated fecal coliform concentrations in the groundwater are a concern because they could indicate potential septic system impacts. Viruses are much smaller than fecal indicator bacteria and can travel considerably farther in groundwater.

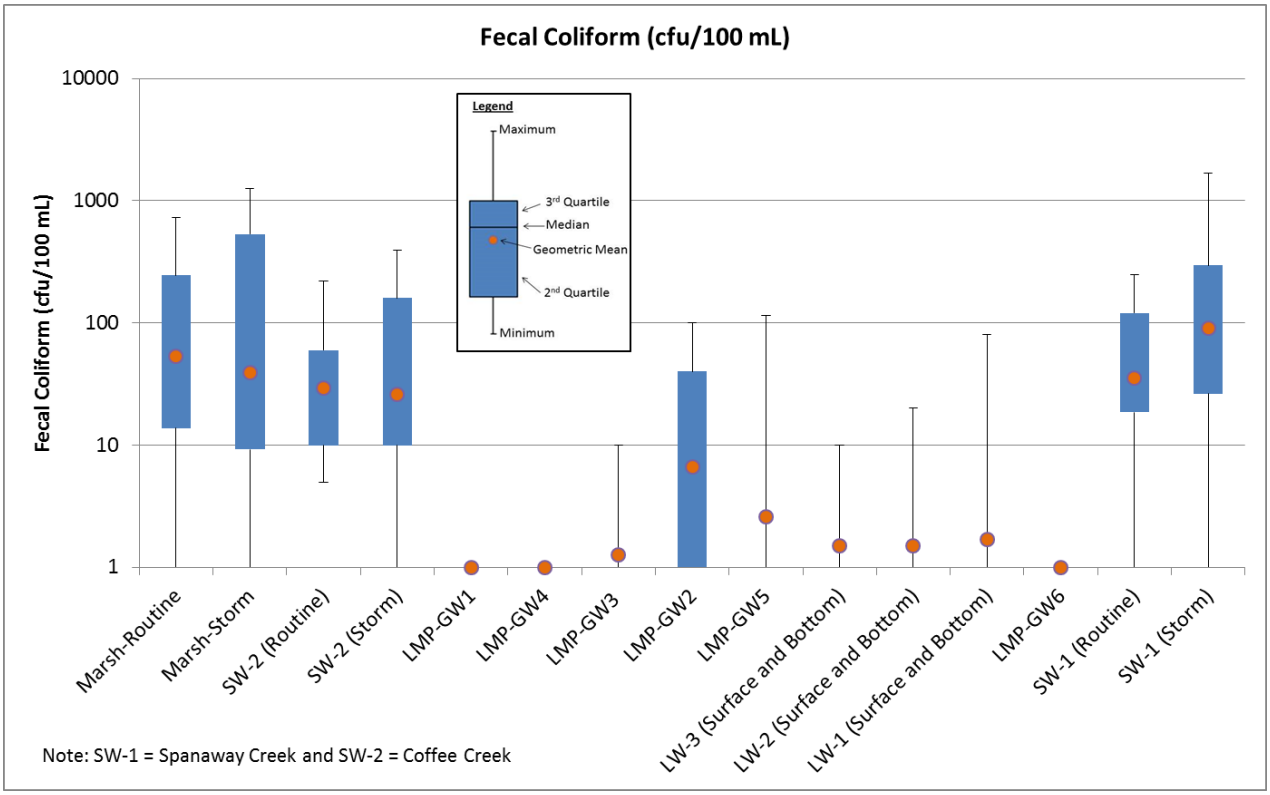

Figure 21. Fecal coliform concentrations in lake, creeks, and groundwater

2.6 Lake-bed Sediment Sample Results

Lake-bed sediment samples were collected throughout the lake. The lake was divided into five areas as shown in Figure 6 above. Five subsamples were collected within each area and combined to form a composite sample for chemical and grain size analyses. Table 5 below lists the analytical results.

As shown in Table 5, TP concentrations ranged from 487 milligrams per kilogram (mg/kg) (or parts per million) to 2,490 mg/kg. The samples contained 2,540 to 18,700 mg/kg of total Kjeldahl nitrogen (TKN) concentration, which measures organic and ammonia-nitrogen (N). TOC concentrations ranged from 11,100 to 315,000 mg/kg.

Four of the five samples were more than 80 percent fine-grained materials (silt and clay), while the fifth contained only 15 percent fines. The sample with only 15 percent fines contained lower TKN and TOC than the other sediment samples. The TOC and particle size results indicate that fine-grained organic materials covered four of the five sediment sampling areas.

The results indicate the lake sediments are mostly fine-grain sediments (silt and clay) and have high concentrations of organic carbon, nutrients, and iron.

Table 5: Lake-bed Sediment Sample Results

Sample location	TP (mg/kg dry)	TKN (mg/kg dry)	TOC (mg/kg dry)	Total Fe (mg/kg dry)	% Fines
Sed-1	1,070	2,540	11,100	23,200	12.7
Sed-2	2,490	18,700	196,000	32,300	85.3
Sed-3	487	17,200	315,000	7,130	82.5
Sed-4	1,010	16,500	254,000	15,400	83.5
Sed-5	1,810	16,600	187,000	26,200	79.2

2.7 Monitoring Results Summary

County staff collected field data from October 2014 through December 2015 to support development of the Spanaway LMP. Field data collection involved monitoring lake water, creek water, groundwater, and lake-bed sediment. The key findings include:

- Secchi depths (transparency) ranged from 1.1 to 4.5 m.
- Blue-green algae comprised about 90 percent of the phytoplankton in the lake.
- N:P ratios indicate that phosphorus is the primary nutrient that limits algal growth in the lake.
- Spanaway Lake became thermally stratified and developed anoxic conditions (DO concentration less than 1 mg/L) in the hypolimnion from about May 15 through September 15, 2015.
- TP concentrations in the hypolimnion samples ranged from 0.005 to 0.250 mg/L, while epilimnion samples ranged from 0.005 to 0.120 mg/L. TP results were similar to Ecology's 1998 samples but hypolimnion concentrations were lower than in the samples collected in 2012 for the REHAB program.
- TP concentrations in the monthly and storm event samples collected from Coffee Creek averaged 0.026 mg/L and 0.028 mg/L, respectively.
- The average TP concentrations in the six groundwater monitoring wells ranged from 0.019 to 0.040 mg/L, with an overall (i.e., combined) average of 0.027 mg/L.
- Fecal coliform concentrations in the lake samples were below state surface water quality criteria.

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- Coffee Creek and Spanaway Creek samples exceeded state surface water quality fecal coliform criteria. Concentrations were higher during storm runoff events.
- TP concentrations in lake-bed sediment samples contained 487 to 2,490 mg/kg (parts per million)
- Most of the lake-bed sediment samples were predominantly composed of fine particles (silt and clay) and had high concentrations of organic matter (187,000 to 315,000 mg/kg of organic carbon).

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Section 3: Spanaway Lake Trophic State

Geosyntec used the lake water quality monitoring data to assess the trophic state of Spanaway Lake. Lakes and ponds are typically categorized according to trophic states as follows:

- Oligotrophic: Low biological productivity. Oligotrophic lakes are very low in nutrients and algae, and typically have high water clarity and a nutrient-poor inorganic substrate. Oligotrophic water bodies are capable of producing and supporting relatively small populations of living organisms (e.g., plants, fish, and wildlife). If the water body is thermally stratified, hypolimnetic (deep water) oxygen is usually abundant.
- Mesotrophic: Moderate biological productivity and moderate water clarity. A mesotrophic water body is capable of producing and supporting moderate populations of living organisms (e.g., plant, fish, and wildlife). Mesotrophic water bodies may begin to exhibit periodic algae blooms and other symptoms of increased nutrient enrichment and biological productivity.
- Eutrophic: High biologically productivity because of relatively high rates of nutrient input and nutrient-rich organic sediments. Eutrophic lakes typically exhibit periods of oxygen deficiency and reduced water clarity. Nuisance levels of macrophytes and algae may result in recreational impairments.
- Hypereutrophic: Dense growth of algae throughout summer. Dense macrophyte beds, but extent of growth may be light-limited because of dense algae and low water clarity. Summer fish kills are possible.

Geosyntec calculated the trophic state of Spanaway Lake using the Carlson Trophic State Index (TSI), one of the most commonly used means of characterizing lake trophic states (Carlson 1977). As illustrated in Figure 22, the TSI assigns values based upon logarithmic scales, which describe the relationship between three parameters (TP, chlorophyll-a, and Secchi disk water clarity) and the overall biological productivity of the lake. TSI scores below 40 are considered oligotrophic, scores between 40 and 50 are mesotrophic, scores between 50 and 70 are eutrophic, and scores from 70 to 100 are hypereutrophic as shown in Table 6.

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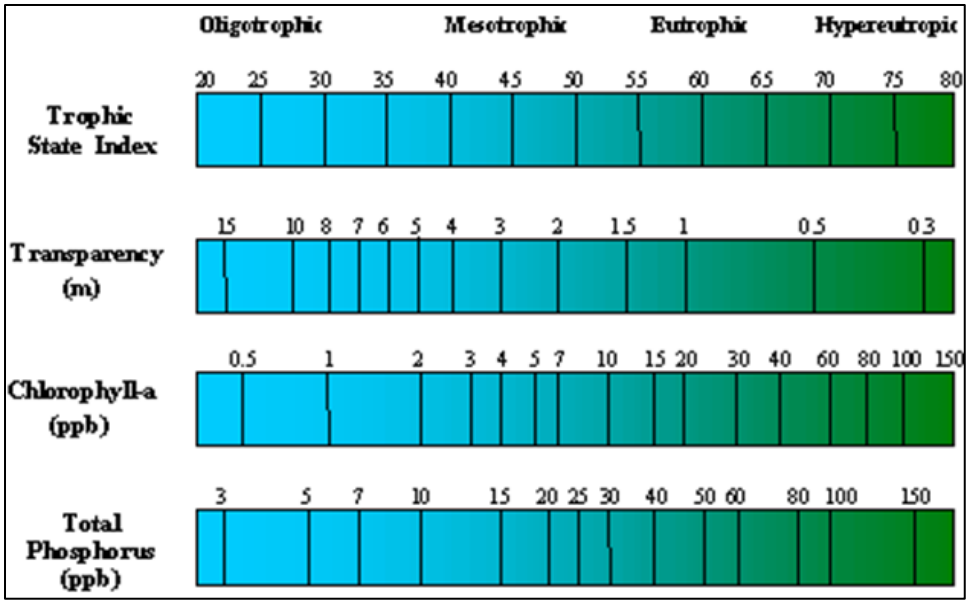

Figure 22. Carlson TSI

(EPA 1988)

Table 6: TSI Ranges				
Trophic State	**TSI**	**TP[a] (ppb)**	**Secchi disk (m)**	**Chlorophyll-a[b] (ppb)**
Oligotrophic	**<40**	**<12**	**>4.0**	**<2.6**
Mesotrophic	**40–50**	**12–24**	**4.0–2.0**	**2.6–7.3**
Eutrophic	**51–70**	**25–96**	**2.0–0.5**	**7.4–56**
Hypereutrophic	**>70**	**>96**	**<0.5**	**>56.0**

a. For TP, parts per billion (ppb) = µg/L.

b. For chlorophyll-a, ppb = mg/m³.

The TSI values for Spanaway Lake were calculated based on the data collected in the summer months (June to September 2015) from the epilimnion water samples during the QAPP data collection time period of 2014–15. Time series plots for respective TSI values calculated from individual sampling events are provided in Appendix C, within the *Nutrient Budget Memorandum*. A summary of the trophic state for the lake is listed below:

- Transparency: Spanaway Lake mean summer Secchi disk (m) = 3.32 m:
  - TSI = 60.00 – 14.41 natural logarithm (*ln)* Secchi disk (m)
  - TSI = 42.7 (mesotrophic)

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- Chlorophyll-a: Spanaway Lake mean summer chlorophyll-a = 0.00553 mg/L:
  - TSI = (9.81) (*ln* chlorophyll-a) + 30.6
  - TSI = 47.4 (mesotrophic)
- TP: Spanaway Lake mean summer TP = 0.0171 mg/L:
  - TSI = (14.42) (*ln* TP mg/L) + 4.15
  - TSI = 45.1 (mesotrophic)

Spanaway Lake has a TSI in the lower/mid-end of the mesotrophic range for chlorophyll-a, Secchi disk transparency, and TP. The close agreement of the TSI scores for these parameters (range of 42.7 to 47.4, respectively) adds confidence to the TSI classification as a lower- to mid-range mesotrophic lake.

The TSI values calculated for this study are slightly lower than the values Ecology calculated based on monitoring conducted in the summer of 1998. Ecology classified the lake as mesotrophic (Ecology 2000).

Although the calculated TSIs agree fairly well, incorporating a larger data set to represent average conditions over the summer months will allow for greater confidence in the TSI assessments from the three water quality parameters.

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Section 4: Lake Water Budget

The County collected flow data from Coffee Creek (SW-2) and Spanaway Creek (SW-1) to support development of the WSP for the County's NPDES Phase 1 municipal stormwater permit. The permit requires development and calibration of a hydrology model for the WSP planning area, which includes Spanaway Lake. The County installed streamflow gauges near SW-1 and SW-2 to provide the flow data needed to calibrate the WSP hydrology model.

BC used the WSP streamflow data and lake water level monitoring data that was collected by County staff to develop a water budget for Spanaway Lake (see Appendix D for the *Spanaway Water Budget Methods Technical Memorandum*). Groundwater elevation measurements from shoreline monitoring wells were also considered in the analysis. Table 7 lists the water budget for the monitoring period.

The flow and elevation data were collected from October 2014 through December 2015. The water budget results for the months of October, November, and December are averages of 2014 and 2015 measurements. Because the monitoring period was unusually warm and dry, the water budget shown in Table 7 may be different from a normal or wet year.

As shown in Table 7, groundwater accounted for about 65 percent of the total volume of surface water that flowed out of the lake via Spanaway Creek during the monitoring period. It is possible that there was also some subsurface discharge from the lake; therefore, groundwater inflow to the lake could have been greater than the amount listed in Table 7. The groundwater model under development for the WSP should provide a better understanding of groundwater flow into and out of the lake.

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Table 7: Spanaway Lake Water Budget[a]						
Month	Stream inflow: SW-2	Stream outflow: SW-1	Precipitation	Evaporation	Groundwater	Direct stormwater
	acre-feet	acre-feet	acre-feet	acre-feet	acre-feet	acre-feet
January	502	1,811	62	37	1,324	4.5
February	574	1,870	85	46	1,256	6.1
March	593	2,092	63	69	1,470	4.6
April	477	1,617	28	84	1,146	2.1
May	409	1,117	11	108	743	0.8
June	257	583	2	128	400	0.1
July	180	339	5	127	244	0.3
August	105	228	34	110	181	2.5
September	71	246	14	77	253	1.1
October	114	296	87	59	157	6.4
November	203	881	123	36	654	9.0
December	617	1,942	148	37	1,296	10.7
Annual	4,101	13,021	661	917	9,123	48.2

a. Based on data collected from October 2014 through December 2015. Values listed for October through December are averages of 2014 and 2015 measurements.

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Section 5: Lake Nutrient Loading

Geosyntec used the water quality data summarized in Section 2 and the lake water budget data described in Section 4 to prepare a draft nutrient budget for Spanaway Lake. As noted in Section 2, the observed N:P ratios in lake water samples indicate that phosphorus is the limiting nutrient for algal productivity; therefore, the nutrient loading focused on phosphorus.

The phosphorus loading for Spanaway Lake consists of loading components attributed to direct stormwater discharge from localized areas to the lake, stream inflow, aerial deposition, groundwater flux, and the internal load generated from the lake itself. The following sections describe how each component was estimated.

5.1 Stream Inflow

To estimate the nutrient load entering the lake via direct surface water stream conveyance, the respective water budget volume was multiplied by the average TP concentration collected from Coffee Creek—the inlet stream to Spanaway Lake.

5.2 Groundwater Inflow

To estimate the nutrient load entering the lake via groundwater flux, the respective water budget volume was multiplied by the average TP concentration collected from area groundwater wells surrounding Spanaway Lake.

Based on the regional groundwater flow direction (i.e., from the south and southeast to the north and northwest), wells LMP-GW1 through LMP-GW4 are located up-gradient of the lake, and wells LMP-GW5 and LMP-GW6 are located downgradient of the lake. Localized groundwater flow directions can vary from the overall regional pattern, particularly near groundwater discharge areas like Spanaway Lake, and areas with steep changes in topography. The average TP concentration for all of the LMP groundwater monitoring wells was not statistically different between groupings of samples from up-gradient and down-gradient wells. The average TP concentration for LMP-GW-1 through 4 was 0.026 mg/L while LMP-GW-5 and GW-6 had an average TP concentration of 0.028 mg/L. Therefore, the average TP concentration for all six shoreline wells (0.027 mg/L) was used to estimate groundwater loads to the lake.

5.3 Aerial Deposition

Atmospheric deposition of phosphorus is an estimate of the load of phosphorus delivered through wet or “dryfall” precipitation depositing phosphorus-containing particles directly on the surface of Spanaway Lake. Deposition rates were determined from published literature (Reckhow 1980). The annual atmospheric deposition load was calculated assuming a deposition rate of 0.19 kg (or 0.24 pounds [lbs]) of phosphorus per acre per year, and multiplied by the lake surface area to generate a load.

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5.4 Direct Stormwater Discharges

Although some limited water quality data were reflective of sampling during storm events, these data were sampled within the water column of surface streams and cannot be attributed to the characteristic concentrations of stormwater runoff into Spanaway Lake. To address this information gap and the ability to estimate the respective load contribution to the lake nutrient loadings, the land use breakdown for areas of direct stormwater discharges were combined with event mean concentrations (EMCs) developed for the Seattle area (see Table 8).

To be conservative, the upper confidence limits (UCLs) of the respective EMCs were used for the future condition while averages were used for current conditions. These were averaged, weighted on a contributing land use basis, and multiplied by the volume of direct stormwater discharge estimated as part of the water budget to produce the respective load. To generate an estimate for pristine conditions, the average EMC for open space/resource lands was applied to the entire volume.

Table 8: Land Use Breakdown and Respective EMCs for Direct Stormwater Discharges to Spanaway Lake

Land use	Area (acres)	% of drainage area	EMC (mg/L)	
			Average	UCL
Commercial/industrial	0.43	0.17	0.23	0.36
Open space/resource lands	2.00	0.78	0.11	0.20
Public places/religious centers	63.20	24.64	0.22	0.34
Residential	176.80	68.92	0.22	0.34
Transportation/communication	0.70	0.28	0.25	0.38
Vacant land/undefined	13.40	5.22	0.22	0.34
TOTAL	256.50	100.00	0.22	0.34

5.5 Internal Load

The internal nutrient load portion of the annual phosphorus loading (W_{int}) was calculated by using published relationships between sediment wet TP concentration and sediment phosphorus release rates. Five sediment samples were collected from Spanaway Lake on July 21, 2015. The average wet TP concentration of the four samples (Sed-1, Sed-2, Sed-4, and Sed-5) in the closest vicinity to the deepest point in the lake was 0.176 milligrams per gram (mg/g). Sediment wet TP concentrations were converted from the dry weight concentrations presented in Table 9.

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Table 9: Sediment Wet TP Concentrations			
Sample location	**TP (mg/g dry)**	**Sediment % solids by weight**	**TP (mg/g wet)[a]**
Sed-1	**1.070**	**32.0**	**0.342**
Sed-2	**2.490**	**6.5**	**0.162**
Sed-4	**1.010**	**6.9**	**0.070**
Sed-5	**1.810**	**7.3**	**0.132**
		Average	**0.176**

a. Wet TP concentration (mg/g wet) = dry TP concentration (mg/g dry) * (sediment % solids by weight/100)

Nürnberg developed a regression relationship between the sediment wet TP concentration and release rates, which is based on a study of internal phosphorus loading in North American lakes (Nürnberg 1998). Given the sediment wet TP concentration of 0.176 mg/g, an estimated release rate for the sediments is 7.5 milligrams per meters squared per day (mg/m^2/day).

The release of phosphorus from the lake sediments was assumed to occur only in sediments located within the hypolimnion, as phosphorus is typically released only under anoxic conditions. However, research has indicated that phosphorus can also be released under oxic conditions with elevated water pH (9+S.U.) in shallow lakes (Niemistö et al. 2011). This condition was not considered in the nutrient budget analysis because of the lack of data to characterize the nature and extent of such conditions. The phosphorus release was also assumed to occur only during the period of the year when anoxic conditions were present in the hypolimnion, with anoxic conditions defined as DO concentrations below 1 mg/L. The DO and temperature profiles indicate that anoxic conditions develop within the hypolimnion between approximately May 15 through September 15, a period of 123 days. During this period, anoxic conditions extend through the portion of the water column deeper than 6 m. Available bathymetric data for Spanaway Lake indicate the area of the lake bottom below 6 m is approximately 625,900 m^2. Estimation of the internal load was calculated as follows:

$$W_{int} = \left(7.5\frac{mg}{m^2 \cdot day}\right)\left(123\ \frac{days}{yr}\right)(625{,}900\ m^2)\left(\frac{1\ kg}{10^6\ mg}\right) = 577\ kg/yr$$

Figure 23 shows the draft results of the TP nutrient loading. As shown in the figure, the internal phosphorus load represents roughly 60 percent of the nutrient loading. The largest external source is groundwater flux, which represents about 26 percent of the TP loading estimate.

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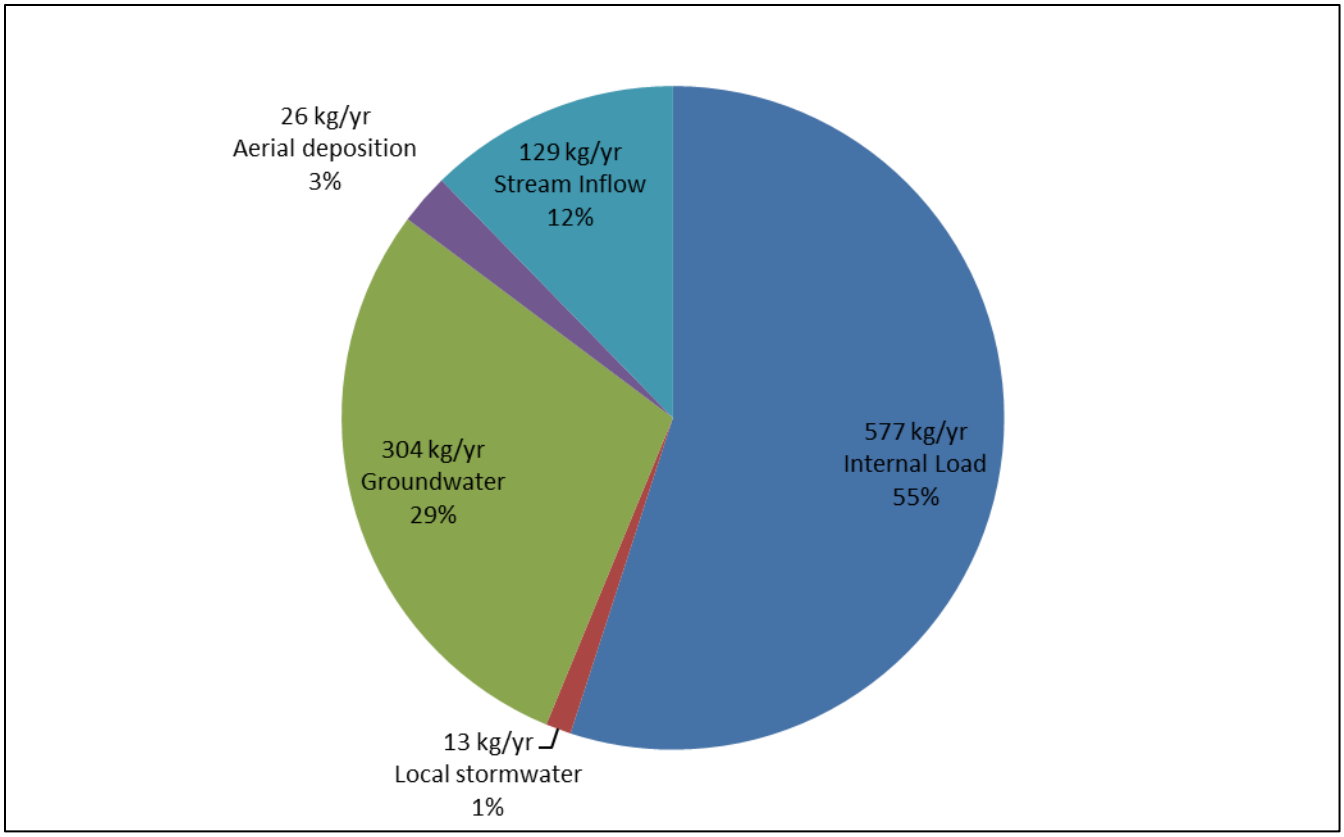

Figure 23. Estimated annual TP loading to Spanaway Lake

To highlight the uncertainty in the water quality modeling based on the estimation of the internal load considering surface area alone (e.g., keeping all other parameters constant), assume a re-calculation of the bathymetric area below the depth of 6 m was estimated to be 507,000 m^2 based on an updated and more detailed bathymetric survey. The estimated fraction of the total lake nutrient loading attributed to internal loading based on this change would be 50 percent (from 55 percent or a 9 percent relative reduction for an associated 19 percent reduction in surface area). Some additional important considerations and limitations with regard to the internal phosphorus load include the details below.

The calculation of internal load is heavily dependent on: (1) the estimated area of sediments that are releasing phosphorus over the course of the anoxic period, and (2) the estimated duration of the anoxic period. The estimates of these factors, as provided above, are based on analysis of the available data and best professional judgment. The estimate of sediment release area could be refined with more detailed bathymetric data for the lake (e.g., 1-foot depth contours) because bathymetric data are limited to 5-foot and 10-foot depth contours. The estimate of the duration of the anoxic period was derived primarily from monthly (2015) DO and temperature profiles at LW-1. Although profiles were available for May and June 2015 for the LW-3 sampling location, additional monthly data (April to October) from this location would

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greatly aid in the estimation of the anoxic period and its relationship to the broad depth zone that exists between 6.5 and 6.0 m.

The available data were not sufficient to provide an estimate of sediment phosphorus release based on in-situ measurements. As such, use of the sediment phosphorus concentration results to estimate internal loading was the best available alternative. In-situ monitoring to estimate sediment phosphorus release would require sampling profiles approximately every 2 weeks from April through October, including both DO and temperature profiles and discrete depth sampling for TP, or experimental measurement using sediment samples.

5.6 In-Lake Phosphorus Modeling

In-lake phosphorus response models are commonly used to predict in-lake phosphorus concentrations as a function of annual phosphorus loading, mean lake depth, and hydraulic residence time. The models are useful for understanding the relationships between current phosphorus loading and in-lake concentration, as well as for estimating in-lake concentrations under hypothetical scenarios, such as future buildout. One of the most commonly used in-lake response models is the Vollenweider model, which predicts an average annual in-lake phosphorus concentration (Vollenweider 1976). A second model, the Nürnberg model, is a more refined response model that considers seasonal effects and internal phosphorus loading (Nürnberg 1998). The following sections discuss the results of these two models for Spanaway Lake.

5.6.1 Vollenweider Model

The Vollenweider model is an equation that is commonly used to predict in-lake phosphorus concentrations as a function of annual phosphorus loading, mean lake depth, and hydraulic residence time. Phosphorus concentrations predicted by the Vollenweider model are based on an assumption that the lake is uniformly mixed, such as at spring turnover. The Vollenweider model is based on a 5-year study of about 200 waterbodies in Europe, North America, Japan, and Australia.

The Vollenweider equation is provided below, with calculations for Spanaway Lake based on the phosphorus loading estimate discussed above. Internal loading is not included in the Vollenweider model because it is an empirical relationship between in-lake phosphorus concentration and external load only. The Vollenweider equation is:

$$p_v = \frac{L_p}{\left(q_s\left(1 + \sqrt{\tau_w}\right)\right)}$$

where:

p_v = mean in-lake phosphorus concentration (mg/L) estimated by Vollenweider equation

L_p = annual phosphorus load/lake area, (grams/m^2/year)

τ_w = hydraulic residence time (yr)

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q_s = hydraulic overflow rate = mean depth/hydraulic residence time (m/yr) = z/τ_w

z = average depth (m)

Table 10: Summary of Vollenweider Model Parameters			
Parameter	**Description**	**Value**	**Units**
W	**TP loading rate**	**471.9**	**kg/yr**
V	**Volume**	**4,846,343**	**m^3**
z	**Average lake depth**	**5**	**m**
Q	**Annual discharge**	**16,061,143**	**m^3/yr**
A_s	**Lake area**	**967,199**	**m^2**
L	**Areal loading rate**	**487.9**	**mg/m^2**
q_s	**Hydraulic overflow rate**	**15.2**	**m/yr**
τ_w	**Hydraulic residence time**	**0.33**	**yr**

$$\text{In-lake phosphorus concentration} = \frac{L_p}{\left(q_s\left(1+\sqrt{\tau_w}\right)\right)} = \frac{487.9}{15.2\left(1+\sqrt{0.33}\right)} = 0.0205\ mg/\mathrm{L}$$

Based on the estimated annual external phosphorus load of 471.9 kg/yr, the Vollenweider equation predicts an in-lake phosphorus concentration of 0.0205 mg/L. Applicable water quality sampling data indicate an average monthly phosphorus concentration range of 10 to approximately 0.034 mg/L (for the period between February and September), indicating the annual phosphorus load and Vollenweider equations have provided a reasonable representation of in-lake phosphorus dynamics. The average phosphorus concentration for the months of October through January was 0.03 mg/L. As presented in Figure 24 below, the slope of the Vollenweider model line for Spanaway Lake estimates a 23 kg/yr change (increase or decrease) in annual phosphorus load will result in a corresponding 0.001 mg/L change to in-lake phosphorus concentration.

Figure 24 also indicates what the Vollenweider model predicts if direct stormwater discharges to lake are assumed to have an EMC characteristic of open space/resource lands and groundwater concentrations are reduced to lower levels (e.g., “pristine”) and what the load would be assuming a greater contribution from groundwater factor (e.g., “future”) that could allow for a greater amount of phosphorus to be transported to the lake.

Although the results should be considered draft pending the results and refinements as part of additional watershed modeling, results of the Vollenweider model indicate the relative trend of increasing in-lake phosphorus concentrations given the generalized assumptions used to generate estimates for the relative condition scenarios.

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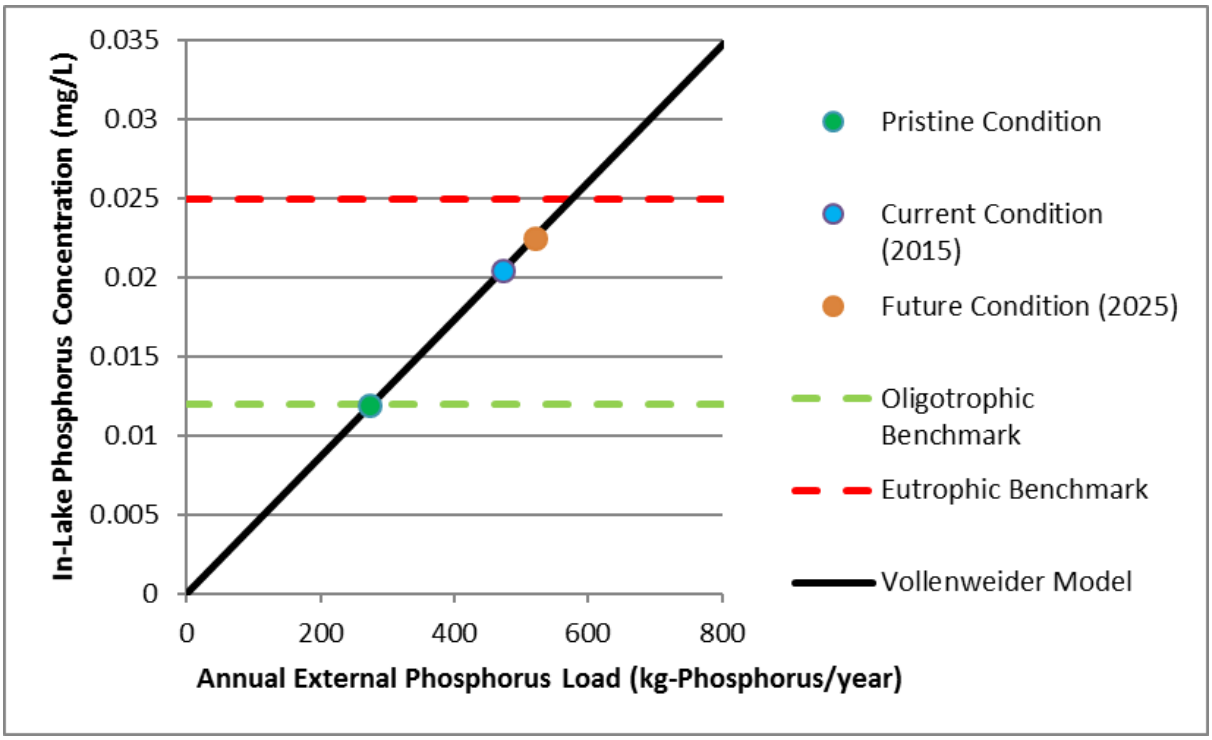

Figure 24. Graphical results of the Vollenweider model presented along with oligotrophic and eutrophic benchmarks

(EPA 1988)

5.6.2 Nürnberg Model

The Vollenweider model estimates an average annual in-lake phosphorus concentration that represents the lake in a fully mixed state (e.g., spring turnover). The Nürnberg model provides a more nuanced estimation of phosphorus concentrations that reflect seasonal changes related to internal loading, which appear to be a significant factor for Spanaway Lake based on a review of the data collected as part of the QAPP. Nürnberg's model uses a parameter, "*R*", which describes the fraction of sediment retained by the lake each year. This fraction is then applied to different subsets of the annual phosphorus load to determine an in-lake phosphorus concentration at various times of the year. The Nürnberg model estimates the value of R to be:

$$R = \frac{15}{18 + q_s}$$

The Nürnberg model then uses the following three equations to calculate an annual average phosphorus concentration (P_{ann}), a summer epilimnion phosphorus concentration (P_{epi}), and a fall phosphorus concentration (P_{fall}):

$$p_{ann} = \left[\frac{(L_{ext} + L_{int})}{q_s}\right](1 - R)$$

$$p_{epi} = \left[\frac{(L_{ext})}{q_s}\right](1 - R)$$

$$p_{fall} < \left[\frac{(L_{ext})}{q_s}\right](1 - R) + \frac{L_{int}}{q_s}$$

For an annual average, the retention factor (R) is applied to the complete annual load, as the internal load will be able to mix throughout the year and be available for uptake, settling, and flushing. The retention factor is applied to the external load only to obtain a summer epilimnion concentration, when any internal phosphorus loading is sequestered in the hypolimnion during stratification and is not available for uptake, settling, and flushing. Finally, the internal load is added to the epilimnion concentration and only subjected to flushing (by being divided by q_s, the hydraulic overflow rate) to represent the relatively rapid mixing of the pulse of soluble phosphorus from the hypolimnion into the epilimnion during fall turnover. This model is particularly useful in characterizing and developing management goals for lakes that experience late summer/early fall algae blooms. The Nürnberg model parameters are provided in Table 11. Model results for current (2015) lake conditions are shown below and indicate an annual average phosphorus concentration of 0.037 mg/L, a summer epilimnion phosphorus concentration of 0.017 mg/L, and a fall phosphorus concentration of 0.053 mg/L.

Table 11: Summary of Nürnberg Model Parameters for Current Conditions

Parameter	Description	Value	Units
W_{ext}	External phosphorus loading rate	471.9	kg/yr
W_{int}	Internal phosphorus loading rate	577.0	kg/yr
V	Volume	4,846,343	m^3
Q	Annual discharge	16,061,143	m^3/yr
A_s	Lake area	967,199	m^2
L_{ext}	External areal loading rate	487.9	mg/m^2
L_{int}	Internal areal loading rate	596.6	mg/m^2
R	Retention factor	0.43	N/A
q_s	Hydraulic overflow rate	16.6	m/yr

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$$p_{ann} = \left[\frac{(L_{ext} + L_{int})}{q_s}\right](1 - R) = \left[\frac{(487.9 + 596.6)}{16.6}\right](1 - 0.43) = 37.0\ \mu g/L$$

$$p_{epi} = \left[\frac{(L_{ext})}{q_s}\right](1 - R) = \left[\frac{(487.9)}{16.6}\right](1 - 0.43) = 16.6\ \mu g/L$$

$$p_{fall} < \left[\frac{(L_{ext})}{q_s}\right](1 - R) + \frac{L_{int}}{q_s} = \left[\frac{(487.9)}{16.6}\right](1 - 0.43) + \frac{596.6}{16.6} = 52.6\ \mu g/L$$

Figure 25 below shows the monthly averaged observed phosphorus concentrations from 2014–15 and the Nürnberg model results.

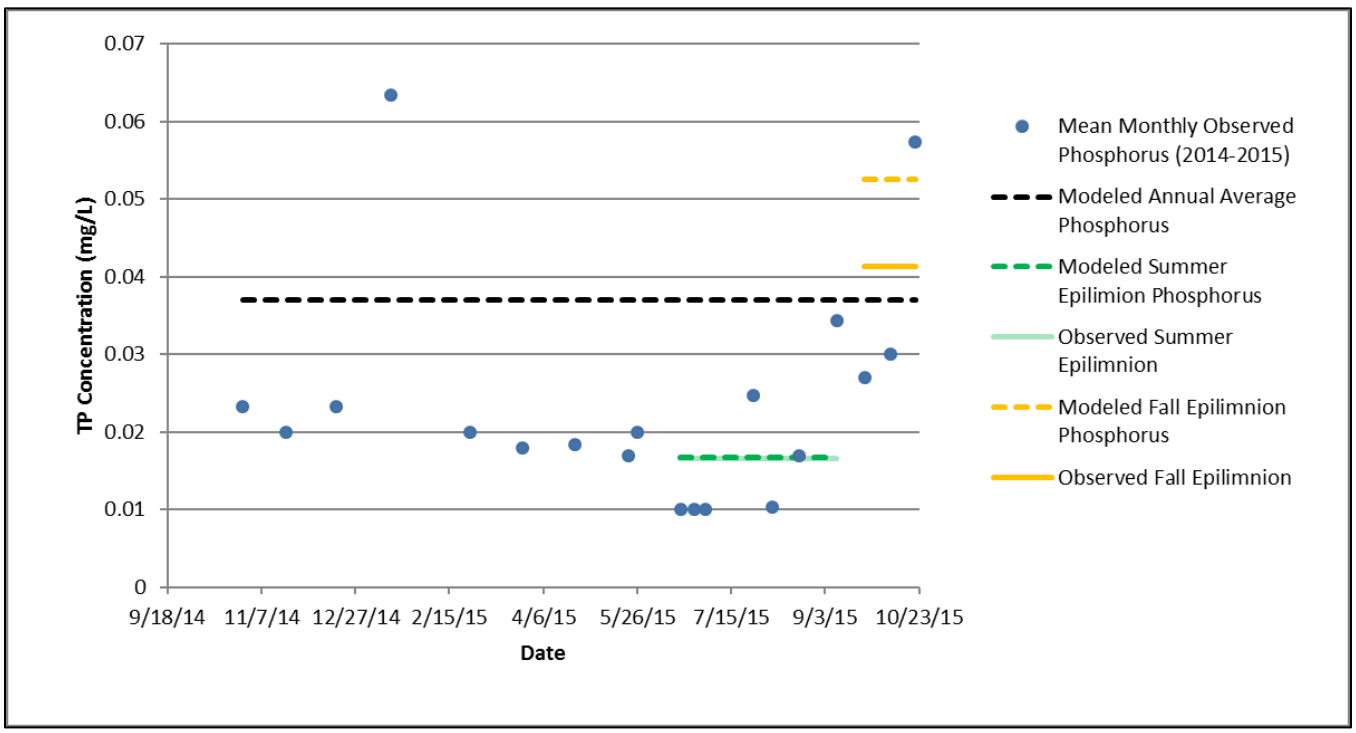

Figure 25. Nürnberg model results presented along with observed epilimnion concentrations

The observed concentration data show the expected seasonal pattern of dropping slightly during summer, when stratification is in effect, and then rising in late fall during lake turnover, when phosphorus-rich water from the hypolimnion is mixed with the surface waters. Summary results from the respective models are presented in Table 12.

Table 12: Summary of In-Lake TP Model for Various Condition Scenarios

Scenario	Annual external phosphorus load (kg phosphorus/yr)	Annual internal phosphorus load (kg phosphorus/yr)	Vollenweider in-lake phosphorus (mg/L)	Nürnberg in-lake phosphorus (mg/L)		
				P_{ann}	P_{epi}	P_{fall}
Pristine	274	0	0.0119	N/A	0.0097	N/A
Current (2015)	472	577	0.0205	0.0370	0.0166	0.0526
Future (2025)	520	577	0.0225	0.0632	0.0183	0.0975

5.6.3 Nutrient Model Uncertainty and Recommendations

The water quality and additional field data collected in 2014 and 2015 have provided very useful information for the lake characterization, nutrient loading estimate, and in-lake water quality modeling of Spanaway Lake. Nevertheless, additional data collection and model refinement would help improve understanding of water quality dynamics within the lake system and allow more definitive evaluation of lake treatment or management strategies for Spanaway Lake. The County may wish to consider the following recommendations:

- Take advantage of WSP models once they are available: The County is developing a Hydrological Simulation Program-Fortran (HSPF) watershed model and MODFLOW groundwater model to support development of the Spanaway WSP, which is required by the state municipal stormwater permit. The calibrated HSPF and groundwater models could be used to confirm and refine the water budget estimates for the Spanaway LMP. This would also allow for better integration within the LMP and ability to use the lake water quality modeling for more informative watershed management measure scenarios. The WSP groundwater model should also be used to refine the loading estimates for septic system and stormwater infiltration facilities.
- Collect additional data to fill key data gaps: The LMP monitoring program generated a great deal of useful information but monitoring was constrained by the available budget. If additional funding becomes available, additional monitoring of water quality near the lake bottom during the stratified period could improve estimates of benthic fluxes. Obtaining higher-resolution bathymetry data would allow a more accurate estimate of the lake bottom area subject to anoxic conditions in the summer and also collect additional data to

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identify and characterize the nature and extent of shallow, oxic, and high-pH areas that may also be a source of releasing phosphorus.

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Section 6: Source Characterization

As discussed above, the monitoring results confirm that phosphorus is the primary limiting nutrient for algal growth in the lake. Fecal indicator bacteria are also a concern. Ecology has classified Spanaway Lake as “impaired” based on past exceedances of state surface water quality fecal coliform criteria.

BC evaluated the LMP monitoring results to evaluate the most likely sources of phosphorus and fecal indicator bacteria in the Spanaway Lake watershed. Appendix E describes the source characterization methods and results. Sections 6.1 and 6.2 summarize the phosphorus and fecal bacteria source evaluations.

6.1 Phosphorus Source Evaluation

Phosphorus can reach Spanaway Lake through Coffee Creek, groundwater inflow, direct stormwater runoff, and aerial deposition. In addition, waterfowl can contribute phosphorus directly to the lake, but its magnitude is less understood. These pathways are summarized below.

6.1.1 Coffee Creek

Coffee Creek was monitored at Spanaway Loop Road about 800 feet upstream of Spanaway Lake. Based on the flow and water quality data collected at SW-2, Coffee Creek contributed about 27 percent of the external phosphorus load to Spanaway Lake during the monitoring period.

The creek originates below a large wetland complex on JBLM and passes through more wetland areas between JBLM and Spanaway Loop Road. The wetlands appear to be groundwater discharge zones. Aside from a few residences in the County portion of the Coffee Creek basin, there is little evident development or infrastructure, so there is little potential for stormwater runoff to enter Coffee Creek upstream of Spanaway Loop Road. The monitoring results and land use data indicate that wildlife and aquifer minerals (from groundwater inflow) are the most likely sources of phosphorus to Coffee Creek at SW-2.

6.1.2 Septic Systems

Approximately 3,900 onsite sewage disposal systems (OSDS) are located hydraulically upgradient of Spanaway Lake. Surface failures of OSDS (i.e., sewage on the ground surface) are rare because very permeable soils cover most of the watershed. TPCHD documented 26 instances of sewage on the ground surface during 2011–15, but none of these were located close to the lake. Surface failures are usually short-lived because they are readily observed and pose an obvious health hazard that must be addressed quickly.

OSDS in very permeable soils have the potential to slowly contribute phosphorus to the groundwater system and the lake (National Environmental Services Center 2013). BC developed a spreadsheet tool to estimate annual phosphorus loads from OSDS to the soil, breakthrough (time and phosphorus-load) to groundwater, and travel time to the lake. The spreadsheet uses

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TPCHD data on septic system locations, approximate installation dates, drainfield types (e.g., gravity or pressurized), typical drainfield area, and average effluent flows. The spreadsheet uses published literature on phosphorus retardation rates, local soil characteristics, depth to groundwater, and aquifer properties to simulate movement of phosphorus through the vadose (i.e., unsaturated) zone and transport to the lake in groundwater flow. The model was run assuming a range of aquifer retention (or retardation) rates. See Appendix E, Section 5 for a more comprehensive discussion of this evaluation within the *Source Characterization Technical Memorandum*.

Table 13 summarizes the results of the OSDS loads modeling. Spanaway Lake is estimated to receive 90 kg (or 200 lbs) of phosphorus in 2015 from OSDS sources. This value supposes 50 percent aquifer retention. 2015 load values would be 54 kg (or 120 lbs) if the aquifer retention factor is 70 percent and 181 kg (or 400 lbs) if there was no aquifer retention.

Table 13: Annual Phosphorus Loads to Spanaway Lake from OSDS Sources

Year	Estimated number of OSDS with breakthrough	Flow-weighted loading rate to Spanaway Lake: no aquifer retention (kgs/yr)	Flow-weighted loading rate to Spanaway Lake: 50% aquifer retention (kgs/yr)	Flow-weighted loading rate to Spanaway Lake: 70% aquifer retention (kgs/yr)
2000	242	128	64	39
2005	267	141	71	42
2010	300	158	79	48
2015	336	178	89	54
2020	381	201	101	60
2025	415	219	110	66

The model was re-run using different effluent phosphorus concentrations to evaluate the potential impact of changes such as the phase out of phosphate-free detergents. In addition, the model was re-run using smaller drainfield sizes for gravity systems to evaluate the potential impacts of reduced effective drainfield areas because of clogging, differential settling, holes or cracks in tank, etc. TPCHD's OSDS inspections found numerous instances of leaking tanks where effluent can bypass the drainfield.

Phosphorus loads to Spanaway Lake may increase as OSDS located farther from the lake continue to break through. Preliminary estimates for 2050 indicate a load of 364 lbs (50 percent aquifer retention), assuming no more OSDS are installed.

Phosphorus retained in the vadose and saturated zones can remobilize if effluent phosphorus concentrations drop or are eliminated. As a result, groundwater phosphorus loads to Spanaway Lake could remain significant for many years after sources are reduced or removed.

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The OSDS loading estimates are based on a simple spreadsheet model. The County is developing more sophisticated watershed (HSPF) and groundwater (MODFLOW) models for the WSP, which must be completed in the fall of 2017. The WSP models could be used to refine the OSDS loading estimates summarized above.

6.1.3 Stormwater Infiltration Facilities

There are approximately 1,500 drywells and 130 stormwater infiltration ponds/basins in the Spanaway Lake watershed. These facilities allow phosphorus contained in stormwater runoff to enter the subsurface, percolate down through the vadose zone to the water table, and then move horizontally through the saturated zone toward the lake in a similar process to phosphorus transport from OSDS. The loads modeling tool developed for OSDS was modified to estimate the phosphorus load from stormwater infiltration facilities, including drywells and infiltrations ponds.

The model results indicate that phosphorus travel times from drywells to Spanaway Lake can vary considerably depending on the depth to groundwater, the distance to the lake, and the hydraulic loading rate. Drywells located in areas with shallow groundwater near the lake could contribute phosphorus in as little as 1.5 years, while drywells far from the lake have estimated breakthrough times ranging from 150 to 600 years. Phosphorus from stormwater infiltration ponds could begin to arrive at the lake as early as 2045.

The model results indicate that the stormwater infiltration facilities contribute smaller phosphorus loads to groundwater and the lake compared to OSDS. For example, the drywell closest to the lake could contribute on the order of 0.25 lbs per year assuming there is no phosphorus removal in the soil above the water table. The stormwater infiltration ponds in the watershed could contribute as much as 85 lbs of phosphorus per year by 2050.

The large differences in the estimated phosphorus loads coming from the drywells/stormwater infiltration facilities and the OSDS are due to differences in the phosphorus concentrations and loading rates as well as the quantity of underlying soil available for treatment. Domestic wastewater entering OSDS drainfields typically has much greater concentrations of phosphorus than stormwater runoff entering stormwater infiltration facilities. The analysis indicated that drywells/stormwater infiltration facilities typically have lower phosphorus loading rates per unit of underlying soil than OSDS, so there is a greater volume of soil for phosphorus removal. See Appendix E, Section 5 for a more comprehensive discussion of this evaluation within the *Source Characterization Technical Memorandum*.

The loading estimates for stormwater infiltration facilities are based on a simple spreadsheet model. After the WSP watershed and groundwater models have been developed, they could be used to refine the loading estimates described above.

6.1.4 Infiltration from Fertilized Areas

Precipitation and irrigation water that infiltrates from fertilized areas could leach phosphorus from the ground surface through the soil and the vadose zone and into the groundwater aquifer. However, this source is expected to be small compared to OSDS and stormwater infiltration facilities, for several reasons:

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- Infiltration occurs over a much larger area so hydraulic loading rates are much lower. The infiltrating water comes into contact with a much larger mass of soil material.
- Phosphorus concentrations in infiltration from landscaped areas are expected to be much lower than phosphorus concentrations in septic system effluent.
- Unlike OSDS and stormwater infiltration systems that bypass the upper soil horizons, the infiltrating water must pass through surface soils that typically have more plant roots, larger microbial populations, more organic matter, and finer-textured soils than underlying soils.
- Recent restrictions on phosphorus in turf fertilizer should reduce phosphorus inputs associated with over-fertilization of residential lawns.
- Phosphorus fertilizer use at the Spanaway Golf Course is limited to the greens and application rates are determined based on soil testing (Mike Milne, project manager, BC; written communication with Tony Bubenas, Pierce County Parks and Recreation, July 2016). U.S. Geological Survey (USGS) groundwater contour data indicate that groundwater recharge from much of the golf course area flows northwest rather than west into the lake.

6.1.5 Direct Stormwater Runoff

Urban stormwater runoff often contains elevated phosphorus concentrations. Potential phosphorus sources include soil erosion, fertilizers, yard waste, street dirt, and animal droppings.

Most of the Spanaway Lake watershed is covered by very permeable soils with high infiltration rates. Areas that are not covered by roads or buildings produce little runoff. Runoff from most impervious areas in the watershed is infiltrated through drywells, ponds, or ditches. However, stormwater runoff from impervious shoreline areas can discharge directly to the lake.

BC estimated the volume of direct stormwater runoff to the lake based on topography, man-made drainage features, land use, and effective (i.e., connected) impervious area. Stormwater EMCs for each land use category were obtained from the stormwater quality data set developed for Seattle's 2015 *Integrated Plan* (SPU 2015). Based on the flow volumes and EMCs, BC estimated that direct stormwater runoff from shoreline area contributed about 13 kg of phosphorus to the lake during the 1-year monitoring period. This is an estimated 1 percent of the calculated total annual phosphorus load.

6.1.6 Waterfowl

Waterfowl droppings can contribute phosphorus to lakes. Loading rates can vary greatly depending on the numbers and species of birds, how long they are present on the lake, their food sources, and other factors.

It is difficult to obtain accurate bird counts at a sufficient frequency to calculate "bird-days" and develop reliable estimates of phosphorus contribution from birds, particularly for lakes with

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limited shoreline access. For example, to estimate waterfowl phosphorus load to Green Lake, the City of Seattle hired an experienced ornithologist to walk the entire perimeter of the lake and count birds once per week over a 3-year period. The study found that the average daily water bird population was approximately 1,500 and that the birds contributed about 21 kg/yr of external phosphorus load to the lake (Scherer et al. 1995). The estimated waterfowl phosphorus load did not appear to correlate with lake water phosphorus, chlorophyll-a, or Secchi depth, suggesting that much of the phosphorus load in bird droppings did not remain in the water column. The authors noted that water birds can alter the rate and pathways of internal nutrient cycling in the lake and increase the nutrient content of the sediments (Scherer et al. 1995).

A recent study of Waughop Lake counted waterfowl populations about once per month during October 2014–15. The 33-acre lake had 0 to 157 geese and 12 to nearly 1,300 ducks. The duck population was highest during the winter when migratory species were present. The estimated phosphorus loading from waterfowl was approximately 23 kg/yr (Mike Milne BC project manager, written communication with Dr. Jim Gawel, University of Washington-Tacoma, July 2016).

At Spanaway Lake, TPCHD staff observed 0 to 75 waterfowl at North Beach and 0 to 20 waterfowl at Main Beach during summer beach monitoring conducted from 2004–16. Ecology's study of Spanaway Lake trophic status observed 0 to 75 geese and 0 to 400 other waterfowl during the late spring and summer of 1998. These bird counts were limited to May through October and did not include a systematic inventory of the entire lake shore, so they are not sufficient to reliably estimate "bird-days". If we assume that waterfowl usage at Spanaway Lake is similar or less than Green Lake or Waughop Lake, waterfowl may contribute up to 21 to 23 kg of phosphorus per year, which is about 5 percent of the estimated external phosphorus load to Spanaway Lake.

6.2 Bacteria Source Evaluation Summary

Fecal indicator bacteria (e.g., fecal coliform and e. coli) can reach Spanaway Lake through Coffee Creek, groundwater inflow, and stormwater runoff. In addition, waterfowl can contribute fecal matter directly to the lake. The following sections summarize each potential pathway.

6.2.1 Coffee Creek

Samples collected from Coffee Creek at Spanaway Loop Road (monitoring location SW-2) contained fecal coliform concentrations ranging from 5 to 395 cfu/100 mL. Samples collected during storm runoff events were higher than the routine monthly samples. Both the routine and storm event samples exceeded the state water quality criterion, with more than 10 percent of the samples above 100 cfu/100 mL. Coffee Creek concentrations were considerably higher than the lake water samples collected from LW-1, LW-2 and LW-3.

The monitoring and land use data suggest that wildlife is the predominant source of fecal bacteria in Coffee Creek upstream of Spanaway Loop Road. Coffee Creek may receive additional

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fecal coliform via stormwater runoff from the residential areas located along the creek downstream of Spanaway Loop Road.

6.2.2 Septic Systems

The model developed to estimate phosphorus loads from OSDS or septic systems was modified to estimate fecal coliform loads. The model results show that subsurface transport of fecal bacteria is much more limited than phosphorus transport. The model results indicate that OSDS more than 350 feet from the lake are unlikely to contribute fecal bacteria to the lake because of filtering, adsorption, and die-off. However, viruses have greater subsurface transport potential than fecal bacteria because viruses are much smaller and die off at slower rates than bacteria.

Approximately 121 OSDS systems are within 350 feet of the lake. Of these systems, approximately 35 to 50 systems have estimated depths to groundwater less than 10 feet. These systems are likely to have fecal coliform removal efficiencies on the order of 2- to 4-log removals (99.00 to 99.99 percent). TPCHD reported a mean concentration of about 750,000 cfu/100 mL in drainfield effluent from pressurized systems in the Spanaway, Tillicum, and Bethel areas (TPCHD 1994). 2-log removal would result in a concentration of 7,500 cfu/100 mL, while 4-log removal would result in 75 cfu/100 mL. These results indicate that fecal bacteria from these systems could reach the lake. However, these results do not account for mixing and dilution with groundwater or lake water.

6.2.3 Stormwater Infiltration Facilities

The OSDS evaluation found that OSDS more than 350 feet from the lake are unlikely to contribute appreciable fecal coliform to the lake. Phosphorus loads from stormwater infiltration facilities are estimated to be considerably lower than the OSDS phosphorus loads. Fecal coliform concentrations in stormwater are typically orders of magnitude lower than fecal coliform concentrations in septic tank effluent. Therefore, stormwater infiltration is not expected to be a significant source of fecal coliform to Spanaway Lake.

6.2.4 Direct Stormwater Runoff

Urban stormwater runoff often contains elevated fecal coliform concentrations from pets and wildlife and sometimes from human sources such as failed septic systems, leaking sewer lines, and homeless encampments. BC estimated the fecal coliform loads from the direct stormwater discharge area using the same method that was used to estimate phosphorus loads. The estimated fecal coliform load from the direct discharge area is approximately 9.5 trillion colonies/yr.

6.2.5 Waterfowl

Several samples collected by TPCHD at North Beach and Main Beach during 2015 had elevated concentrations of E. coli, a type of fecal coliform bacteria. For example, a sample collected near North Beach on June 9, 2015, contained 801 cfu/100 mL, while a sample collected from Main Beach on August 10, 2015, contained 540 cfu/100 mL. The TPCHD data suggest that fecal bacteria are a concern in the shoreline areas.

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Waterfowl can be a significant source of fecal bacteria to lakes and other surface water bodies. Alderisio and DeLuca (1999) reported that Canada goose droppings had an average fecal coliform content of 15,300 per gram of wet feces. Hussong et al. (1979) estimated that a Canada goose generates about 36,000 fecal indicator bacteria per day. Moriarty et al. (2011) found that duck feces contained approximately 95 million E. coli per gram. In a 3-year study of Green Lake (Seattle), Scherer et al. (1995) estimated that 50 percent of the goose droppings and 80 percent of the duck droppings were deposited directly into the lake, but each duck generated about one-fourth as much fecal material as the average goose dropping.

Ecology and TPCHD have observed as many as 75 geese and 400 other waterfowl at Spanaway Lake. Assuming that 75 geese and 400 ducks are present at Spanaway Lake all day, and that direct fecal output and bacteria concentrations are similar to the studies cited above, the daily fecal coliform load would be on the order of 1.8 trillion fecal coliforms. This suggests that waterfowl may be an important source of fecal bacteria, particularly near popular feeding and resting areas such as the area between North Beach and the lake outlet.

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Section 7: Management Measures

This section describes the identification and evaluation of measures for managing Spanaway Lake, with the goal of improving water quality and beneficial uses.

7.1 Lake Management Goals

The Spanaway LMP has had a robust public involvement process. The County hosted a project kickoff meeting for the community on December 4, 2013, at Spanaway Lake Elementary. Throughout the lake characterization phase of the project, interested parties were kept informed with updates to the Spanaway Lake LMP website and through mailed updates. In March 2016, the County sent a mailing and advertised the need for advisory group members and applications were accepted online. The Spanaway Lake Advisory Group (Advisory Group) is made up of 23 members including Spanaway Lake area residents and relevant local agencies.

The initial meeting of the Advisory Group members was held on July 13, 2016, and included an introduction to general lake processes and vocabulary as well as a briefing on the contents and findings of the characterization report. Between July 27 and December 7, 2016, the Advisory Group met nine times. The Advisory Group also hosted a public open house on November 9, 2016, at Spanaway Lake Elementary. During the course of those meetings, the Advisory Group identified lake management goals, defined problems, and developed action categories needed to address the identified problems and meet the group's goals. The Advisory Group used the action categories to screen and evaluate the management measures proposed by the project team.

The overall goal of the Spanaway LMP is to protect the water quality of the lake. The Advisory Group developed the following specific, measurable long-term goals intended to achieve this overall goal:

- Toxic algae blooms resulting in swimming advisories will be significantly reduced in frequency, area, and toxicity
- Swimming and consumption of aquatic organisms from the lake will not result in human, wildlife, or pet illnesses
- Water quality will be monitored consistently and will meet state standards (Washington Administrative Code [WAC] 173-201a) for fishable, swimmable, and aesthetic beneficial uses
- Aquatic plants will be managed to prevent unsafe conditions for recreational uses and to remove invasive species
- Healthy, diverse, native wildlife populations will be supported and sustainably managed
- An organizational framework will be instituted to support the ongoing stewardship actions needed to effectively manage conditions on Spanaway Lake

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7.2 Screening Evaluation of Potential Management Measures

The project team reviewed the monitoring data, water budget, nutrient budget, and source evaluation results (described in Sections 2 to 6 above) to identify potential watershed and in-lake management measures. The team developed a preliminary list of more than 25 potential measures to improve water quality and help attain the Advisory Group's goals for Spanaway Lake. The potential measures included watershed and in-lake measures to address cyanobacteria and fecal indicator bacteria issues. The Advisory Group reviewed the project team's preliminary list and suggested several additional measures for consideration. Table 14 lists all potential management measures considered during the screening process.

Table 14: Potential Spanaway Lake Management Measures for Initial Screening				
Watershed Measures				
Stormwater treatment/removal	**Septic system improvement or central sewering**	**Waterfowl management**	**Public education**	**Landscaping management**
In-lake Measures				
Hypolimnetic aeration or oxygenation	**Vigorous epilimnetic mixing**	**Dredging**	**Phosphorus precipitation and inactivation (whole lake treatment, alum emitters, alum injectors)**	**Competition and allelopathy (e.g., plantings for nutrient control, plantings for light control, addition of barley straw)**
Drawdown	**Circulation and destratification**	**Light-limiting dyes and surface covers**	**Selective nutrient addition**	**Floating wetland**
Algaecides (e.g., copper, endothall, diquat, sodium carbonate peroxyhydrate)	**Dilution and flushing**	**Mechanical vegetation control (harvesting, hydroraking)**	**Enhanced grazing (herbivorous fish, herbivorous zooplankton)**	**Pump and treat system (chemical treatment, constructed wetland)**
Fungal/bacterial/viral pathogens	**Increase outlet conveyance capacity**	**Selective hypolimnetic withdrawal (golf course irrigation, siphon system)**	**Bottom-feeding fish removal**	**Groundwater interception**

The project team performed a screening-level evaluation of the initial list of measures based on technical and cost considerations. The team tentatively ranked each measures as low, medium, or high priority for additional evaluation. Table 15 below summarizes the screening evaluation results. The potential measures were discussed during several Advisory Group meetings held during September through November 2016.

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Table 15: Preliminary List of Spanaway Lake Management Measures: Screening Evaluation Results

Measure	Summary Description	Potential problem(s) addressed		Other	Other	Potential suitability for Spanaway Lake			Comments
		Cyanobacteria; phosphorus loading	Fecal indicator bacteria			Low	Medium	High	
Watershed Measures									
Stormwater treatment/removal	Treat or infiltrate runoff prior to discharge to lake.	✓	✓				✓		Relatively small source but still a good idea to control. Potential measures could include constructed wetlands and Low Impact Development (LID) retrofits where feasible.
Central sewering	Extend central sewer lines to septic system areas, require connection to sewer. Could focus on areas closest to lake.	✓	✓				✓		Very costly. Could take many years for phosphorus concentrations in groundwater inflow to drop to predeveloped levels.
Septic system improvements	Retrofit systems to improve treatment (e.g., new pressurized drainfield, sand filter). Could focus on systems close to lake.	✓	✓				✓		Costly to very costly depending on the scale. Less phosphorus load reduction than sewering. Could take many years to reduce phosphorus loading in groundwater entering lake.
Waterfowl management	Use harassment (e.g., dogs) and/or shoreline landscaping to discourage waterfowl from using beaches, play fields, etc.	✓	✓					✓	Probably a minor phosphorus source but could be important bacteria source in parts of the lake that attract a lot of waterfowl.
Public education	Encourage people to landscape shorelines to deter waterfowl, minimize phosphorus fertilizer use, discourage feeding of waterfowl.	✓	✓					✓	Focus on landscaping practices, waterfowl management. Probably minor benefits for cyanobacteria, but could reduce fecal bacteria in lake areas with heavy bird use.
Landscaping	Improve landscaping practices to reduce runoff of sediment and nutrients.	✓	✓					✓	Focus on shoreline areas where stormwater runoff can flow directly into lake.
In-Lake Measures									
Hypolimnetic oxygenation	Introduce oxygen to help create aerobic conditions near lake-bed and thereby reduce phosphorus release from sediment. Likely would form aerobic crust on upper sediment that would isolate underlying anoxic sediments and limit nutrient release.	✓						✓	Would require pipes, pumps, etc. System would need to be run when lake is stratified. Could include an alum injector for small additional cost. Additional evaluation would be needed to estimate performance, amount of internal phosphorus load released from sediments, and cost.
Vigorous epilimnetic mixing	Adds air to lake and also causes slow vertical mixing that disrupt cyanobacteria.	✓					✓		Method is relatively new but has worked well at Cherry Creek reservoir near Denver and in Cardiff Bay Barrage in the United Kingdom (~20 km of air lines with attached diffusers on bottom). Could be implemented to augment hypolimnetic oxygenation in future (e.g., shallow coves). Additional evaluation would be needed to estimate performance and cost.
Circulation and destratification	Use air or water to keep water in motion and prevent or break stratification.	✓				✓			Uncertain benefits, could have unintended consequences.
Dilution and flushing	Add relatively clean water to lower phosphorus concentrations and decrease hydraulic residence time.	✓	✓			✓			Infeasible. Would need large source of water with low phosphorus.
Increase outlet conveyance capacity	Remove excess vegetation and debris from lake outlet upstream of Military Road.	✓		Shoreline flooding				✓	Could lower lake elevation and reduce shoreline inundation. Small decrease in hydraulic residence time, slight reduction in TP from shoreline septic systems.
Drawdown	Lower water level to oxidize, desiccate, and/or compact sediments.	✓		Aquatic plant control		✓			May not provide much benefit for algae. No existing infrastructure to drawdown or convey.

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Table 15: Preliminary List of Spanaway Lake Management Measures: Screening Evaluation Results

Measure	Summary Description	Potential problem(s) addressed		Other	Other	Potential suitability for Spanaway Lake			Comments
		Cyanobacteria; phosphorus loading	Fecal indicator bacteria			Low	Medium	High	
Dredging	Remove phosphorus-rich sediment from lake bed using clamshell or hydraulic dredge. Dewater spoils and transport them to appropriate disposal area(s).	✓		Aquatic plant control		✓			Very expensive, especially if the dredge spoils must be shipped away for disposal. Would need to collect sediment cores to estimate depth/volume to be removed, and perform additional monitoring (e.g., benthic flux chambers, hypolimnion sampling) to estimate phosphorus reductions. Dredging might need to be repeated in future if external phosphorus sources are not controlled.
Light-limiting dyes and surface covers	Limit light to suppress aquatic plant growth.	✓		Aquatic plant control		✓			Not recommended. Would interfere with lake uses.
Dyes	Limits light penetration to inhibit algal growth.	✓				✓			Not feasible or appropriate for a lake of this type.
Surface covers	Opaque material applied to water surface.	✓				✓			Infeasible for a lake of this type.
Mechanical vegetation control (harvesting, hydroraking)	Remove aquatic plants (and the phosphorus in the tissues).	✓		Aquatic plant control				✓	Rooted aquatic plants play an important ecological role in balancing the dominance of microscopic algae. Would need to consider timing and scope. Could have unintended consequences (e.g., other species could become dominant).
Selective withdrawal	Withdraw water from hypolimnion for use outside lake.	✓						✓	Remove phosphorus-rich water from lake.
Golf course irrigation	Move intake for golf course irrigation system to hypolimnion.							✓	Irrigate golf course using phosphorus-rich water from hypolimnion. Small potential benefit.
Siphon system	Install diversion structure and pipe to convey Coffee Creek inflow to lake bottom. Install siphon to remove hypolimnion water from lake and reduce phosphorus loading when lake turns over.	✓						✓	Siphon would be driven by gravity so no pumping required. Potential to cause water quality impacts downstream of lake (e.g., Lake Ballinger). Ecology may require treatment prior to discharge.
Algaecides	Apply chemicals to lake to kill algae.	✓					✓		Homeowners have been applying herbicides for years. Could be an option in conjunction with long-term nutrient source controls if applied very conservatively only as-needed. Reducing algae could increase light penetration and rooted plant growth.
Forms of copper	Toxic to algae.	✓			< 1 year	✓			Ecology generally does not allow copper treatment. Short-term benefit.
Forms of endothall	Amine formulation (e.g., Hydrothol 191) can be used at low concentrations to control algae.	✓			< 1 year		✓		Short-term benefit; may require several treatments per season. Hydrothol is effective on algae but is acutely toxic to fish.
Forms of diquat	Fast-acting, non-selective contact herbicide applied as a liquid.	✓		Aquatic plant control		✓			Most commonly used as a broad-spectrum herbicide for control of rooted aquatic plants, but applicators have reported that it appears to kill or suppress some species of algae. Short-term benefits.
Sodium carbonate peroxyhydrate	Fast-acting algaecide.	✓			< 1 year		✓		Acts as an oxidizing agent to kill algae. Active for only a short time in the water column.
Phosphorus precipitation and inactivation	Apply buffered alum (or similar chemical) to bind with and remove soluble phosphorus from the lake. Phosphorus precipitation focuses on shorter-term removal of phosphorus from the water column, while inactivation aims for longer-term control settling the control compound on the lake bottom to inactivate phosphorus in the lake-bed sediments.	✓						✓	Uncertain how long treatment will last because of rooted plants and continuing phosphorus loads from Coffee Creek and groundwater. Reducing algae populations could increase growth of rooted plants.
Whole lake alum treatment	Apply to entire lake. Could apply increased dose to coat sediment in areas of suspected groundwater inflow.	✓						✓	Uncertain how long treatment will last because of rooted plants, Coffee Creek, and groundwater phosphorus loads.

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Table 15: Preliminary List of Spanaway Lake Management Measures: Screening Evaluation Results

Measure	Summary Description	Potential problem(s) addressed		Other	Other	Potential suitability for Spanaway Lake			Comments
		Cyanobacteria; phosphorus loading	Fecal indicator bacteria			Low	Medium	High	
Alum emitter(s)	Install alum emitters at key inflow points (e.g., Coffee Creek, known groundwater discharge zones) to remove phosphorus as it enters the lake. Could add to hypolimnetic oxygenation system. Alum emitter may also help remove fecal coliform.	✓	✓					✓	Could help reduce phosphorus in the lake water column. Could prolong benefits of whole lake treatment. May be hard to delineate groundwater discharge areas. May be impractical if groundwater discharge occurs at a low rate over a large area.
Selective nutrient addition	Add nutrients to change composition of algal community.	✓				✓			Hard to predict outcomes, could have unintended consequences. Would require additional study (nutrient enrichment experiments) to determine feasibility.
Enhanced grazing	Encourage species that eat algae.	✓				✓			Lake ecology is complex so it is hard to predict outcomes. Could have unintended consequences.
Herbivorous fish	Stock fish that eat algae.	✓				✓			Not recommended. Hard to predict outcomes, could have unintended consequences.
Herbivorous zooplankton	Encourage zooplankton that graze on algae.	✓				✓			Hard to predict outcomes, could have unintended consequences. Better to encourage indirectly by fostering a healthy and diverse native aquatic plant community.
Bottom-feeding fish removal	Remove bottom-feeding fish that eat water weeds and stir up sediment.	✓				✓			Benefits are unclear. Hard to predict outcomes, could have unintended consequences.
Fungal/bacterial/viral pathogens	Add inoculum to initiate attack on algal cells.	✓				✓			Hard to predict outcomes, could have unintended consequences.
Competition and allelopathy	Add plants that outcompete or excrete substance that inhibit cyanobacteria.	✓				✓			Hard to predict outcomes, could have unintended consequences.
Plantings for nutrient control	Plant species that can outcompete algae for nutrients.	✓				✓			Hard to predict outcomes, could have unintended consequences. Algae typically out-compete rooted plants for nutrients.
Plantings for light control	Plant species that can shade out algae.	✓				✓			Hard to predict outcomes, could have unintended consequences.
Addition of barley straw	May release substances that inhibit algal growth.	✓				✓			Ecology considers this a "home remedy". Hard to predict outcomes, could have unintended consequences.
Floating wetlands	Use floating plants to remove phosphorus from water column.	✓				✓			Could interfere with lake uses.
Pump and treat system	Pump water from lake, treat to remove phosphorus, discharge treated water back into lake.	✓	✓			✓			Likely to be expensive. Limited space on shoreline for treatment facility.
Chemical treatment	Pump lake water to shoreline treatment facility, add polymer to flocculate and remove phosphorus. Discharge treated water back into lake.	✓	✓			✓			Likely to be expensive. Limited space on shoreline for treatment facility.
Constructed wetland	Pump lake water to wetland treatment system to remove phosphorus and algae. Discharge treated water back into lake.	✓	✓			✓			Likely to be expensive. Treatment wetland would require large area. Limited space on shoreline.
Groundwater Interception	Place reactive material (such as dewatered floc from water treatment facility) around the perimeter of the lake (outside of the lake) to remove phosphorus and pathogens.	✓	✓			✓			Would be very expensive and may be technically infeasible because of long shoreline and limited public land.

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As noted in Table 15, the initial evaluation identified three watershed measures as highly suitable for Spanaway Lake: (1) waterfowl management, (2) public education, and (3) landscaping. Snohomish County's LakeWise program could easily be tailored to help address these issues at Spanaway Lake. Stormwater treatment, septic system retrofitting, and central sewering were assigned a medium ranking. The rationale for the moderate stormwater treatment ranking is that the lake receives very little stormwater runoff, so this measure has a low potential to reduce external phosphorus loads to the lake in a meaningful way.

The septic system retrofitting and central sewering measures were ranked as medium even though the source evaluation indicates that septic systems contribute appreciable phosphorus to the lake via groundwater. The medium ranking was assigned because sewering or retrofitting throughout the area upgradient of the lake would likely take many years, and many more years for groundwater phosphorus concentrations to decline to predevelopment levels after sewering. Sewering or retrofitting costs are likely to be in the tens of millions. The County's Parkland-Spanaway-Midland Communities Plan and Unified Sewer Plan Update recommended sewering the Spanaway Lake area because it contains numerous septic systems overlying a sole-source aquifer (Pierce County Planning and Land Services, 2002; Pierce County Public Works and Utilities – Sewer Utility, 2010). Sewering could help reduce external phosphorus loads to the lake over the long term.

Based on the preliminary screening evaluations described above, the Advisory Group selected the following in-lake measures for additional evaluation:

- Hypolimnetic oxygenation
- Hypolimnetic siphon
- Hypolimnetic withdrawal for golf course irrigation
- Phosphorus inactivation: whole lake treatment or alum emitter
- Improve conveyance capacity of lake outlet
- Aquatic plant management
- Waterfowl management
- Hypolimnetic oxygenation with the option of adding an alum injector

7.3 Additional Evaluation of the Selected Management Measures

The project team further evaluated the lake management measures listed above. The results are described in Sections 7.3.1 through 7.3.8 and summarized in Table 16. The preliminary planning-level cost estimates provided below follow the Association for the Advancement of Cost Engineering (AACE) Class 5 Cost Estimate Classification System, providing estimates in the range of -50 percent to +100 percent for the candidate actions. The planning-level estimates of annual operation and maintenance (O&M) costs are in 2016 dollars.

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The project team and Advisory Group discussed the need for additional field monitoring to fill key data gaps (e.g., aquatic plant distribution) and to evaluate the lake water quality over time to assess progress (baseline monitoring) and support refinements in the management measures. Section 7.4 discusses potential monitoring considerations.

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Table 16: Management Measures Selected for Additional Evaluation

Measure	Preliminary planning-level cost estimates[a]			Relative water quality benefit to lake[b]	Other potential benefits?	How long will water quality benefits last?	Other potential impacts/costs?	What predesign work would be needed?
Hypolimnetic oxygenation	$1,900,000	$49,000/yr for O&M	$2,900,000	High. Reduce phosphorus release from sediment, increase DO.	Flexible operation. Increased DO should improve fish habitat. Few conflicts with other uses.	Long term	Speece cone and small building would be required. Energy use. Oxygen and delivery truck traffic.	Bathymetry, geotech, additional hypolimnion benthic flux sampling and modeling to confirm viability and refine sizing/cost estimate.
Hypolimnetic siphon	$4,300,000 (includes $1,500,000 for water treatment)	$146,000/yr for O&M	$7,220,000 (including water treatment costs)	High. Should remove appreciable phosphorus and low DO water from lake annually.	Siphon driven by gravity—no power required.	Long term	Potential adverse impacts on water quality downstream of lake (e.g., Lake Ballinger). Ecology likely to require treatment. Treatment facility would require about 3 acres of land.	Same as above, plus evaluation of potential downstream impacts and treatment requirements, and identification of suitable site for treatment facility.
Hypolimnetic withdrawal for golf course irrigation	$140,000	Small increase in O&M cost	TBD	Low. Would remove <1% of annual internal phosphorus load, based on recent irrigation use.	Increased phosphorus in irrigation water.	Long term	Small increased in energy use.	Bathymetry, geotech for pipe and intake, integration with golf course master plan.
Phosphorus inactivation: whole lake treatment	$689,000 for prep and initial treatment	$350,000 every 2–5 yrs	$2,080,000–$4,180,000 depending on treatment frequency	High initially, slow decline over time.	Minimal infrastructure, no conflicts with other lake uses.	Uncertain how long treatment will last because of continuing phosphorus loads from Coffee Creek and groundwater.	Reducing algae populations could increase growth of rooted plants. Would likely need to be repeated every 2–5 years.	Jar testing, lake bathymetry, additional sediment and lake water quality analyses.
Phosphorus inactivation: alum emitter	$175,000 capital (alum feed system and small building)	$30,000/yr for O&M	$780,000	Medium	Would help to manage phosphorus loads from Coffee Creek and nearby groundwater. Would also help reduce bacteria concentrations.	Long term	Reducing algae populations could increase growth of rooted plants. Requires routine O&M and has an annual operating cost.	Jar testing, lake bathymetry, additional sediment and lake water quality analyses.
Phosphorus inactivation: alum injector (add-on to hypolimnetic oxygenation)	$100,000	$32,000/yr for O&M	$740,000	Highest. Flexible operation can target key periods (e.g., turnover).	Increased DO should improve fish habitat. Few conflicts with other uses.	Long term	Alum storage tank. Alum delivery truck traffic.	Monitor lake response to determine alum dosing and timing. Jar testing.
Maintain conveyance capacity of lake outlet	None[c]	See costs for plant removal below	Varies	Low. Small decrease in residence time. Small reduction in groundwater table below <50 septic systems.	Small decrease (e.g., 4") in lake depth and shoreline inundation.	Short term	Habitat disturbance during removal. Could alter plant composition.	Bathymetric survey, plant/debris survey in outlet reach.
Aquatic vegetation management: mechanical harvesting	$7,000 – $12,000 for plant survey, plan, field guide	$1,200 – $2,500 /acre for high-density plants	Varies	Low. Removes phosphorus contained in plant material.	Improved recreation and aesthetics.	Short term	Could alter lake ecology (e.g., by freeing up phosphorus for algae, reducing habitat for zooplankton that eat algae, providing openings for invasive plants). Can promote spread of species that propagate by fragments.	Aquatic plant survey, plant management plan.
Aquatic vegetation management: aquatic vegetation harvesting, Hydroraking	$7,000 - $12,000 for plant survey, plan, field guide	$1,900 – 5,000/acre for submerged plants and $7,000 – $12,000/acre for emergent growths	Varies	Low. Removes phosphorus contained in plant material.	Improved recreation and aesthetics.	Short term	Could alter lake ecology as noted above. Short-term turbidity impacts.	Aquatic plant survey, plant management plan.
Aquatic vegetation management: aquatic vegetation harvesting, diver hand harvesting	$7,000 – $12,000 for plant survey, plan, field guide	$4,000 – $10,000/acre	Varies	High, if targeted to contain and eradicate new invasive plant infestations.	Minimize removal of non-target species.	Can provide multi-year benefits.	Labor-intensive.	Aquatic plant survey, plant management plan.

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Table 16: Management Measures Selected for Additional Evaluation								
Measure	Preliminary planning-level cost estimates[a]			Relative water quality benefit to lake[b]	Other potential benefits?	How long will water quality benefits last?	Other potential impacts/costs?	What predesign work would be needed?
Waterfowl management	$5,000[d]	N/A	N/A	Medium	Minimal infrastructure, no conflicts with other lake uses. Assumed to be a volunteer effort with no capital or ongoing costs.	Can provide multi-year benefits.	N/A	N/A
Lake education program	$30,000[e]	$23,000/yr[f]	N/A	Medium	Minimal infrastructure, no conflicts with other lake uses.	Can provide multi-year benefits.	N/A	N/A

a. *Based on the planning-level information and concept development stage of this project, conceptual level costs were estimated following the AACE Class 5 Cost Estimate Classification System, providing estimates in the range of-50 percent to +100 percent for the candidate actions.*

b. *Long-term lake monitoring is recommended to evaluate the effectiveness of the selected lake management measure(s).*

c. *Currently being done by County Parks and Recreation staff.*

d. *Assumes program would be implemented primarily by volunteers with limited support from County staff.*

e. *Includes one-time activities such as audience research, LakeWise signage, pet waste stations, and printing.*

f. *Staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.*

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7.3.1 Hypolimnetic Oxygenation

Hypolimnetic oxygenation injects pure oxygen near the lake bottom to prevent anoxic conditions that cause phosphorus release from sediments. Oxygenation is different from aeration in that it uses pure oxygen rather than air. Oxygenation requires about one-fifth as much gas volume as aeration because air is only about 20 percent oxygen. Thus, hypolimnetic oxygenation systems are less likely to cause turbulence or accidental destratification (Beutel and Horne 1999).

A properly designed hypolimnetic oxygenation system can increase DO, reduce hypolimnetic phosphorus accumulation and internal cycling, and increase habitat for fish (Beutel and Horne 1999; Moore et al. 2012). The hypolimnetic oxygenation system in Newman Lake (Spokane County, Washington) appears to have been a major factor in lowering hypolimnetic phosphorus by reducing internal cycling, and is likely a major contributor in the overall trend of lower in-lake phosphorus concentrations (Moore et al. 2012).

A hypolimnetic oxygenation system must be sized to deliver enough oxygen to overcome the total hypolimnetic oxygen demand. It can take several years to deplete the legacy oxygen demand that is associated with organic material stored in the sediment (Moore et al. 2014; personal communication between Bill Faisst of Brown and Caldwell and Alex Horne of University of California, Berkeley, June 2016).

The hypolimnetic oxygenation management measure for Spanaway Lake would pump water from the hypolimnion to a Speece cone on the lake shore where pure oxygen gas would be added (see Figure 26). The oxygenated water would then be returned to the hypolimnion. This type of oxygenation system minimizes the risk of disrupting thermal stratification (Moore et al. 2009). Spanaway lake-bed sediment samples had an average iron to phosphorus ratio of 15:1, indicating that there should be enough iron to retain phosphorus under oxic conditions. A Speece cone and electric motor-driven pump housed in a new building extension would be needed, along with high-density polyethylene (HDPE) pipes placed along the lake bottom to draw and return water from the hypolimnion. O&M costs are based on an assumed 8-month per year operation.

The hypolimnetic oxygenation management measure has significant capital and operating costs. The diffuser system should be designed to avoid resuspension of the fine-grained sediments. Prior to implementing hypolimnetic oxygenation, the County should collect additional data (e.g., bathymetry, spatial extent of hypolimnion, phosphorus release rates from sediment, iron, phosphorus and organic carbon concentrations in hypolimnion sediment) and perform modeling to confirm viability and refine the system configuration and cost estimate. During the first several years of operation, lake and sediment results should be reviewed and the hypolimnetic oxygenation system operations modified as appropriate to maximize efficiency. An alum injector could be added to the hypolimnetic oxygenation system to take advantage of its mixing and distribution systems, as described in Section 7.3.4.3 below.

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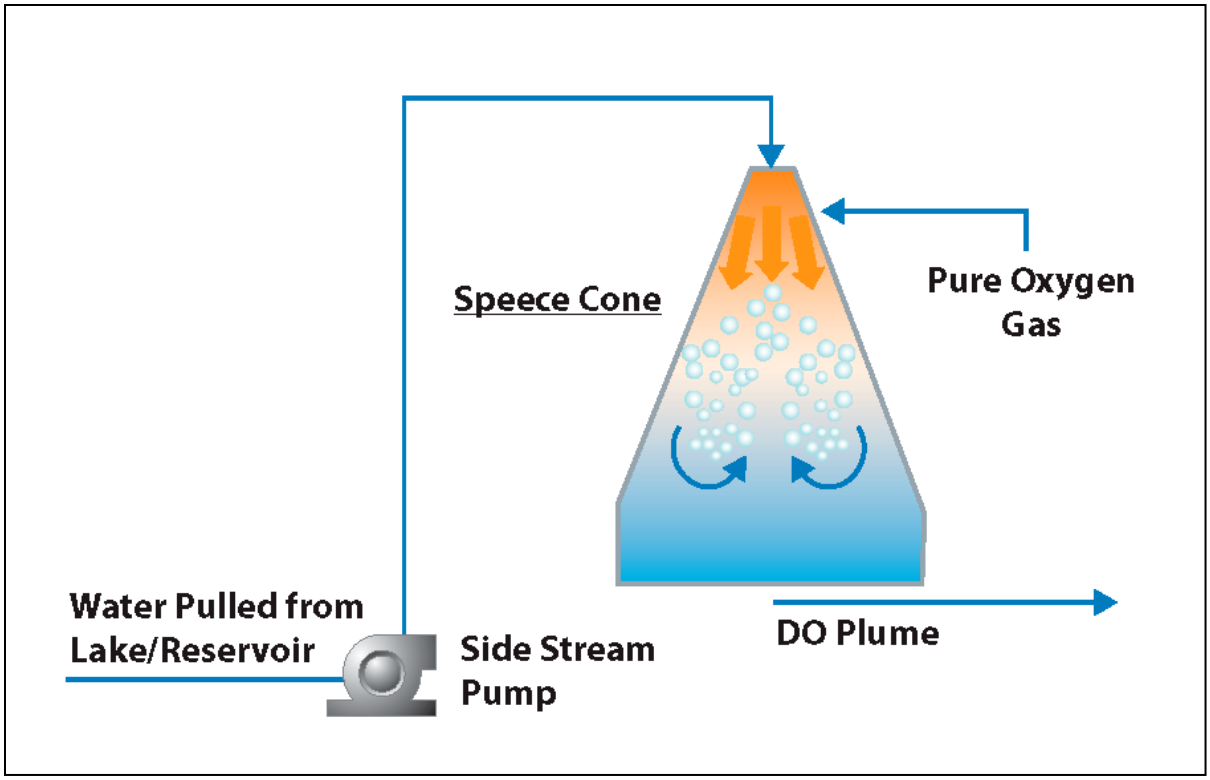

Figure 26. Schematic diagram of Speece cone

7.3.2 Hypolimnetic Siphon

Hypolimnetic withdrawal is intended to enhance the removal of nutrients and electro-chemically reduced substances that build up when the hypolimnion becomes anoxic. This method exports nutrient-rich water from the lake (Dunalska et al. 2007). Nürnberg (2007) notes that hypolimnetic withdrawal can be an effective low-cost restoration technique to combat and potentially reverse eutrophication in stratified lakes and reservoirs. However, a recognized disadvantage of this method is its potential impact on downstream waters including eutrophication, oxygen depletion, and odor development, which may violate state water quality standards (Nürnberg 2007).

The hypolimnetic siphon measure would entail installing a siphon to remove water from the bottom of Spanaway Lake and discharge it downstream. The preliminary cost estimate assumes that a diversion structure and pipe would be required to bring cool, oxygenated water from Coffee Creek to the lake bottom. The estimate includes a concrete diversion weir, approximately 5,000 feet of 16-inch-diameter HDPE pipe for the inflow, and approximately 2,700 feet of 18-inch-diameter HDPE pipe for the siphon. The siphon pipe size is based on a design discharge rate of 2 million gallons per day (mgd) (~3.7 cubic feet per second [cfs]), which is about 85 percent of the minimum flow observed during August 2015. This flow rate was selected to avoid lowering the lake level. Based on an average hypolimnion phosphorus concentration of 0.07 mg/L and a 123-day anoxic period, and 2 mgd flow rate, the siphon would

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remove about 65 kg of phosphorus per year (~11 percent of the estimated annual internal phosphorus load). The siphon would be driven by gravity, so no power would be required. The preliminary planning-level capital cost estimate for the siphon system is $2,800,000, with minimal operating costs. This estimate assumes that water quality treatment is not needed.

A similar siphon system was installed in Lake Ballinger (Montlake Terrace, Washington) in 1983. Ecology conducted a study in 2008 and found that the siphon had improved lake water quality by removing phosphorus and low DO water (Ecology 2008a). However, the study also found that the siphon discharge was adversely affecting water quality downstream of the lake by discharging water with low DO and high phosphorus, so Ecology directed the City of Montlake Terrace to shut off the siphon (Ecology 2008b, 2008c). Ecology indicated that the siphon could be re-opened in the future if the siphon water is treated prior to discharge.

Ecology's lake restoration website notes that hypolimnetic withdrawal systems can have severe impacts on downstream water quality (Ecology 2016). Advisory Group members noted that Tule Lake residents might object to the proposed discharge from Spanaway Lake. Therefore, a siphon system at Spanaway Lake would likely need to include treatment to remove phosphorus and increase DO prior to discharge. Preliminary estimates indicate that if water quality treatment is required, the construction cost for the siphon management measure could exceed $4,300,000, with O&M costs on the order of $146,000/yr. Predesign work would include a bathymetric survey, benthic flux sampling, evaluation of potential downstream water quality impacts, discussions with Ecology regarding potential treatment requirements, and identification of a suitable treatment facility site, if required.

7.3.3 Hypolimnetic Withdrawal for Golf Course Irrigation

The Lake Spanaway Golf Course withdraws water from the lake to irrigate the golf course each year. The existing intake is located in the epilimnion of the lake. This measure would extend the irrigation pipe so that it withdraws water from the hypolimnion. Based on current irrigation use and the average phosphorus concentrations observed in the hypolimnion, this measure would remove less than 1 percent of the estimated annual internal phosphorus load from the lake.

This management measures proposes to relocate the in-lake pump from its current location to the deepest part of the lake just south of Enchanted Island (approximately 700 feet from the existing pump house). Preliminary planning-level cost estimates include an initial cost of $140,000 to extend the pipe and minimal increase in O&M costs related to higher pumping rates. Predesign work would include bathymetry and geotechnical evaluation of the pipe route and coordination with the golf course.

7.3.4 Phosphorus Inactivation

Internal phosphorus loading in Spanaway Lake may be controlled with alum, or a similar binding agent, to inactivate phosphorus in the sediment. Alum is commonly used to inactivate phosphorus in lake sediment, strip phosphorus from the water column, reduce internal loading, and mitigate algae problems. Whole-lake alum treatments have been used successfully throughout the United States since 1970, including numerous lakes in Washington (Burghdoff

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et al. 2012). The North American Lake Management Society (NALMS) notes that alum is a safe and effective lake management tool especially where watershed phosphorus reductions are neither adequate nor timely, provided that alum applications are designed and controlled to avoid concerns with toxicity to aquatic life (NALMS 2004).

Alum or a similar binding agent is applied to the lake surface, usually from a boat or barge, with long arms to spread the alum into the lake from nozzles or trailing tubes. The treatment is typically done using computerized dosing control to apply the appropriate amount of alum for the water depth and volume at any point in the lake.

Alum reacts with water to form a fluffy aluminum hydroxide precipitate or floc that has a high capacity to adsorb phosphorus (NALMS 2004). Aluminum hydroxide can also remove phosphorus by coagulation/entrapment of phosphorus-containing particulates and by precipitation of aluminum phosphate (Kennedy and Cooke 1983). As it moves through the water column, the floc removes particulate matter such as algae, thereby increasing water clarity (Figure 27). When properly applied, the aluminum hydroxide floc forms a blanket on the lake bottom that limits phosphorus release from the sediment, even under anoxic conditions (NALMS 2004; Burghdoff et al. 2012).

Figure 27. Whole-lake alum treatment in Spring Lake

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Boat traffic in shallow areas can stir up the aluminum precipitates coating the lake bottom. However, the phosphorus remains bound in insoluble form so it is not available for use by algae. The floc will typically resettle to the lake bottom when quiescent conditions return.

Alum addition to a lake can rapidly lower pH levels of the water, making the lake more acidic, especially in lakes with soft water and low buffering capacity. For this reason, alum treatments are often buffered by adding another chemical, such as sodium aluminate, to balance the pH and prevent negative impacts to organisms living in the lake (Burghdoff et al. 2012). The recent, successful whole-lake treatment of Green Lake (Seattle, Washington) included alum and sodium aluminate. The cost provided in Table 16 assumes that both alum and sodium aluminate would be used. Jar testing with the lake water and different coagulants and doses must be performed to determine the optimum mix of coagulants and doses.

It is extremely important for an experienced and qualified firm to conduct the treatment. As noted above, NALMS has determined that alum treatments are an effective and safe lake management tool provided that alum applications are designed and controlled to avoid concerns with toxicity to aquatic life (NALMS 2004).

7.3.4.1 Phosphorus Inactivation: Whole Lake Treatment

The management measure for whole lake treatment of phosphorus inactivation assumes the addition of approximately 125,000 gallons of alum and approximately 56,000 gallons of sodium aluminate to remove phosphorus from the water column and form an aluminum precipitate layer on the sediment. These coagulant volumes are based on the amount of phosphorus in the top 10 cm of lake-bed sediment along with the amount of phosphorus in the lake water column. BC assumed that a lower dose may be needed subsequently, every 2 to 5 years. The initial planning-level cost estimates are $689,000 for preparation and initial treatment and $350,000 every 2 to 5 years. The water quality benefit would be high initially, with a slow decline over time. This measure requires minimal infrastructure and does not conflict with other lake management measures; however, it could increase macrophyte growth by clarifying the water column and the floc could negatively impact some filter-feeding fish.

7.3.4.2 Phosphorus Inactivation: Alum Emitter

One management measure to treat inflows and lake water with alum is the strategic installation of alum emitters near known phosphorus input points such as Coffee Creek. As shown in Table 15, the management measure for using an alum emitter includes the installation of an alum emitter (or similar chemical) near Coffee Creek and requires a chemical feed system, chemical storage tank, small building to house the alum feed system, and a flow meter. The initial planning-level cost estimates are $175,000 for capital (alum feed system and small building only) and $30,000 per year for O&M. The water quality benefit would be medium, and would help to manage phosphorus loads from Coffee Creek and nearby groundwater. It would also help reduce bacteria concentrations.

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7.3.4.3 Phosphorus Inactivation: Alum Injector

If the hypolimnetic oxygenation measure is selected for implementation in Spanaway Lake, an alum injection system could be added to take advantage of the hypolimnetic oxygenation mixing and distribution system. Alum would be injected into the Speece cone to mix with the hypolimnion water before being pumped back into the hypolimnion via diffusers that create ultra-small aluminum precipitate particles. These particles would capture phosphorus in the water column and also potentially in the sediment. This type of hypolimnetic oxygenation and alum system has proven very effective at improving water quality in Newman Lake near Spokane, Washington. Volume-weighted TP was reduced from 0.055 mg/L to 0.021 mg/L and peak cyanobacteria concentrations decreased from 160.0 million to 1.1 million/m^3 (Moore et. al 2009). The preliminary planning-level capital cost for adding alum injection to the hypolimnetic oxygenation system is $100,000 with an estimated annual O&M cost of $32,000.

7.3.5 Improve Conveyance Capacity of Lake Outlet

The Advisory Group expressed interest in the potential benefits of removing excess vegetation and debris from the lake outlet, thereby reducing the lake level and hydraulic residence time as well as inundation of docks and yards in an area (~3.5 acres) upstream of Military Road. The project team used an existing hydraulic model, and topographic and bathymetric elevation data to evaluate this measure. Appendix F describes the analytical methods and results.

The evaluation found that lake levels are controlled by a shallow area where Little Spanaway Lake flows into Spanaway Creek, upstream of Military Road (see Figure 28). The preliminary hydraulic analysis indicates that managing vegetation, debris, and minor obstructions in the lake outlet area could affect lake levels by about 4 inches, inundated area by about 3 percent, and lake volume by about 1 percent. Substantial blockages within the channel could cause greater impacts, but it would greatly depend on the size and location of the obstruction. For example, a 2-foot blockage at the Military Road culvert would not affect lake levels because it is too far downstream, while a 2.5-foot blockage could raise lake levels buy about 0.1 foot.

Given the small change in lake volume, this measure is expected to have little impact on hydraulic residence time. The decrease in inundated area might provide for a slight reduction in phosphorus loads from shoreline septic systems.

Pierce County Parks and Recreation staff indicated that they have the necessary permits and are already implementing this measure. Ongoing costs for plant removal are estimated to be between $1,900 and $5,000 per acre for submerged plants and $7,000 to $12,000 per acre for emergent plants. Additional data collection needs include a bathymetric survey and a plant/debris survey of the outlet reach area. Local residents have suggested that rocks from an old bridge could be impeding flow in the lake outlet area. The plant/debris survey should look for remnants of the former bridge to assess whether they could be impeding lake outflow.

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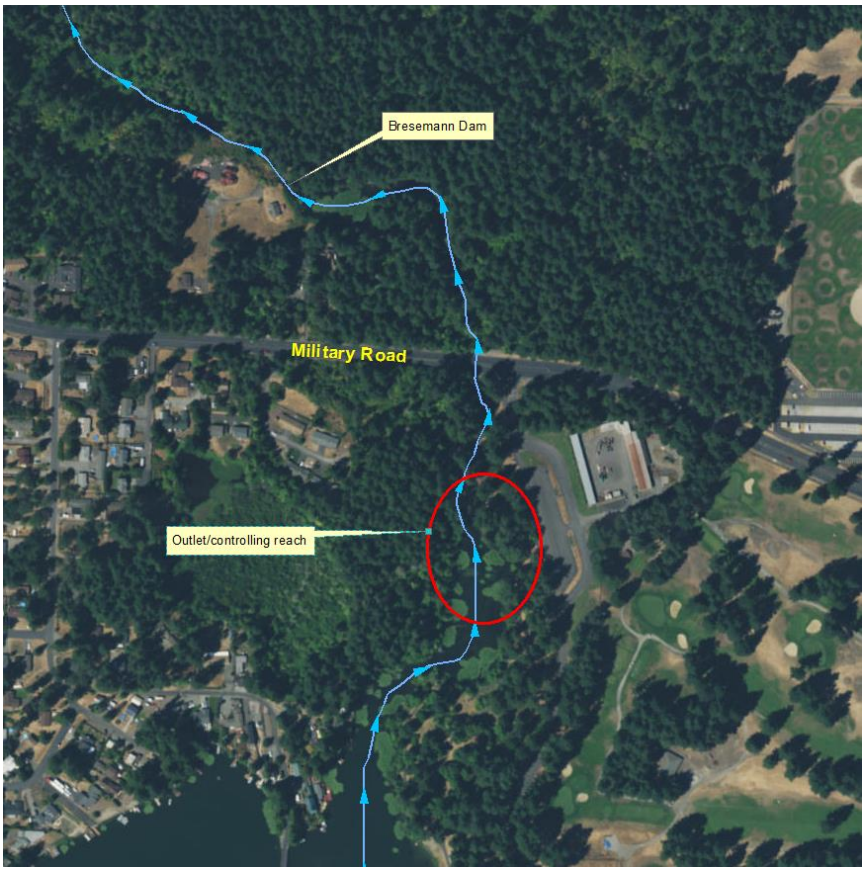

Figure 28. Spanaway Lake outlet location

7.3.6 Aquatic Vegetation Management

Native aquatic plants are an essential component of a healthy lake ecosystem. Aquatic plants provide oxygen, food, and habitat for fish, zooplankton, waterfowl, and aquatic mammals. Fortunately, the Spanaway Lake plant community is composed mostly of beneficial native species, although two non-native, invasive aquatic species are also found in the lake (e.g., fragrant water lily and curly-leaf pondweed). Non-native plants can often spread aggressively and outcompete native species, harming lake recreation and ecology.

Aquatic vegetation management includes a variety of mechanical, chemical, and physical control methods. These methods are important lake management tools that must be used cautiously to avoid unintended consequences. For example, broad-scale control of vegetation can lead to algae blooms as plant matter decays and releases nutrients that fuel algae growth. Some methods provide short-term control, but can promote the spread of undesirable plant species.

Annual vegetation monitoring is recommended to provide the basis for informed plant management decisions, document plant community changes over time, and ensure rapid identification and response to any future non-native species infestations. A preliminary

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planning-level cost estimate to conduct an aquatic plant survey—and develop a plant management plan and field guide—is $7,000 to $12,000.

7.3.6.1 Aquatic Vegetation Harvesting

Aquatic vegetation harvesting includes techniques that range from hand pulling of nuisance plants to large-scale mechanical cutting, collection, and offsite plant disposal. These techniques can provide effective but short-term control, immediately restoring open water in areas where plant growth impedes recreational uses such as swimming and boating. However, without careful application and management, aquatic vegetation harvesting can promote the spread and increase the future growth density of some nuisance plant species. For this reason, these techniques should only be conducted where appropriate, based on a recent aquatic vegetation survey of Spanaway Lake and development of a detailed aquatic vegetation map and inventory of species in targeted areas.

Mechanical Harvesting. Mechanical harvesting involves the use of boats that are designed to cut and collect aquatic plants. Most harvesting machines are designed to cut plants from 4 to 8 feet below the water surface. Plants can be transported to shore for storage and disposal by the harvester, although using a separate transport barge can increase the efficiency of the cutting operation (see Figure 29).

Figure 29. Mechanical harvester

Commercial harvesting costs vary depending on the target plant(s), density of growth, travel distance for disposal of harvested plants, and the number of obstructions present. The harvesting cost per acre usually ranges from $450 to $700, including trucking and disposal. The cost per acre of harvesting is inversely proportional to the size of the area harvested; there is an economy of scale for larger projects. A cost range of $260 to $770 per acre for mechanical harvesting at typical densities and $1,200 to $2,500 per acre for very high densities of plants is suggested.

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Hydroraking. A hydrorake is typically a paddle-driven boat with a York rake attachment that is used to rake the upper sediment layer, collecting plants and root systems. The hydrorake is used in combination with a transport barge that brings the collected material to the shoreline for storage and disposal. The hydrorake is most effective at removing plants with large root systems, typically floating-leafed (e.g., pond lilies) and emergent species (e.g., cattails). Plants with slender stems and root systems that can pass between the tines of the hydrorake and re-root from fragments (e.g., milfoil) are not well-suited for control by this technique. By disturbing the sediment and uprooting plants, hydro-raking results in a temporary increase in turbidity in the locus of operation (see Figure 30 below).

Figure 30. A hydrorake loading water lilies onto a barge for offshore disposal

Estimated costs for hydroraking range from about $1,900 to $5,000 per acre for submerged plants and $7,000 to $12,000 per acre for emergent growths, large floating mats, and dense root masses. As with mechanical harvesting, per acre costs tend to be lower for larger projects.

Diver Hand-Harvesting/Diver Assisted Suction Harvesting. Hand harvesting is conducted by divers who pull targeted aquatic plants, place them in collection bags, and remove them from the lake. This method is used primarily to remove early infestations of invasive species and allows for selectively removing individual plants. Plants should be pulled out with the entire root structure to minimize the potential for plant re-growth.

Diver-assisted suction harvesting (DASH) is conducted by divers that pull plants and root masses by hand and feed them into a boat-mounted vacuum hose for later disposal. The cost of hand harvesting and DASH varies widely on a per-acre basis because the rate at which divers can harvest an area varies greatly depending on the density of plant growth, stem height, and substrate composition. Water bodies with highly flocculent sediments will become turbid quickly as plants are pulled, making it difficult for divers to see what they are doing and slowing the rate of harvesting.

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Estimated costs vary widely ($4,000 to $10,000 per acre) based on plant density, sediment type, and project area. For new infestations with moderate growth, the lower end of this cost range ($4,000 to $7,000 per acre) is expected.

7.3.6.2 Herbicides/Algaecides

Although a powerful tool for plant and algae control, the use of herbicides and algaecides can be controversial because of perceptions regarding toxicity to humans and non-target organisms. All aquatic herbicides approved for use in Washington are regulated by Ecology. For a more complete discussion of this complex topic, see Ecology's Fact Sheet for the Aquatic Plant and Algae Management NPDES General Permit (Ecology 2016).

Herbicides and algaecides (referred to as herbicides) contain active ingredients that are toxic to target plants. Herbicides are typically classified as contact or systemic herbicides:

- Contact herbicides are toxic to plants by uptake in the immediate vicinity of external contact, which typically excludes the root system. Contact herbicides tend to be relatively fast-acting, and can often be used to "spot-treat" target areas—leaving other areas of a lake untreated.
- Systemic herbicides work more slowly than contact herbicides because they require translocation throughout the entire plant and its root system. Because they require longer exposure time (up to 30 to 40 days), some systemic herbicides are not well-suited for spot-treatments and may require booster applications to offset dilution during the application period. Systemic herbicides can provide more effective control of perennial plants because they kill the entire plant under favorable conditions. Re-growth from seeds should be expected following use of both contact and systemic herbicides.

Ecology issues permits for seven aquatic herbicides and two algaecides for aquatic plant treatment for lakes, rivers, and streams (Ecology 2016).

Any application of herbicide in Spanaway Lake should carefully consider both short-term and long-term aquatic plant management goals. Repeated herbicide treatments may alter the composition of a plant community over time by giving a competitive advantage to species that are either less susceptible to the active ingredient or are better suited to colonizing new areas that have been opened up by the treatments. Such shifts can be beneficial in some cases, although it can also result in a dominant plant community that is even more of a nuisance than the original target species. For this reason, it is important to have a complete inventory of plant species that are present in the target areas, and to use this information as the basis for a long-term plant management strategy.

7.3.7 Waterfowl Management

Spanaway Lake has numerous types of waterfowl including geese, ducks, and cormorants, which have different habits, food preferences, and fecal bacteria output. Based on the limited waterfowl survey data and technical literature regarding fecal bacteria output content, ducks appear to be a significant source of fecal bacteria for Spanaway Lake. This waterfowl

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management measure includes incorporating various methods for managing waterfowl with lake water quality in mind including the implementation of landscaping/physical barriers, deterrents/scaring techniques, depredation permits, and public outreach.

7.3.8 Education Program

The Lake Management Plan recommends ongoing lake education and awareness efforts to aid in protecting water quality over the long-term. The initial step will be to conduct specific research to help identify the methods of communication and areas of focus for the targeted audiences. After that initial step, the specific measures that could be considered are:

- Review and update LakeWise materials based on audience research, which could include developing and purchasing LakeWise signage, printing copies of the PCDs Lake Book, updating the signage checklist and ordering printed materials, as well as direct mailings.
- Offer technical assistance visits to:
  - Verify LakeWise checklist activities completed
  - SWM drainage/stormwater site visits
  - Install pet waste stations
- Conduct shoreline site visits and identify best management practices (BMPs) and potential shoreline restoration projects.
- Assess the effectiveness of educational and outreach activities with pre- and post-workshop questionnaires or via direct mailing.
- Coordinate with other programs, help establish a Spanaway Lake Committee and volunteer lake monitoring program, communicate monitoring results.
- This program would have a one-time cost of about $30,000, and annual costs of about $23,000.

7.4 Monitoring

The lake characterization involved monitoring lake water quality, creek inflow and outflow, creek water quality, groundwater quality, and lake sediment. The characterization sampling and modeling were limited by the available budget so some data gaps remain. Additional monitoring would help refine the initial estimates of hypolimnion area and volume, internal phosphorus loads, hypolimnetic oxygen demand, sediment release rates, macrophyte distribution, and waterfowl inputs of nutrients and bacteria. As noted in Table 16 above, targeted data collection should be performed to confirm the viability, configurations, and cost estimates for some of the potential lake management measures.

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A long-term monitoring program would provide useful information on the overall water quality status of Spanaway Lake as well as the effectiveness of the lake management measures. Monitoring can include continued water quality monitoring of in-lake and tributary phosphorus concentrations to directly measure the reduction in phosphorus loading and associated algae blooms in Spanaway Lake. Sediment sampling can be conducted to estimate nutrient and organic matter concentrations, while benthic flux chambers can be used to estimate the rate at which phosphorus is released into the water column during anoxic periods. Vegetation monitoring is recommended to provide the basis for informed plant management decisions, to document plant community changes over time, and to ensure rapid identification and response to any future non-native species infestation. Biological monitoring for lakes can include a wide range of biota, such as mammals, fisheries, waterfowl and macroinvertebrates. Continued monitoring of the abundance and composition of the lake algal community will provide a useful metric for understanding water quality trends in response to implementation of the measures recommended in the LMP.

With proper training, professional guidance and a modest investment in sampling equipment, volunteers can conduct much of the lake monitoring needed to support the scientific understanding of lake baseline conditions, provide historical context for water quality trends, and allow for early detection and response to new threats such as invasive, non-native plant species. Monitoring activities that require special equipment or training (e.g., benthic flux monitoring and phytoplankton analysis) may require more involvement by professional staff.

7.5 Summary and Recommendations

Table 17 summarizes the measures recommended for Spanaway Lake based on the existing monitoring data, technical evaluations, and input from the Advisory Group. Appendix F includes more details on each of the measures listed in Table 17, including planning-level cost estimates consistent with AACE Class V guidelines. The following paragraphs summarize the rationale for selection of each measure:

- Hypolimnetic oxygenation system with alum injector: This measure was selected because it should substantially reduce internal phosphorus loading, which was identified as the largest source of phosphorus affecting the lake (see Section 5 above). A hypolimnetic oxygenation system should minimize the release of phosphorus from sediment by maintaining oxic conditions in the hypolimnion. Over time, a hypolimnetic oxygenation system can reduce the amount of organic carbon in the sediment, thereby decreasing the hypolimnetic oxygen demand. The alum injection system allows targeted treatment at key times of the year (e.g., spring and fall turnover) to remove phosphorus from the water column and help bind sediment phosphorus. A hypolimnetic oxygenation/alum injector system has proven very effective at improving water quality in Newman Lake near Spokane, Washington (Moore et al. 2009, 2012, 2014). The hypolimnetic oxygenation system should also increase the amount of cold water fish habitat.

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- Aquatic plant management: This measure was selected to address Advisory Group concerns regarding dense aquatic plant growth in some areas of the lake. Native aquatic plants are an essential part of the Spanaway Lake ecosystem, but non-native plants can spread aggressively and outcompete native species, harming lake recreation and ecology. This measure should reduce the risk of invasive plants and improve lake water quality.
- Waterfowl management: This measure was selected because the source evaluation (see Section 6) identified waterfowl as an important source of fecal contamination, and species that feed in upland areas (e.g., geese) can also add phosphorus to the lake. Also, waterfowl feces on beaches, docks, and play areas interferes with recreation activities.
- Public education: This measure was selected because local support is crucial to successful funding and implementation of the LMP. Public education should also help reduce phosphorus and fecal contamination from shoreline landscaped areas, pets, and septic systems.
- Monitoring: Focused, short-term monitoring was recommended to address key data gaps, such as lake bathymetry and sediment oxygen demand. Long-term monitoring was recommended to collect the data needed to evaluate progress and support adaptive management.

Maintaining the conveyance capacity of the lake outlet may help reduce inundation of docks and shoreline areas – an important concern for many Advisory Group members. It may also provide minor water quality benefits by slightly reducing hydraulic residence time and slightly better phosphorus removal for shoreline septic systems. County Parks and Recreation staff recently began inspecting the lake outlet area and have obtained the requisite permits for removing vegetation and debris when necessary. Since this measure is already being implemented, it is not included as a recommendation in Table 17.

Several of the candidate measures are not recommended for implementation at this time, for the reasons summarized below:

- Whole-lake alum treatment is expected to be highly effective at phosphorus inactivation, but the longevity of the benefits is uncertain due to ongoing phosphorus inputs from groundwater and Coffee Creek. Consequently, the long-term costs are hard to predict.
- Alum injectors could be used to help inactivate phosphorus from discrete sources like Coffee Creek, but additional evaluation would be needed to estimate overall benefits to the lake. Injectors are impractical for diffuse groundwater inflows.

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- The hypolimnetic siphon measure could potentially remove high phosphorus/low DO water from the lake without pumping, but could adversely affect water quality downstream of the lake. Also, it may not be feasible to withdraw enough water during the summer months to significantly reduce phosphorus in the lake without affecting lake level. Ecology would likely require treatment prior to discharge. If water quality treatment is required, capital and operating costs would be much higher.
- Withdrawal of hypolimnion water for golf course irrigation would have relatively low capital costs, but would remove only a small percentage of the internal phosphorus load from the lake.

The County's Parkland-Spanaway-Midland Communities Plan and Unified Sewer Plan Update recommended sewering the Spanaway Lake area because it contains numerous septic systems overlying a sole-source aquifer, as noted in Section 7.2 above (Pierce County Planning and Land Services, 2002; Pierce County Public Works and Utilities – Sewer Utility, 2010). The source evaluation conducted for this LMP indicates that sewering would also reduce long-term phosphorus loads to the lake. Therefore, sewering of the Spanaway Lake area is recommended to support the objectives of this LMP.

As discussed in Section 5.6.3, the County should take advantage of the HSPF watershed model and MODFLOW groundwater model that are being developed for the WSP. These models could be used to refine the water budget, nutrient budget, and source evaluations, and potentially modify the measures recommended in this LMP.

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Table 17: Recommended Measures for Spanaway Lake				
Measure	**Description**	**Anticipated Water Quality Benefits**	**Estimated Costs**	
			Initial	**Ongoing**
Hypolimnetic oxygenation system with alum injector	**Inject oxygen near lake bottom to minimize phosphorus release from sediment under anoxic conditions. Add alum at key times to increase phosphorus removal.**	**Reduced internal phosphorus load, increased DO, more fish habitat.**	**$2,000,000**	**$81,000**
Aquatic plant management	**Perform aquatic plant survey. Develop aquatic plant management plan tailored to Spanaway Lake. Routine monitoring by volunteers. Perform targeted plant removal when necessary, in accordance with LMP.**	**Reduced risk of invasive plants, improved recreation, small reduction in sediment phosphorus.**	**$12,000 for plant survey, plan, field guide**	**$16,500 assumes removal of aquatic plants from 5 acres/yr at average cost of $3,500/acre.**
Waterfowl management	**Initial survey to characterize bird use of lake. Use landscaping/physical barriers, deterrence measures and education to help control waterfowl.**	**Reduced fecal loads to lake, less fecal matter on docks, beaches, and lawns.**	**$5,000 to support initial survey.[a]**	**TBD[a]**
Public education and outreach	**Support lake committee. Adapt LakeWise program to encourage lake-friendly landscaping, septic system maintenance, pet waste cleanup, and responsible boating.**	**Reduced phosphorus from shoreline landscapes and septic systems, reduced bacteria loads from waterfowl and pets, public support for LMP activities.**	**$30,000 [b]**	**$23,000[c]**

Table 17: Recommended Measures for Spanaway Lake				
Measure	**Description**	**Anticipated Water Quality Benefits**	**Estimated Costs**	
			Initial	**Ongoing**
Focused monitoring	**Bathymetric survey, equipment acquisition, grab sampling and profiling at several deep locations in the lake, limited sediment sampling.**	**Fill key data gaps to confirm and refine selected measures and cost estimates.**	**$26,000[d]**	**None**
Long-term monitoring	**Monthly monitoring from early spring through late fall throughout the lake water column, sampling in Coffee Creek, deep hole sampling, algae sampling.**	**Evaluate LMP progress and support adaptive management.**	**None**	**$33,000[d]**

a. Assumes program would be implemented primarily by private property owners and volunteers with limited support from County staff.

b. Includes one-time activities such as audience research, LakeWise signage, pet waste stations, and printing.

c. Staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.

d. Assumes program would be implemented primarily by volunteers, with some support from County staff. Focused monitoring cost includes $2,000 for equipment that could also be used for long-term monitoring.

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Section 8: Implementation

This section describes potential funding sources for implementing the recommended management measures described in Section 7.5. It also describes the recommended overall approach for implementing this LMP.

8.1 Potential Funding Sources

The Spanaway LMP has identified various actions to improve conditions in Spanaway Lake. These measures vary considerably with regard to capital costs and ongoing costs. The County currently does not have a funding source dedicated to lake management activities. Given the estimated costs of the recommended measures, implementation of this LMP may require funding from multiple sources.

Some funding mechanisms, such as state grants or state legislative appropriations may be more suited to initial startup actions or capital investments. Other types of funding may be more advantageous for establishing more stable, long-term funding, such as those achieved through establishing a special benefit district. A successful lake management funding strategy will likely employ a number of different funding mechanisms for various purposes and at various times throughout the life of the lake management efforts. Further policy discussion will be needed in selecting the appropriate measures from among the available potential funding sources.

Whatever funding mechanisms are selected for further investigation, it will be important to continue with public involvement to help the County direct lake management work and respond to community issues and values. Many of the funding mechanisms that are available to lake management programs require establishment of some sort of oversight or advisory body. Whether establishing an informal advisory group, an independent non-profit entity, or a group formally chartered by the County Executive or Council, some level of funding will be necessary to support the activities of the group.

Additional staff or contract resources will be necessary for future lake management administration, public education and outreach, O&M, and contract management. A number of potential lake management funding mechanisms are discussed below.

8.1.1 Lake Management District

A Lake Management District (LMD) is a form of special-service district that funds lake management activities through charges on lake-area properties. A LMD can finance a range of activities, including:

- Controlling aquatic vegetation
- Improving water quality, including control of stormwater and agricultural runoff
- Performing water quality studies to pinpoint problems and identify solutions
- Maintaining ditches or streams associated with the lake

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- Maintaining lake levels
- Maintaining beaches

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 with access to community beach areas are commonly included. It may be possible to include the entire watershed in a LMD.

LMD assessments or charges can be based on any reasonable factors, including: benefit, use, front footage, acreage, improvements, and services to be provided. LMD charges may include differing benefit zones throughout the district. For example, upland lots with access to a community beach may be included at a lower rate than waterfront lots. Waterfront lots could be further designated into different zones, which reflect a reduced benefit where wetlands or other factors limit the shoreline use. Public and private recreational areas may be placed in a special class and assessed based on the benefit to users from the lake management program.

Income from LMD rates is used only for activities specified in the legislation establishing the LMD. Allowances may be included for low-income property owners. A separate elected commission is not necessary for a LMD—as there would be for a drainage district or water district—and the County Council may serve as the governing board. Ongoing involvement by the lake property owners and users is crucial to a successful program. Forming a committee of lake users is the preferred way to achieve appropriate working relationships with County staff and elected officials in initiating and implementing a LMD program.

The City of Tumwater's Barnes Lake LMD provides an example of how LMD funding can work. This LMD was formed by the Tumwater City Council following the approval of a citizen petition of lake property owners to help improve aquatic conditions around the lake. LMD activities include management of aquatic plants, noxious weed prevention/eradication, and vegetative debris removal. Environmental education and wetland habitat management and preservation are also included.

The Barnes LMD annual financial assessments is based on the estimated benefits that each parcel derives from lake management activities. The assessments are based on land use designations and view. This assessment generates approximately $17,000 annually.

A theoretical application of Barnes LMD funding criteria to a potential Spanaway LMD could yield annual revenue on the order of $57,000. For rate equity purposes, a County Parks and Recreation contribution might be on the order of an additional $8,000 for a total annual LMD revenue stream of approximately $65,000. How a park contribution would be realized is an open question with possible answers including a park usage surcharge, a general fund budget allocation, and/or some in-kind services contribution. A Spanaway Lake funding strategy, based on the City of Tumwater's Barnes Lake LMD model, is shown in Table 18.

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Table 18: Example LMD Annual Assessment Schedule for Spanaway Lake			
Property class	**Rate**	**Number of properties**	**Total revenue per class**
Residential with frontage	**$240**	**174**	**$41,760**
Condo with view	**$192**	**62**	**$11,904**
Residential with view	**$77**	**23**	**$1771**
Undeveloped residential with view	**$48**	**26**	**$1,248**
	Total from Property Class	**285**	**$56,683**
Spanaway Lake perimeter (feet)	**Perimeter of park on lake (feet)**	**% perimeter park**	**Park fee based on % of total lake frontage**
35,100	**4834**	**14**	**$7,806**
Total Private + Park (Assuming park fee based on % of lake frontage)			**$64,489**

Table 18 above provides parcel annual fees of a LMD assuming the exact assessment scheme that was developed for the Barnes Lake LMD. If a LMD is deemed appropriate for Spanaway Lake, an assessment method would need to be developed to meet the unique needs and properties of the Spanaway Lake properties.

8.1.2 Flood Control Zone District

A Flood Control Zone District (FCZD) can be a useful mechanism in funding actions addressing a broad range of watershed issues from flood control and water quality improvement to watershed management. The FCZD may include—but not be limited to—the extension, enlargement, construction, or acquisition of dikes and levees, drain and drainage systems, dams and reservoirs, or other flood control or stormwater control improvements. FCZD resources can be used for widening, straightening, or relocating of stream or water courses and the acquisition, extension, enlargement, or construction of any works necessary for the protection of stream and water courses, channels, harbors, life, and property.

A FCZD is governed by a board, which can be the local legislative authority. The board may initiate the creation of a zone or additional zones within the FCZD for the purpose of undertaking, operating, or maintaining flood control projects or stormwater control projects or groups of projects that are of special benefit to specified areas within the FCZD. Formation of a zone may also be initiated by a petition signed by 25 percent of the electors within that proposed zone (based on the vote cast in the last county general election).

The County created a FCZD in 2012. The County FCZD is a special purpose district governed by a board of supervisors and an executive committee. The County Council serves as board of supervisors. An advisory committee, with County participation, provides input and recommendations to the board to carry out the FCZD's approved projects and programs.

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Funding for the County's FCZD comes from a county-wide property levy of $0.10 per $1,000 of assessed value. The levy raises approximately $8,000,000 a year. Ten percent of the County's FCZD's levy proceeds are assigned to an Opportunity Fund, which is made available to jurisdictions throughout the County's FCZD on a proportional basis, based on assessed valuation. The Opportunity Fund for 2015 was $733,833 with grants dispersed among the 24 jurisdictions in the County—based on certified assessed values—with the unincorporated County share at $329,000 or 42.53 percent of available funds county-wide.

The Opportunity Fund grants can be used for a number of purposes consistent with actions called for in the Spanaway LMP, including:

- Watershed management projects, studies, plans, and activities that are for water supply
- Water quality and water resource and habitat protection and management
- Studies and plans for flood control or stormwater control improvements that will be constructed or acquired by the jurisdiction
- Major equipment used for stormwater control or water quality protection
- Flood control or stormwater control improvements (whether extended, enlarged, acquired, or constructed)
- O&M of flood control and stormwater control improvements that were constructed or acquired by the jurisdiction

Accessing allocations from the Opportunity Fund requires entering into an Interlocal Agreement with the County's FCZD, and the jurisdiction must prepare and submit (to the County's FCZD administrator and the Director of Pierce County Public Works Department):

- Preliminary engineering studies
- State Environmental Policy Act (SEPA) determinations and plans for any project
- Cost estimates and underlying project data
- A description of the benefit to be provided by the project

A number of purposes and uses are called "projects" for the purposes of accessing the Opportunity Fund, and the County FCZD suggests that potential eligible projects might include:

- O&M for projects
- Developing green infrastructure such as rain gardens and stream flow controls
- Building compensatory storage for flood relief
- Acquiring vactor equipment

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County FCZD funds could potentially complement funding from a Spanaway LMD. FCZD funds could also possibly be applied to specific lake management activities such as:

- County SWM or TPCHD staff provide support for lake management activities (e.g., education, outreach, monitoring)
- Water quality monitoring and environmental assessment
- Waterfowl management support (for public health and water quality protection)
- Aquatic plant management (e.g., targeted removal of invasive plants)
- Supporting citizen's committees in areas where lakes management plans have been developed
- Outreach and education
- Local match for other grants

While currently earmarked for other purposes, some of the County's Opportunity Funds could potentially be allocated to lake management activities. These funds could also potentially be allocated to various lake projects around the County on an as-needed, priority basis. However, the FCZD would need to approve use of the Opportunity Fund allocation for lake management activities.

Opportunity Fund recipients may choose to bank their allocation for use in future years, saving up for larger projects and efforts; however, the County's FCZD holds the right to review any banking activity. Opportunity Fund allocations are issued on a reimbursement basis following a jurisdiction's invoice submittal, although the County's FCZD has some ability to grant funds in advance within pre-defined constraints as a percentage of the jurisdictions total current allocation.

Given the County FCZD approval process and criteria, it would be prudent to discuss possible projects with them well in advance of project funding need.

8.1.3 State Legislative 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 Spanaway Lake 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. Successful pursuit of a legislative budget request in the range of $2,500,000 to $4,000,000 could address Spanaway Lake capital investment needs depending on the specific lake management actions or projects that are selected. Other funding mechanisms could provide the ongoing O&M resources necessary to protect those capital investments.

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8.1.4 Grants and Loans

Both federal and state grant programs applicable to lake management efforts are administered by Ecology. Grant and loan funding is limited, generally applies to specific types of projects/activities depending on the funding program, and competition for funds can be significant. However, some of these funding sources could potentially be applied to lake management efforts, including Clean Water State Revolving Fund (CWSRF) loans, Centennial Clean Water grants, Section 319(h) Clean Water grants, stormwater financial assistance grants, Aquatic Invasive Plant Management grants, Freshwater Algae Control grants, Washington Wildlife and Recreation Program grants and onsite sewage financial assistance loans. A brief summary of each of these funding sources is provided below.

8.1.4.1 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. Local governments, special purpose districts, and Tribes can apply for these funds. No match is required and CWSRF loans can be used to match Centennial Clean Water and Section 319(h) grants. No more than 50 percent of the total available funds can go to any one applicant.

A reliable revenue source is needed for CWSRF loan repayment. Potential revenue sources include a potential LMD, FCZD funds, general tax revenues, and utility service charge or surcharge revenue among others discussed here. Assuming a $2,038,000 capital investment is needed at a 20-year CWSRF repayment schedule at a 2 percent interest rate, a loan repayment revenue stream on the order of $124,000,000 annually would be required. Long-term funding for a SRF loan repayment could potentially be provided by a LMD, FCZD, or one of the other fee-based (non-grant) funding mechanisms discussed below.

8.1.4.2 Centennial Clean Water Grants

The Centennial Clean Water program 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. Nonpoint source pollution projects require a 25 percent match.

8.1.4.3 Section 319(h) Clean Water Grants

EPA provides “Section 319(h)” grant funds to Washington State with the State 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 program. Eligible projects include lake water quality planning, riparian and wetlands habitat restoration and enhancement, and other water quality improvement efforts. Non-profit organizations are

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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.

8.1.4.4 Stormwater Financial Assistance

Stormwater financial assistance funds come through various Washington State grant programs including the Capacity Grants, Grants of Regional or Statewide Significance (GROSS), and capital construction grants whose funding comes from a combination of state bond and hazardous substance tax dollars. Stormwater financial assistance is available through a number of programs:

- Capacity grants are non-competitive and are awarded to holders of Phase I and Phase II NPDES municipal permits for activities and equipment necessary for permit implementation. While some funds might be used for lake management efforts, they are generally applied to NPDES permit compliance activities. Funds are limited to availability per state budget and no match is required.
- GROSS are competitive grants that assist permittees in completing projects that will benefit multiple permittees and are generally applied to permit compliance efforts. No match is required and budgets are limited to $300,000.
- Stormwater Financial Assistance Program (SFAP) grants are capital grants that have had several different names over the years including Low-Impact Development and State-wide Retrofit, Low-Impact Development grants, and Supplemental State-wide Stormwater grants. These funds could be applied to stormwater management improvements and retrofits in the Spanaway Lake watershed. A 25 percent match is required (15 percent for hardship communities) with a $5,000,000 limit per community.
- SFAP Preconstruction grants can be used to develop construction plans for stormwater capital projects. Preconstruction funding may be available as part of the combined program or may run as a standalone program. These funds are typically limited to a maximum of $250,000.

8.1.4.5 Aquatic Invasive Plant Management Grants

This state grant account provides funding for technical assistance, public education, and to help control aquatic invasive plants. Revenue for the account comes from a $3.00 fee on the annual registration of boat trailers, state agencies, counties, cities, special purpose districts, and Tribes—all of which are eligible for these grants. A 25 percent match is required and funds are limited to $30,000 (state share) for planning grants and $75,000 (state share) for other projects. Each public body is limited to $75,000 per annual grant cycle.

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8.1.4.6 Freshwater Algae Program Grants

These state grants are scheduled to become available in 2018. Funds will be available from an annual $1.00 license fee on vessel registration. A 25 percent local match is required and the maximum grant amount for a freshwater algae program grant is $50,000 ($66,667 total eligible project cost).

8.1.4.7 Washington Wildlife and Recreation Program Grants

The Washington Wildlife and Recreation Program provides funding for a broad range of land protection and outdoor recreation projects, including park acquisition and development, habitat conservation, farmland preservation, and construction of outdoor recreation facilities. Some grant categories within this program are not capped but local park development projects are capped at $500,000. Local agencies and special purpose districts must provide a 50 percent match, and at least 10 percent of the total project cost must be from a non-state, non-federal contribution.

8.1.4.8 Onsite Sewage Financial Assistance Loans

TPCHD and SWM applied for and received Ecology funding for a regional loan program to support the origination and servicing of loans to property owners for the repair and replacement of failing onsite sewage systems (OSS) throughout the marine (Puget Sound and coastal) counties. Ecology also contracted with local lender Craft3, a non-profit Community Development Financial Institution (CDFI), to originate and service loans for the Regional Onsite Sewage System Program. The program may provide lending measures to repair/replace failing OSS within the Spanaway Lake drainage system.

8.1.5 Park User Fee

One of the measures proposed for generating revenue in support of lake management water quality projects was through a park user fee or user fee surcharge. Spanaway Lake is a popular park and one of only two parks in the County's park system that provide users access to lakes. A nominal parking fee of $3.00 per day per vehicle is charged May through September to help control and regulate overcrowding at the waterfront park. Even this nominal fee is contentious and unpopular with park users (personal communication with Jess Stone, Pierce County Parks and Recreation, December 29, 2016).

There are substantial barriers to using a park user fee or user fee surcharge as an avenue to generate revenue. First, entrance fees collected by the park go into Pierce County's general fund, they are not specifically set aside to support park programs. This fiscal management structure would make it difficult to guarantee that revenue from a fee increase would be returned to the park for water quality projects. Second, there is no controlled access point or system in place to require all park visitors, which includes pedestrians, cyclists, and trail users, to pay an entrance fee. Third, a fee increase would violate established County policies and values. Adopted County Parks policies state that park facilities are intended to be as accessible as possible to all County residents and the economically disadvantaged in particular (personal communication with Jess Stone, Pierce County Parks and Recreation, December 29, 2016).

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8.1.6 Surface Water Rate Surcharge-Area of Special Benefit

Some local jurisdictions have successfully implemented surcharges on stormwater utility rates or service charges. Revenue generated from these surcharges can fund improvements and programs that provide services and benefits beyond those provided in the rest of the utility service area. Surcharges are calculated based on specific improvements and programs that are not provided across the general utility service area. Such a surcharge is implemented through revisions to the surface water utility rate ordinance and revenue is collected through the utility billing process. Any use of a special benefit assessment under SWM fees would compete with findings of the County Council's Performance Audit Committee 2015 report that current rates are insufficient to pay for existing ongoing legal commitments, let alone desirable but discretionary actions such as a LMD.

8.1.7 Report of System Status Surcharge

The TPCHD Report of System Status (RSS) is required for real estate transactions of structures served by a septic system prior to transfer of ownership. The goal of this reporting program is to ensure that the buyer receives a properly functioning system. Additionally, groundwater quality is improved with properly functioning septic systems, and nutrient inputs to the lake may be reduced.

Reports or operation evaluations are generally submitted by the private inspection and pumping company working at the behest of the home owner. O&M report fees are on the order of $23 for a septic tank pumping report and $53 for an operational evaluation report. With agreement from TPCHD there may be the potential for a RSS surcharge to be applied to fund certain lake management activities.

8.1.8 Local Improvement Districts

Local Improvement Districts are a means of financing needed capital improvements through the formation of a special assessment district. Special assessment districts allow improvements to be financed and paid for over a period of time through assessments on the benefiting properties. A variation of the Local Improvement District is the Utility Local Improvement District (ULID). The difference between ULIDs and Local Improvement Districts is that utility revenues are pledged to the repayment of the ULID debt, in addition to the assessments on the benefiting properties. State statutes provide that a Local Improvement District can be converted to a ULID after formation. The reverse is not possible.

The Local Improvement District financing mechanism is a process to finance infrastructure improvements and does not provide a mechanism to construct those improvements. Construction projects must be managed by the County. Local Improvement District project financing is based on the sale of bonds to investors and the retirement of those bonds via annual assessments to owners of property within a district. The assessment per parcel must not exceed the special benefit of the improvement to that parcel.

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8.1.9 Special Purpose Districts

Another option for the County to consider is the development of special purpose districts. Special purpose districts are generally created through the local legislative authority to meet a specific need of the local community. The needs may include new services or higher levels of existing services. There are many types of special purpose districts authorized in Washington including diking, drainage, flood control and environmental protection districts. Some lake management efforts may be appropriate to the financing available through creation of a special purpose district, although one objection to some special purpose districts is that they result in an additional layer of government.

Special purpose districts can be political subdivisions of the state and can come into existence, acquire legal rights and duties, and be dissolved in accordance with statutory procedures. Enabling legislation sets forth the purpose of the district, procedures for formation, powers, functions and duties, composition of the governing body, methods of finance, and other provisions. The districts may be quasi-municipal corporations—though some districts can be statutorily defined as municipal corporations. Although the general provisions for some special district statutes have been consolidated, such as for diking and drainage districts, there is no set of uniform provisions covering all special districts in Washington as there is with cities and counties.

8.1.10 Non-traditional Lake Management Funding

A number of private foundations and charitable trusts operating within the state of Washington provide grants for environmental works. Further research into these foundations as potential lake management funding sources may be worthwhile; it may be that partnering with non-profit organizations may enhance access to various non-governmental entity grant funding opportunities.

8.2 Example Funding Strategies

As the County moves forward in helping the community to explore various funding strategies for LMP implementation, it may be instructive to consider some examples of how potential funding sources might be applied. To that end, this section describes four potential strategies for funding implementation of this LMP.

Table 19 summarizes the one-time and ongoing costs needed to implement the Spanaway LMP. Tables 20 through 23 each provide a different funding method example. The four funding method examples share some common terms of one-time initial costs (shown in green) and ongoing costs (shown in yellow). These costs are based on the additional evaluation and selected measures described in Section 7.3 above. For all the examples, it is assumed that any difference in funding beyond the loans, grants, and state legislative appropriations will be funded by the County's FCZD Opportunity Fund. That source was selected because it is already in effect; however, its actual availability will be determined by the District Board of Supervisors.

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Table 19: One-Time Initial and Ongoing Costs Needed to Implement Spanaway LMP	
One-Time Initial Cost	
Hypolimnetic oxygenation + alum injector	$2,000,000
Aquatic plant management[a]	$12,000
Focused monitoring[b]	$26,000
Public education and outreach[c]	$53,000
Ongoing Cost	
Hypolimnetic oxygenation + alum injector O&M[d]	$81,000
Public education and outreach[e]	$23,000
Aquatic plant management[f]	$16,500
Long-term monitoring[g]	$33,000
Ongoing debt service payment for $2,038,000 at 2% for 20 years[h]	$124,000
Ongoing debt service payment for $1,019,000 at 2% for 20 years[h]	$62,000

a. *Includes cost to perform plant survey and prepare field guide for volunteers.*

b. *Includes $13,000 to $15,000 for bathymetric survey, $7,000 to $9,000 for internal phosphorus load sampling, $1,000-$2,000 for sediment sampling.*

c. *Includes $30,000 for one-time activities such as audience research, LakeWise signage, pet waste stations, and printing, plus $23,000 for the first year of annual ongoing activities.*

d. *Includes $49,000 for hypolimnetic oxygenation and $32,000 for the alum treatment.*

e. *Includes staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.*

f. *Includes removal of aquatic plants from 5 acres/yr at average of $3,500/acre.*

g. *Includes $27,000 for labor and $6,000 for equipment rental and lab costs.*

h. *Debt service payment is estimated for CWSRF loan based on Financing Alternatives Comparison Tool (FACT-LITE) developed by EPA. Discount rates and financing costs are not included.*

Example 1: Appropriation or Grant to Fund Capital Improvements. This example assumes that a state grant or state budget allocation is obtained to cover the initial costs for the hypolimnetic oxygenation with alum injector measure. Table 20 shows the breakdown of costs and sources of funding under this example for the 20-year period. Details on each of these components are described in Section 7.3 above. Under this example, an initial one-time capital investment is fully funded through a grant or state legislative appropriation while the ongoing costs are funded via a combination of funds from a LMD and FZCD. It is assumed that the revenue from a LMD will remain at $65,000 as per the hypothetical Spanaway LMD revenue based on the Barnes Lake LMD, as described in Section 8.1.2—whereas the funds from the FCZD are assumed to cover the remainder of the costs such that the total cost and the total sources of funding are equal.

Table 20: Total Costs and Sources of Funding for Spanaway LMP Implementation, Example 1		
One-Time Initial Cost	**Year 1**	**Year 2**
Hypolimnetic oxygenation + alum injector	$2,000,000	$0
Aquatic plant management[a]	$12,000	$0
Focused monitoring[b]	$26,000	$0
Ongoing Cost	**Year 1**	**Year 2-20**
Hypolimnetic oxygenation + alum injector O&M[c]	$81,000	$81,000
Public education and outreach[d]	$53,000	$23,000
Aquatic plant management[e]	$16,500	$16,500
Long-term monitoring[f]	$33,000	$33,000
Total cost	$2,221,500	$153,500
Sources of Funding	**Year 1**	**Year 2-20**
Grant or Appropriation that funds the entire capital cost[g]	$2,038,000	$0
LMD[h]	$65,000	$65,000
FCZD[i]	$118,500	$88,500
Total sources of funding	$2,221,500	$153,500
Difference (Funding - Cost)	$0	$0

a. Includes cost to perform plant survey and prepare field guide for volunteers.

b. Includes $13,000 to $15,000 for bathymetric survey, $7,000 to $9,000 for internal phosphorus load sampling, $1,000-$2,000 for sediment sampling.

c. Includes $49,000 for hypolimnetic oxygenation and $32,000 for the alum treatment.

d. Includes staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.

e. Includes removal of aquatic plants from 5 acres/yr at average of $3,500/acre.

f. Includes $27,000 for labor and $6,000 for equipment rental and lab costs.

g. Grant or legislative appropriation will essentially take away the debt service payment requirement.

h. Based on the Hypothetical Spanaway LMD Revenue based on Barnes Lake (Section 8.1.1).

i. FCZD is assumed to fund remainder of the cost such that the total cost and the total sources of funding match.

Advantages of this example include fully funding the important capital investment needs through a state appropriation and securing funding contributions from both near lake residents (through the LMD) and from those farther away from the lake (via the FCZD). Disadvantages include the effort needed to secure state funding of the capital projects and the effort needed to form a LMD and secure FCZD approval to commit funds over the long term.

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Example 2: Borrow to Partially Fund Capital Investment. This example assumes that a grant or budget allocation can be obtained to cover $1,000,000 of the initial costs, with the balance from a SRF loan. LMD and FCZD revenues are used to pay for ongoing costs including loan repayment. Table 21 shows the breakdown of costs and sources of funding under this example assuming a 20-year debt repayment period. Capital investments are funded through a combination of borrowing and grants and/or legislative appropriation. In this case, either a CWSRF loan or some County bond issuance is employed to fund half the capital costs. This approach results in the need for annual revenue of $62,000 to retire the debt. Assuming that the LMD revenue remains at $65,000 as described in Section 8.1.1, the funds from the FCZD are assumed to cover the remainder of the costs such that the total cost and the total sources of funding are equal.

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Table 21: Total Costs and Sources of Funding for Spanaway LMP Implementation, Example 2		
One-Time Initial Cost	**Year 1**	**Year 2-20**
Hypolimnetic oxygenation + alum injector	$2,000,000	$0
Aquatic plant management[a]	$12,000	$0
Focused monitoring[b]	$26,000	$0
Ongoing Cost	**Year 1**	**Year 2-20**
Hypolimnetic oxygenation + alum injector O&M[c]	$81,000	$81,000
Public education and outreach[d]	$53,500	$23,000
Aquatic plant management[e]	$16,500	$16,500
Long-term monitoring[f]	$33,000	$33,000
Ongoing debt service payment for 1.019M at 2% for 20 years[g]	$62,000	$62,000
Total Cost	$2,283,500	$215,500
Sources of Funding	**Year 1**	**Year 2-20**
CWSRF loan	$1,019,000	$0
Grant/State appropriation[h]	$1,019,000	$0
LMD[i]	$65,000	$65,000
FCZD[j]	$180,500	$150,500
Total sources of funding	$2,283,500	$215,500
Difference (Funding - Cost)	$0	$0

a. *Includes cost to perform plant survey and prepare field guide for volunteers.*

b. *Includes $13,000 to $15,000 for bathymetric survey, $7,000 to $9,000 for internal phosphorus load sampling, $1,000-$2,000 for sediment sampling.*

c. *Includes $49,000 for hypolimnetic oxygenation and $32,000 for the alum treatment.*

d. *Includes staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.*

e. *Includes removal of aquatic plants from 5 acres/yr at average of $3,500/acre.*

f. *Includes $27,000 for labor and $6,000 for equipment rental and lab costs.*

g. *Debt Service Payment is estimated for CWSRF loan based on FACT-LITE developed by EPA. Discount rates and financing costs are not included.*

h. *Grant or legislative appropriation will essentially take away the debt service payment requirement.*

i. *Based on the Hypothetical Spanaway LMD Revenue based on Barnes Lake (Section 8.1.1).*

j. *FCZD is assumed to fund remainder of the cost such that the total cost and the total sources of funding match.*

Advantages include addressing the important capital investment needs and securing funding contributions from both near-lake residents (through the LMD) and from those farther away from the lake (via the FCZD). Disadvantages include the effort needed to form an LMD and secure FCZD approval to commit funds over the long term.

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Example 3: Borrow to Fully Fund Capital Investment. In this example, a SRF loan is obtained to cover all of the capital costs for the hypolimnetic oxygenation system and alum injector. LMD and FCZD revenues are used to pay for ongoing costs including loan repayment. Table 22 shows the breakdown of costs and sources of funding under this example assuming a 20-year debt repayment period. All the one-time initial capital investment is funded through borrowing. In this case either a CWSRF loan or some County bond issuance is used, both of which result in the need for annual revenue of $124,000 to retire the incurred debt. Assuming that LMD revenue remains at $65,000 as described in Section 8.1.1, the funds from the FCZD are assumed to cover the remainder of the costs such that the total cost and the total sources of funding are equal.

Table 22: Total Costs and Sources of Funding for Spanaway Lake Plan Implementation, Example 3

One-Time Initial Cost	Year 1	Year 2-20
Hypolimnetic oxygenation + alum injector	$2,000,000	$0
Aquatic plant management[a]	$12,000	$0
Focused monitoring[b]	$26,000	$0
Hypolimnetic oxygenation + alum injector O&M[c]	$81,000	$81,000
Public education and outreach[d]	$53,000	$23,000
Aquatic plant management[e]	$16,500	$16,500
Ongoing debt service payment for 2.038M at 2% for 20 years[f]	$124,000	$124,000
Total Cost	$2,312,500	$244,500
Sources of Funding	**Year 1**	**Year 2-20**
CWSRF loan	$2,038,000	$0
LMD[g]	$65,000	$65,000
FCZD[h]	$209,500	$179,500
Total sources of funding	$2,312,500	$244,500
Difference (Funding - Cost)	$0	$0

a. Includes cost to perform plant survey and prepare field guide for volunteers.

b. Includes $13,000 to $15,000 for bathymetric survey, $7,000 to $9,000 for internal phosphorus load sampling, $1,000-$2,000 for sediment sampling.

c. Includes $49,000 for hypolimnetic oxygenation + $32,000 for the alum treatment = $81,000.

d. Includes $49,000 for hypolimnetic oxygenation and $32,000 for the alum treatment.

e. Includes removal of aquatic plants from 5 acres/yr at average of $3,500/acre.

f. Includes $27,000 for labor and $6,000 for equipment rental and lab costs.

g. Based on the Hypothetical Spanaway LMD Revenue based on Barnes Lake (Section 8.1.1).

h. FCZD is assumed to fund remainder of the cost such that the total cost and the total sources of funding match.

Advantages include addressing the important capital investment needs and securing funding contributions from both near-lake residents (through the LMD) and from those farther away from the lake (via the FCZD). Disadvantages include the effort needed to form a LMD and secure FCZD approval to commit funds over the long term.

Example 4: No Capital Investment. This example assumes that no grants, budget allocations, or loans are available to fund the capital improvements. LMD and FCZD revenues are used to pay for public education and outreach, aquatic plant management, and long-term monitoring. Table 23 shows the breakdown of costs and sources of funding for this example. It is assumed that all the costs will be funded through the LMD revenues and FCZD funds. Assuming that the LMD revenue remains at $65,000 as described in Section 8.1.1, the funds from FCZD are assumed to cover the remainder of the costs such that the total cost and the total sources of funding are equal. Example 4, No Capital Investment, is not recommended because without the hypolimnetic oxygenation + alum injector capital improvement project, lake water quality goals are unlikely to be met. Rather, it is shown here for illustrative purposes.

Table 23: Total Costs and Sources of Funding for Spanaway Lake Plan Implementation, Example 4

One-Time Initial Cost	Year 1	Year 2-20
Aquatic plant management[a]	$12,000	$0
Public education and outreach[b]	$53,000	$23,000
Aquatic plant management[c]	$16,500	$16,500
Long-term monitoring[d]	$33,000	$33,000
Total Cost	$114,500	$72,500
Sources of Funding	**Year 1**	**Year 2-20**
LMD[e]	$65,000	$65,000
FCZD[f]	$49,500	$7,500
Total sources of funding	$114,500	$72,500
Difference (Funding - Cost)	$0	$0

a. Includes cost to perform plant survey and prepare field guide for volunteers.

b. Includes staff time for shoreline visits, program assessment, and coordination with other programs and the lake management committee.

c. Includes removal of aquatic plants from 5 acres/yr at average of $3,500/acre.

d. Includes $27,000 for labor and $6,000 for equipment rental and lab costs.

e. Based on the Hypothetical Spanaway LMD Revenue based on Barnes Lake (Section 8.1.1).

f. FCZD is assumed to fund remainder of the cost such that the total cost and the total sources of funding match.

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Advantages include funding programmatic actions and weed control and no need for long-term capital facility O&M. The major disadvantage is that this example would provide much less water quality benefit as compared to the previous examples.

8.3 Funding Options Summary

Full implementation of the Spanaway LMP will likely require funding from multiple sources. For example, capital costs could be funded by state grants, budget allocations, and/or a SRF loan, while long-term O&M costs and SRF loan payments could be funded by revenues from special benefit districts such as a LMD and/or the FCZD (with Pierce County FCZD approval). In addition, there are a number of other potential funding sources identified in Section 8.1 that could be mixed and matched to cover the costs. Selection of potential funding mechanisms should include assessment of the need for interlocal agreements, memoranda of understanding, lease agreements, easements, etc., as may be necessary to establish specific lake management funding mechanisms.

Implementing the Spanaway LMP will probably require a local funding source to help pay for ongoing O&M activities. To gain approval, the local funding source would need to be tailored to local conditions and community preferences and perceived as equitable by potential rate payers.

8.4 LMP Implementation Strategy

Full implementation of the measures recommended in Section 7.5 will require considerable funding. The preceding sections describe a range of potential funding sources. However, the specific funding sources and anticipated revenues are uncertain at this time.

The recommendations outlined in this LMP are based on available data and analyses completed using that data. The monitoring for this study was completed during an unusually dry 1-year period. Short- and longer-term weather patterns—including temperature, sunlight, and rainfall—can have a major influence on lake water quality. While the monitoring completed for this LMP generated a great deal of useful information, it may not encompass the full range of water quality conditions that are affecting Spanaway Lake. Moreover, due to limited funding for lake characterization, there are several known data gaps, such as lake bathymetry and spatial variation in hypolimnion water quality. There are many factors that influence the lake response to pollutant loadings and management measures. At any point in time there are numerous physical, biological, and chemical processes ongoing in the lake, and these are constantly changing.

Given the technical and funding uncertainties noted above, the project team recommends an adaptive management approach for implementing this LMP. The basic approach is to: (1) work with the community, stakeholders, and policy makers to determine fund source support; (2) based on available funding, implement strategies to address known issues; (3) as funding allows, continue to collect data; and (4) refine strategies using the additional information and the measured response to the implemented strategies. Adaptive management is a process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes

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from management actions and other events become better understood. Under anoxic conditions, lake bottom sediments release a substantial phosphorus load to the overlying water column. Groundwater contributes a substantial phosphorus load to the lake. These are known issues that can be addressed by the selected management measures. See Figure 31 for a diagram of an adaptive management approach. An adaptive management approach should help ensure efficient progress toward achieving the Spanaway LMP goals. The adaptive management approach for this LMP includes short-term and long-term monitoring. Short-term monitoring focused on key data gaps 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 and adjust or augment the lake management measures.

The adaptive management approach should also take advantage of the HSPF watershed model and MODFLOW groundwater model that are being developed for the WSP. These models, which should be calibrated by the fall of 2017, could be used to refine the water budget, nutrient budget, and source evaluations, and potentially modify the measures recommended in this LMP.

Full implementation of the Spanaway LMP will be contingent upon support from the community, stakeholders, and decision makers for the recommended capital and non-capital projects included in the LMP and for its funding. Public review of this Draft LMP will focus on these two key components of success. Results of that review will be included in the final Spanaway LMP.

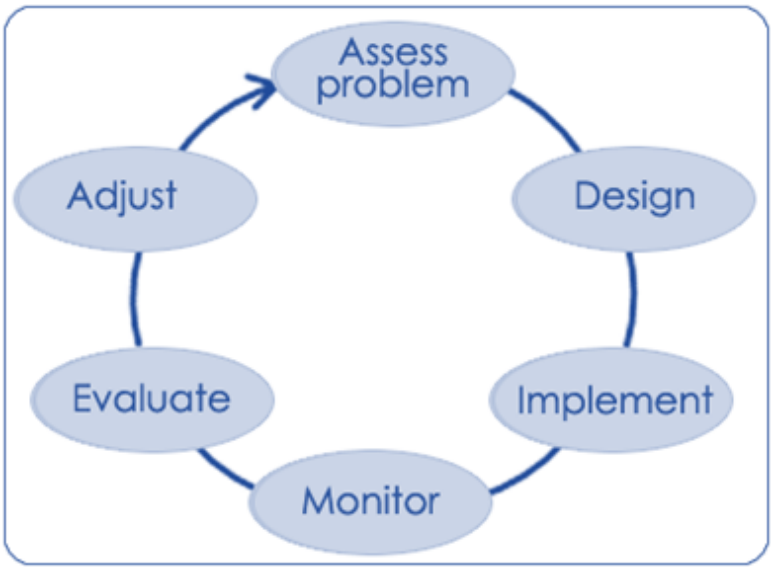

Figure 31. Diagram of adaptive management approach

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8.5 Limitations

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Appendix E: Source Characterization Memorandum

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Technical Memorandum

Prepared for: Pierce County

Project Title: Spanaway Lake Management Plan

Project No.: 145775

Attachment to the Lake Management Plan Report

Subject: Phosphorus and Bacteria Source Assessment

Date: December 12, 2016

To: Mike Milne

From: Jon Turk, James Bush, Paul Thomas and Sharonne Park

Limitations:

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List of Abbreviations

µg/L	microgram(s) per liter
ac	acre(s)
ac-ft	acre-foot/feet
ASTM	American Society of Testing and Materials
BC	Brown and Caldwell
cfu	colony-forming unit(s)
County	Pierce County
DEM	digital elevation model
Ecology	Washington State Department of Ecology
EMC	event mean concentration
EPA	U.S. Environmental Protection Agency
FC	fecal coliform
ft	foot/feet
ft^2	square foot/feet
ft^3	cubic foot/feet
gal	gallon(s)
gpd	gallon(s) per day
in.	inch(es)
JBLM	Joint Base Lewis-McChord
kg	kilogram(s)
lb(s)	pound(s)
LiDAR	light detecting and ranging
LMP	Lake Management Plan
MG	million gallons
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mL	milliliter(s)
NRCS	National Resources Conservation Service
OSDS	onsite sewage disposal systems
P	phosphorus
ppm	part(s) per million
PSLC	Puget Sound LiDAR Consortium
SC	sorption capacity
SPU	Seattle Public Utilities
TM	technical memorandum
TPCHD	Tacoma Pierce County Health Department
TP	total phosphorus
UCL	upper confidence limit
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
yr	year(s)

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Section 1: Introduction

Spanaway Lake has a history of blue-green algae (cyanobacteria) blooms. Cyanobacteria blooms are often associated with excessive nutrient concentrations, particularly phosphorus (P). The Washington State Department of Ecology's (Ecology) 2014 *Water Quality Assessment* identified Spanaway Lake as a "water of concern" for total phosphorus (TP) (Ecology 2014).

Fecal coliform (FC) bacteria concentrations are also a concern for Spanaway Lake. Ecology's 2014 *Water Quality Assessment* lists Spanaway Lake as "impaired" based on elevated FC and E. coli bacteria concentrations in samples collected from 2003 to 2010.

Phase 1 in the development of the Spanaway Lake Management Plan (LMP) included monitoring to identify nutrient and fecal bacteria sources affecting the lake. The results will help identify potentially appropriate management measures.

Nutrient loading and bacterial contaminant transport are directly linked to sources of recharge to the lake. Lake recharge is dominated by groundwater (65 percent), with inflow from Coffee Creek contributing approximately 29 percent of the total inflows. A summary of the lake water budget is provided in the Spanaway Lake Characterization, Water Budget Technical Memorandum (TM), issued concurrently with this TM.

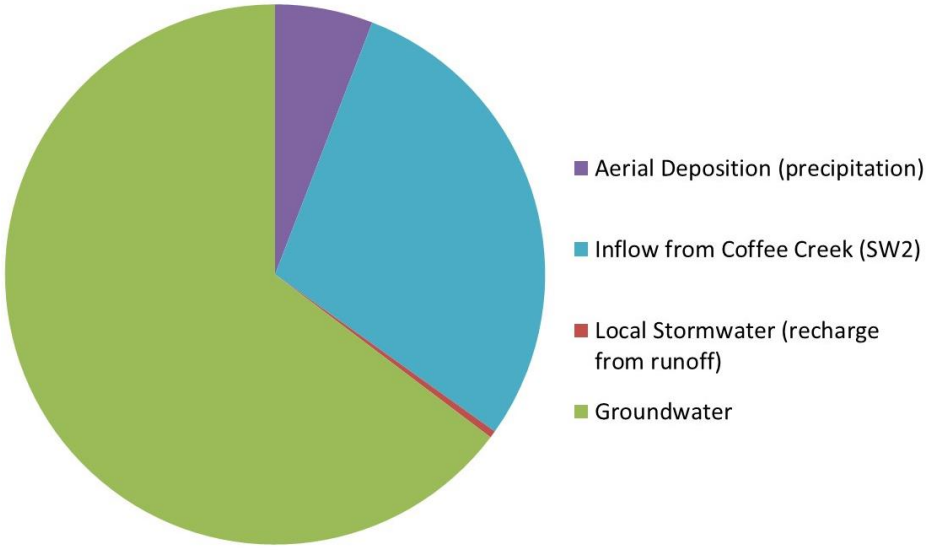

Figure 1. Distribution of inflow to Spanaway Lake

Phosphorus and bacteria sources are summarized in the following sections by pathway, following the components of the water budget. This TM describes the source identification methods and results.

Section 2: Aerial Deposition

The following section describes potential sources associated the aerial deposition pathway.

2.1 Precipitation

Atmospheric deposition of phosphorus is an estimate of the load of phosphorus delivered through wet or "dryfall" precipitation depositing phosphorus-containing particles directly on the surface of Spanaway Lake. Deposition rates were determined from published literature (Reckhow 1980). The annual atmospheric deposition load was calculated assuming a deposition rate of 0.24 pounds of phosphorus per acre per year (lbs P/ac/yr) and multiplied by the lake surface area to generate a load.

No bacterial sources are assumed for the precipitation pathway.

2.2 Waterfowl

Waterfowl can contribute phosphorus and fecal bacteria to lakes. Loading rates can vary greatly depending on the numbers and species of birds, how long they are present on the lake, their food sources, and other factors.

2.2.1 Phosphorus Loads

It is difficult to obtain accurate bird counts at a sufficient frequency to calculate "bird-days" and develop reliable estimates of phosphorus contributions from birds, particularly for lakes with limited shoreline access. For example, to estimate waterfowl phosphorus loads to Green Lake, the City of Seattle hired an experienced ornithologist to walk the entire perimeter of the lake and count birds once per week over a 3-year period. The study found that the average daily water bird population was approximately 1,500 and that the birds contributed about 21 kilograms per year (kg/yr) of external phosphorus load to the lake (Scherer et al. 1995). The estimated waterfowl phosphorus load did not appear to correlate with lake water phosphorus, chlorophyll-a, or Secchi depth, suggesting that much of the phosphorus load in bird droppings did not remain in the water column. The authors noted that water birds can alter the rate and pathways of internal nutrient cycling in the lake and increase the nutrient content of the sediments (Scherer et al. 1995). Unckless found that nutrients in goose feces would likely settle to the sediment quickly, thereby limiting potential uptake by phytoplankton (Unckless 2006).

A recent study of Waughop Lake counted waterfowl populations about once per month during October 2014–15. The 33-acre lake had 0 to 157 geese and 12 to nearly 1,300 ducks. The duck population was highest during the winter when migratory species were present. The estimated phosphorus loading from waterfowl was approximately 23 kg/yr (Mike Milne, BC project manager, written communication with Dr. Jim Gawel, University of Washington-Tacoma, July 2016).

At Spanaway Lake, Tacoma Pierce County Health Department (TPCHD) staff observed 0 to 75 waterfowl at North Beach and 0 to 20 waterfowl at Main Beach during summer beach monitoring conducted from 2004 to 2016. Ecology's study of Spanaway Lake trophic status observed 0 to 75 geese and 0 to 400 other waterfowl during the late spring and summer of 1998. These bird counts were limited to May through October and did not include a systematic inventory of the entire lake shore, so they are not sufficient to reliably estimate "bird-days." If we assume that waterfowl usage at Spanaway Lake is similar to Green Lake or Waughop Lake, waterfowl may contribute roughly 5 percent of the external phosphorus load to Spanaway Lake.

2.2.2 Fecal Coliform Loads

Several samples collected by TPCHD at North Beach and Main Beach during 2015 had elevated concentrations of E. coli, a type of FC bacteria. For example, a sample collected near North Beach on June 9, 2015, contained 801 colony-forming units per 100 milliliters (cfu/100 mL), while a sample collected from Main Beach on August 10, 2015, contained 540 cfu/100 mL. The TPCHD data suggest that fecal bacteria are a concern in the shoreline areas.

Waterfowl can be a significant source of fecal bacteria to lakes and other surface water bodies. Alderisio and DeLuca reported that Canada goose droppings had an average FC content of 15,300 cfu per gram of wet feces (Alderisio and DeLuca 1999). Hussong et al. estimated that a Canada goose generates about 36,000 fecal indicator bacteria per day (Hussong et al. 1979). Moriarty et al. found that duck feces contained approximately 95 million E. coli per gram (Moriarty et al. 2011). In a 3-year study of Green Lake (Seattle), Scherer et al. estimated that 50 percent of the goose droppings and 80 percent of the duck droppings were deposited directly into the lake, but each duck generated about one-fourth as much fecal material as the average goose dropping (Scherer et al. 1995).

Ecology and TPCHD have observed as many as 75 geese and 400 other waterfowl at Spanaway Lake. Assuming that 75 geese and 400 ducks are present at Spanaway Lake all day, and that direct fecal output and bacteria concentrations are similar to the studies cited above, the daily FC load would be on the order of 1.8 trillion FCs. Although some of these bacteria probably fall to the lake bottom (rather mixing with the lake water), the available data suggest that waterfowl may be an important source of fecal bacteria, particularly near popular feeding and resting areas such as the area between North Beach and the lake outlet.

Section 3: Phosphorus Loads from Direct Stormwater Runoff

Urban stormwater runoff often contains elevated phosphorus and FC concentrations because of soil erosion, fertilizers, yard waste, street dirt, and animal droppings.

3.1 Phosphorus Load from Direct Stormwater Runoff

Most of the Spanaway Lake watershed is covered by very permeable soils with high infiltration rates. Areas that are not covered by roads or buildings produce little runoff. Runoff from most impervious areas in the watershed is infiltrated through drywells, ponds, or ditches. However, stormwater runoff from impervious shoreline areas can discharge directly to the lake.

Monthly runoff contributions to Spanaway Lake were estimated from the product of the impervious surface area surrounding the lake and the monthly precipitation totals, using the following procedure:

1. Delineate potential areas of direct runoff
2. Clip Pierce County's (County) planimetric data to this area
3. Review planimetric data to estimate the percent directly connected to the lake
4. Sum the directly connected area
5. Multiply the area by the total monthly precipitation at the County's Golf Course weather station

The delineated area of direct runoff is presented in Figure 2, below. To delineate this direct stormwater runoff subbasin the land area topographically upstream of stormwater collection infrastructure was subtracted from the Lake Spanaway watershed. County planimetric data within this subbasin were reviewed to determine the total effective impervious area directly connected to the lake. Approximately 17 acres of impervious surfaces appear to be directly connected to the lake.

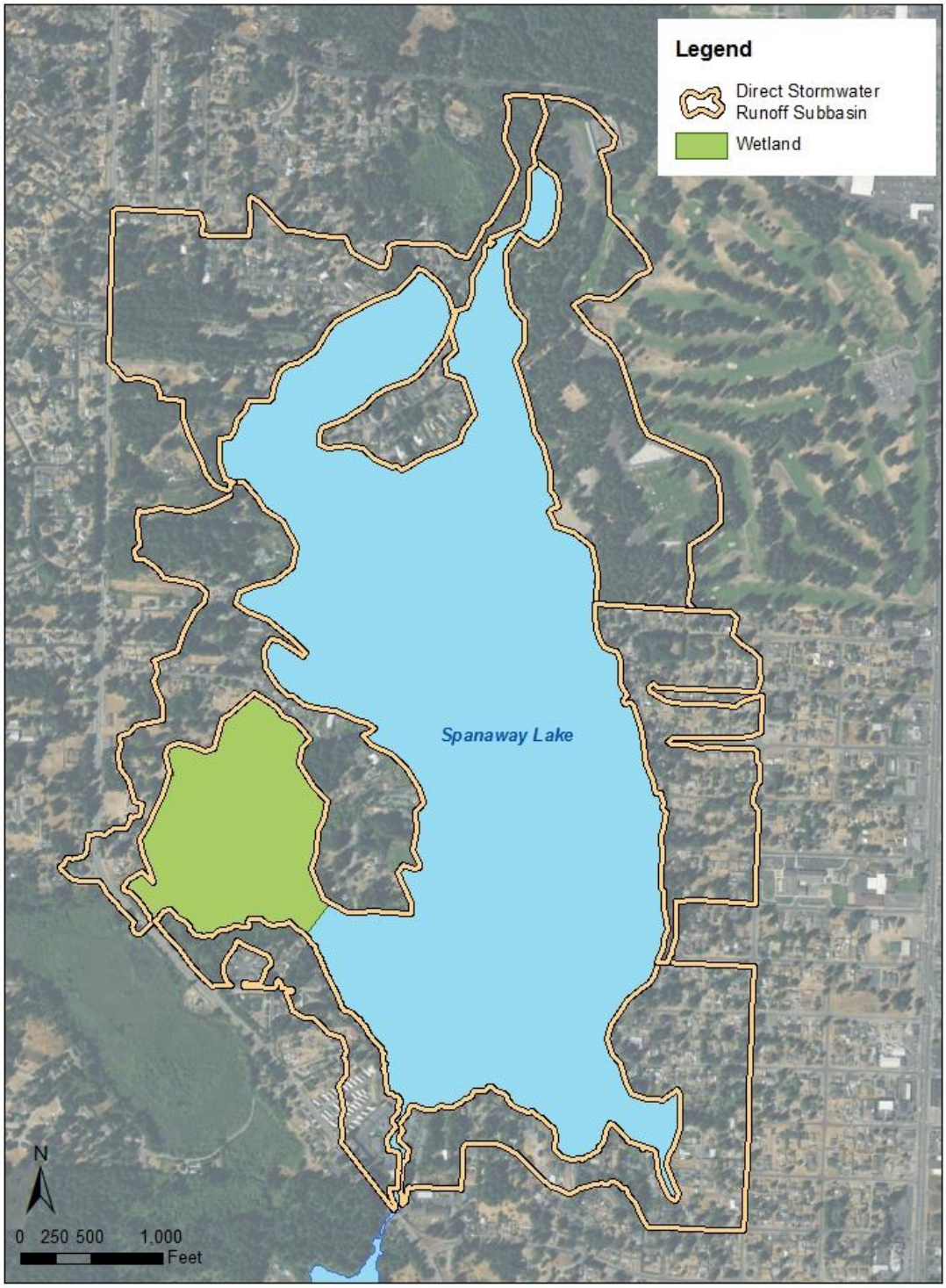

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Figure 2. Direct stormwater runoff area for Spanaway Lake

Stormwater runoff rates were estimated from 2014 and 2015 precipitation data recorded at the Spanaway golf course. The product of the total effective impervious area and monthly precipitation record are presented in Figure 3.

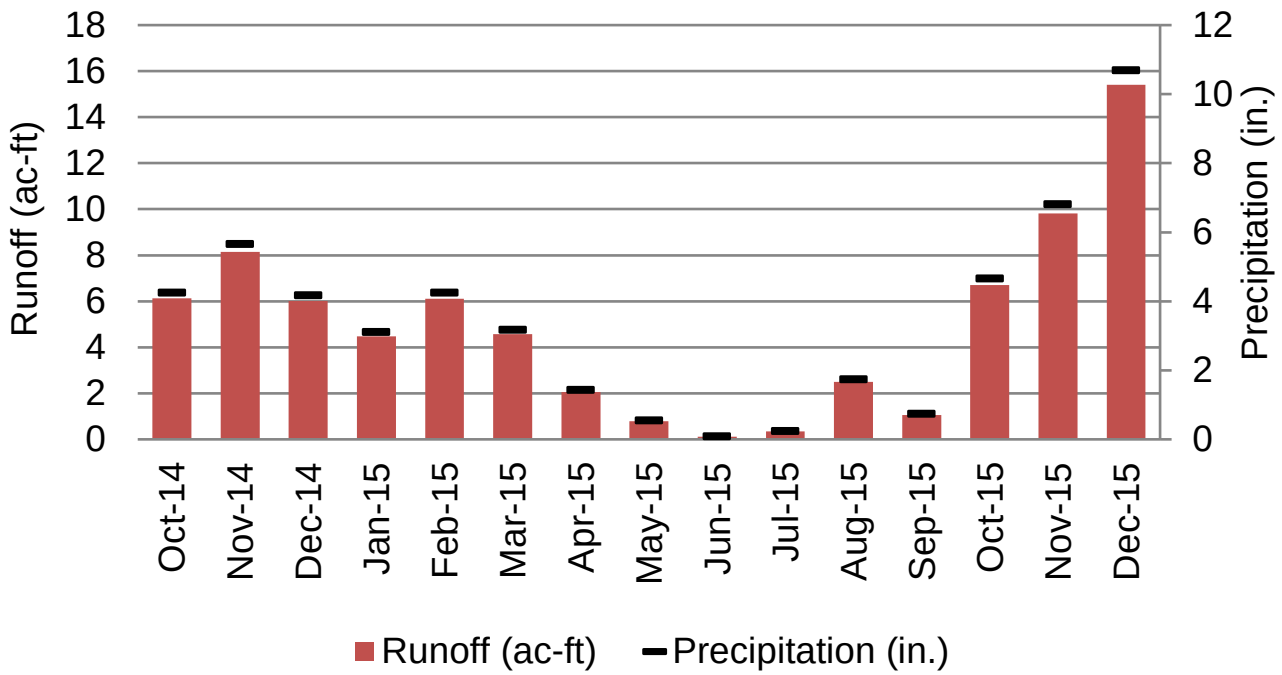

Figure 3. Direct stormwater runoff contributions to Spanaway Lake

Table 1 lists the estimated volumes of stormwater runoff entering the lake each month during the 15-month monitoring period. The estimated runoff volumes for October, November, and December are averages based on the 2014 and 2015 precipitation data.

Table 1. Estimated Stormwater Runoff into Spanaway Lake

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Direct stormwater (ac-ft)	4.5	6.1	4.6	2.1	0.8	0.1	0.3	2.5	1.1	6.4	9.0	10.7	**48.2**

Table 2 lists the land uses in the areas of direct stormwater discharge subbasin together with average and upper confidence limit (UCL) stormwater event mean concentrations (EMCs) for TP. The EMC statistics were developed for Seattle Public Utilities (SPU) based on local and regional stormwater monitoring data (SPU 2015). As shown in the table, TP concentrations can vary considerably even within a land use category.

Table 2 Land Use Breakdown and Respective Phosphorus EMCs for Direct Stormwater Discharges to Spanaway Lake

Land use	Area (ac)	% area	TP EMC (mg/L)	
			Average	UCL
Commercial/industrial	0.43	0.17	0.23	0.36
Open space/resource lands	2.00	0.78	0.11	0.20
Public places/religious centers	63.20	24.64	0.22	0.34
Residential	176.80	68.92	0.22	0.34
Transportation/communication	0.7	0.28	0.25	0.38
Vacant land/undefined	13.4	5.22	0.22	0.34
Total	256.5	100.0	0.22	0.34

The EMC statistics are based on stormwater sampling conducted before the recent restrictions on phosphorus in turf fertilizer. Thus TP concentrations in stormwater runoff from residential land uses (and other land uses with turf areas) may decline over time.

The EMCs listed in Table 2 were averaged, weighted on a contributing land use basis, and multiplied by the volume of direct stormwater discharge to estimate the TP and FC loads. Table 3 lists the estimated loads.

Table 3. Estimated Annual Phosphorus Load from Shoreline Area Stormwater Runoff

Estimated annual TP load based on average EMC (0.22 mg/L)	13.0 kg/yr
Estimated annual TP load based on 95% UCL EMC (0.34 mg/L)	20.2 kg/yr

3.2 Fecal Coliform Loads in Direct Stormwater Runoff

FC loads from direct stormwater discharge were estimated using the method described in Section 3.1, above. Table 4 lists the estimate EMCs for FC in stormwater runoff from the land use categories found in the Spanaway Lake shoreline area.

Table 4. Land Use Breakdown and Respective FC EMCs for Direct Stormwater Discharges to Spanaway Lake				
			FC EMC (cfu/100 mL)	
Land use	Area (ac)	% area	Average	UCL
Commercial/industrial	0.43	0.17	26,434	49,456
Open space/resource lands	2.00	0.78	12,531	24,406
Public places/religious centers	63.20	24.64	16,882	31,215
Residential	176.80	68.92	15,612	30,106
Transportation/communication	0.70	0.28	34,716	66,589
Vacant land/undefined	13.40	5.22	15,606	30,106
Total	256.50	100.00	15,970	30,467

The annual FC load was estimated by multiplying the area-weighted average and UCL EMCs (from Table 4) by the annual runoff volume (from Table 1). Table 5 lists the results.

Table 5. Estimated Annual FC Load from Shoreline Area Stormwater Runoff	
Estimated load based on average EMC (15,970 cfu/100 mL)	9.5 trillion/yr
Estimated load based on 95% UCL EMC (30,467 cfu/100 mL)	18.0 trillion/yr

Section 4: Surface Water Inflow

Coffee Creek contributed about 29 percent of the inflow to Spanaway Lake during the monitoring period. Sections 4.1 and 4.2 discuss phosphorus and fecal coliform loads in Coffee Creek.

4.1 Phosphorus Loads from Coffee Creek

Coffee Creek begins at the northern boundary of Joint Base Lewis-McChord (JBLM) less than a mile southwest of the lake (see Figure 4, below). The creek originates immediately downstream of a large wetland complex within JBLM. Regional groundwater data indicate the JBLM wetland receives flow from groundwater discharge, while monitoring completed during this study suggests that smaller localized areas can both gain and lose flow from the groundwater system (Savoca 2010).

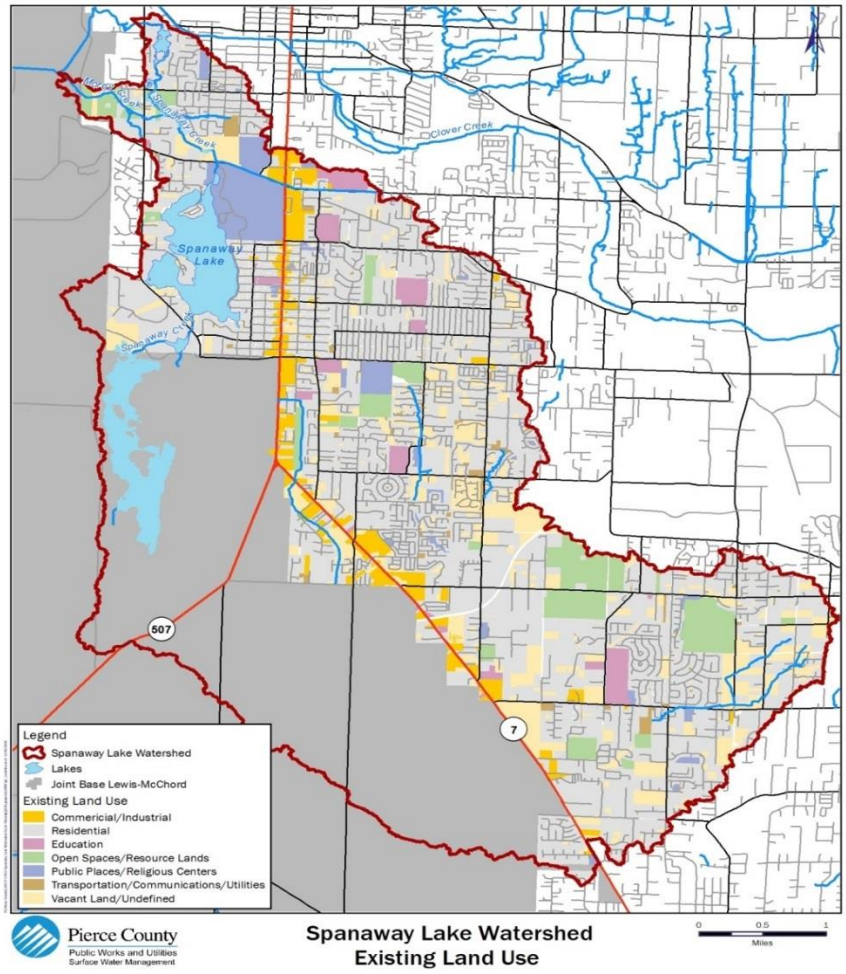

Figure 4. Land use

There are several residences in the Coffee Creek basin between the LMP monitoring location at Spanaway Loop Road and the JBLM boundary. The large wetland complex on JBLM upstream of Coffee Creek is designated as habitat for threatened chinook salmon, bull trout, and steelhead. County and Brown and Caldwell (BC) staff observed large numbers of waterfowl in the wetland complex during a tour led by JBLM staff in spring 2014.

The JBLM portion of the Coffee Creek basin also contains designated habitat areas for threatened Mazama pocket gophers. As shown in Figure 5 below, the available data indicate there is little evident development or infrastructure (aside from roads) in the JBLM portion of the Coffee Creek basin.

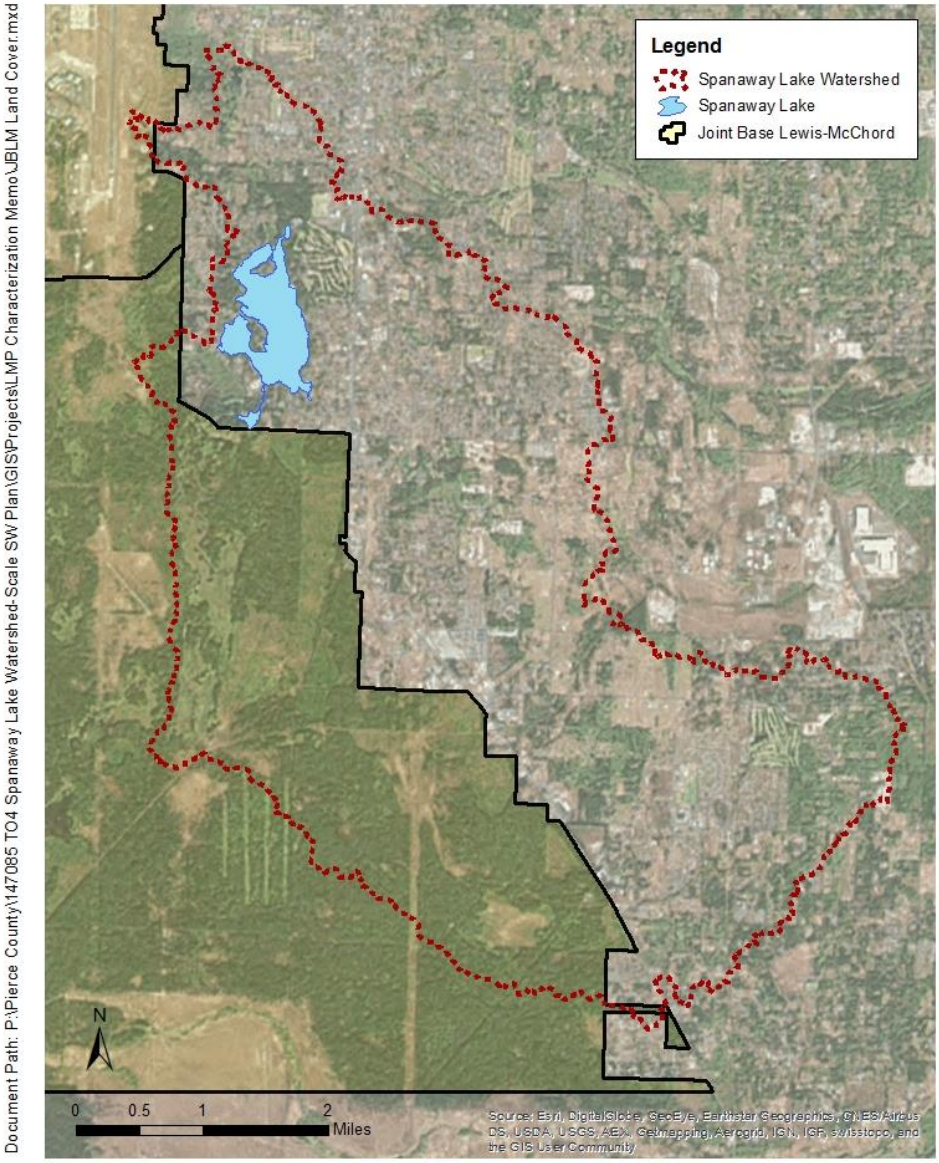

Figure 5. Satellite imagery for Spanaway Lake watershed

The Spanaway Lake watershed-scale stormwater planning project included water quality sampling in Coffee Creek just below the JBLM wetland. The routine monthly grab samples had an average TP concentration of 0.07 milligrams per liter (mg/L) while the storm event samples ranged from 0.10 to 0.11 mg/L. The routine and storm event samples collected from Coffee Creek at Spanaway Loop Road (SW2) contained an average of 0.03 mg/L. Flows near the wetland outlet were generally higher than at SW2, indicating that water was lost to groundwater between the wetland and Spanaway Loop Road. These results suggest that the JBLM wetland is contributing much of the phosphorus observed in Coffee Creek at Spanaway Loop Road. The higher concentrations near the wetland may be due to wildlife input and phosphorus release from wetland sediment under anoxic conditions.

Coffee Creek contributed about 27 percent of the external phosphorus load to Spanaway Lake during the LMP monitoring period.

4.2 Fecal Coliform in Coffee Creek

Coffee Creek originates just downstream of a large wetland complex located within BLM (see Figure 4 above). The reach downstream of JBLM encompasses riparian wetland areas. There are only a few residences along Coffee Creek reach between JBLM and Spanaway Loop Road (monitoring location SW2).

Figure 5 shows that FC concentrations in the JBLM marsh were slightly higher than concentrations in Coffee Creek at Spanaway Loop Road (SW2). The monitoring and land use data suggest that wildlife is the predominant source of fecal bacteria at SW2. Coffee Creek may receive additional FC via stormwater runoff from the residential areas located along the creek downstream of Spanaway Loop Road.

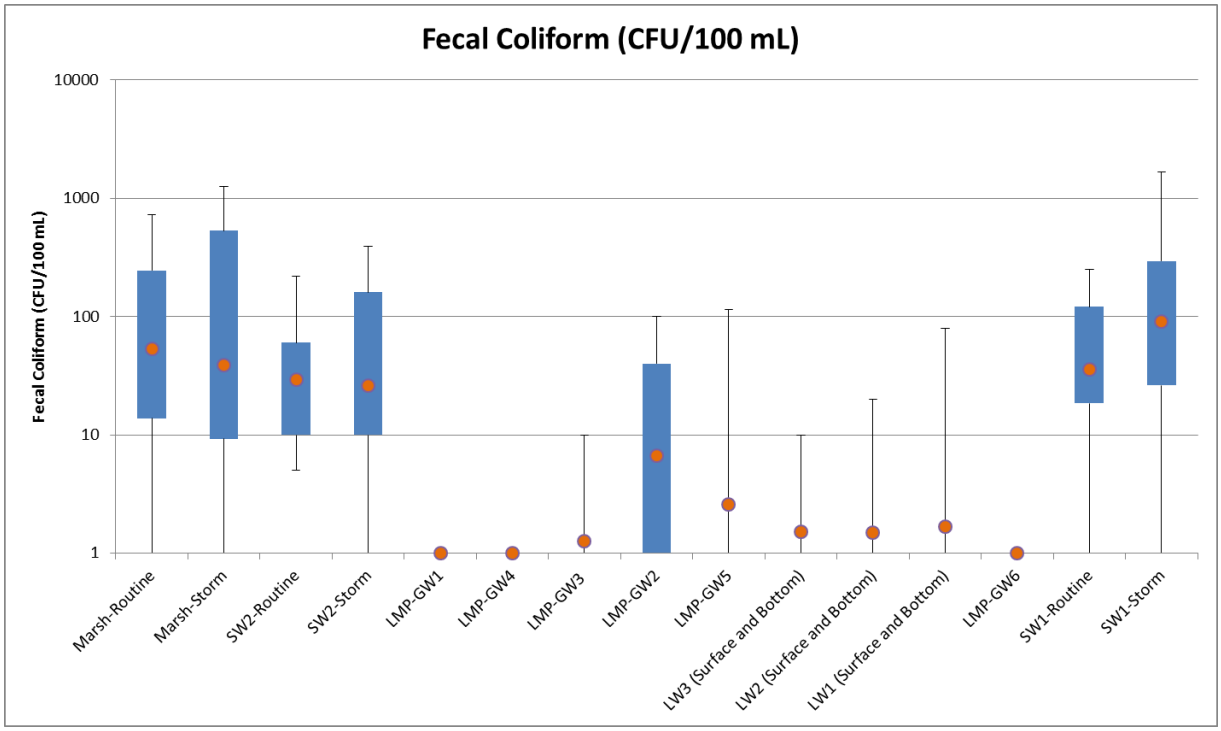

Figure 5. FC concentrations from upstream to downstream

Section 5: Groundwater

Approximately 65 percent of the Spanaway Lake inflows are derived from groundwater. Phosphorus and FC bacteria can be introduced to the lake through the groundwater pathway from a number of sources including natural percolation of precipitation through surface soils, recharge from surface water, stormwater infiltration facilities, and septic systems. Spanaway Lake is in direct contact with the regional groundwater aquifer. Most of the watershed is covered by very permeable soils with high infiltration rates. Nearly all of the stormwater runoff from impervious areas is infiltrated through drywells, infiltration basins, ditches, or adjacent pervious areas. The U.S. Geological Survey (USGS) estimates that in an average year 20 to 30 inches of rainfall infiltrates and recharges the groundwater aquifer within the watershed (Savoca 2010).

The Spanaway Lake watershed encompasses numerous onsite sewage disposal systems and stormwater infiltration facilities that could contribute phosphorus and FC to the lake via groundwater. Fertilized pervious areas, domestic animals, and wildlife could contribute phosphorus and FC to groundwater via direct

infiltration. However, these other sources are typically orders of magnitude lower than stormwater or septic system discharges. Additionally, the distribution of minerals within the soil and aquifer system can contain natural levels of phosphorus. Hydroxyapatite is a common mineral present in most sediments that has the potential to provide low-level background concentrations of phosphorus in the groundwater system.

5.1 Onsite Sewage Disposal Systems

There are 4,712 registered onsite sewage disposal systems (OSDS) located within the Spanaway Lake watershed (TPCHD 2015). Based on groundwater potentiometric surfaces generated using the USGS's Chambers-Clover Creek groundwater flow model, 3,862 of the 4,712 OSDS within the watershed are located hydraulically upgradient of Spanaway Lake (Figure 6) (Johnson et al. 2011).

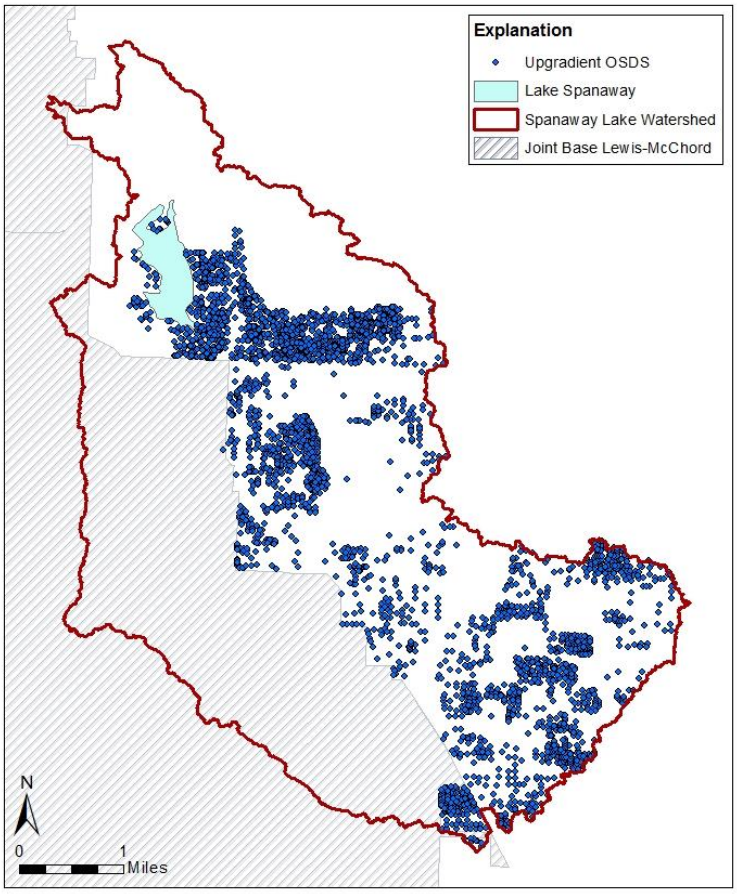

Figure 6. OSDS upgradient of Spanaway Lake, Pierce County, Washington

5.1.1 Phosphorus Loading from OSDS

Phosphorus loading to Spanaway Lake from OSDS sources was estimated using the following general processes:

- Assess County septic systems and soils data to establish conceptual model of vadose zone conditions
- Estimate the mass of phosphorus discharged from the OSDS into the vadose zone based on literature values

- Model the vertical movement transport of phosphorus through the vadose zone to the water table through a series of soil compartments
- Model the lateral movement of phosphorus through the saturated zone into Spanaway Lake under advective transport conditions
- Estimate time series and cumulative loading values and proportion the phosphorus load that reaches the lake based groundwater flow paths

The rate at which phosphorus moves through the system and is removed from the aqueous phase was calculated for each of three soil compartments and the saturated zone, resulting in an estimate of the annual phosphorus load to Spanaway Lake in pounds per year (Figure 7).

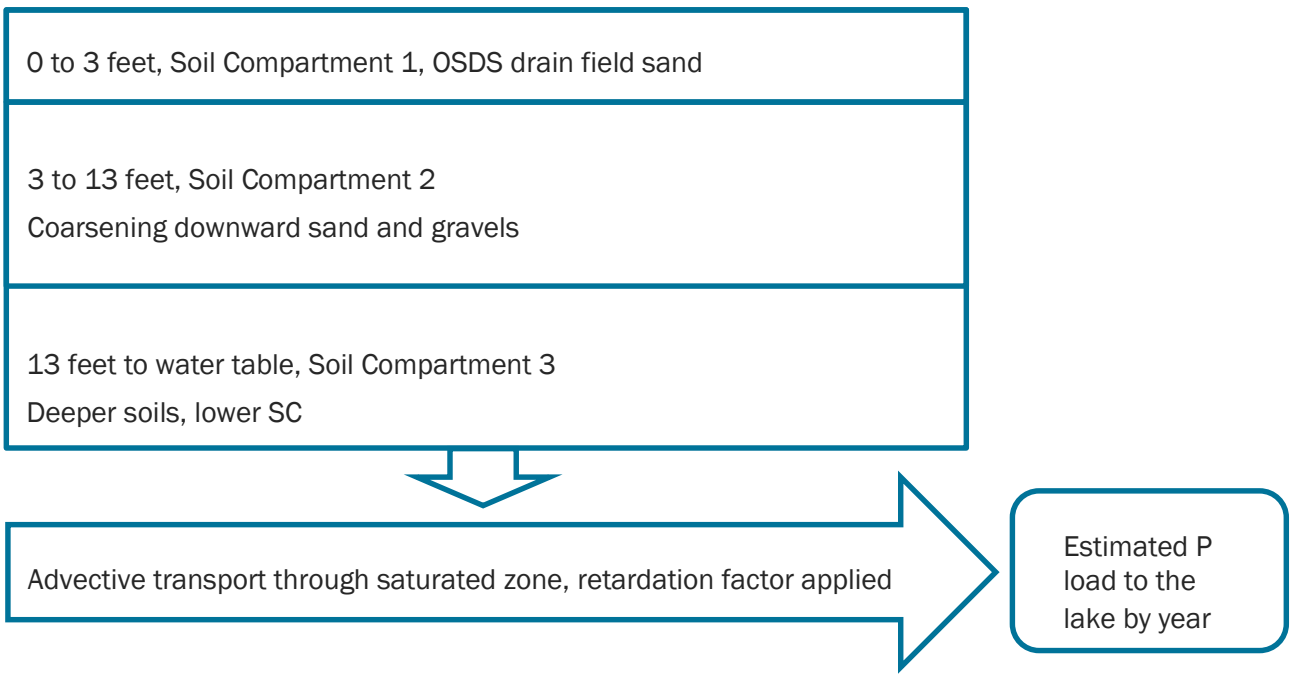

Figure 7. Conceptual model of phosphorus transport from OSDS to Spanaway Lake

The rate of phosphorus discharge from OSDS was calculated by estimating the total effluent flow rate at each OSDS and a constant average phosphorus concentration within the effluent, as described below:

$$\dot{m}_E = Q * C_P$$

In which:

$\dot{m}_E$ = mass flow rate of phosphorus from the OSDS to the vadose zone (lbs/yr)

Q = annual effluent flow rate (million gallons per year [MG/yr])

C_P = phosphorus concentration (pounds per gallon [lbs/gal])

Phosphorus in domestic wastewater is derived primarily from human waste and synthetic detergents. Although modern laundry detergents contain minimal phosphorus, dishwasher detergents continue to be a major source of phosphorus in domestic effluent discharges. Phosphorus concentration levels in effluent have decreased over time with the phasing out of phosphate laundry detergents. Phosphate detergent bans went into effect in the mid to late 1980s.

A variety of sources are available for typical septic tank effluent characteristics, including studies from the Spanaway area and greater Puget Sound region. Spanaway Lake OSDS have phosphorus effluent concentrations from 1,000 to 26,000 micrograms per liter (µg/L), with literature values typically falling within the range of 5,000 to 12,000 µg/L (HDR 2007). This evaluation does not consider the decrease of phosphorus concentration levels through as the residence time for historical loads and potential for poorly operating systems suggests that a sustained load is likely present. An average value of 12,000 µg/L (1×10^{-4} lbs/gal) was selected as the phosphorus concentration discharged from OSDS drainfields. A lower-end value of 8,000 µg/L was also used to assess the model sensitivity to effluent phosphorus concentration.

These values were selected based on the work presented by HDR, Inc. (HDR), BC, and TPCHD (HDR 2007; BC 2000; TPCHD 1994). In addition to these reviewed values, personal communication with TPCHD further confirmed this value as a reasonable average (Paul Thomas, BC, written communication with George Waun, TPCHD, 2016).

A constant effluent flow rate of 228 gallons per day (gpd) was selected for all OSDS. This value was used in the Chambers-Clover Creek Watershed groundwater flow model as the average effluent flow rate for all modeled OSDS. The 228 gpd average is close to the average daily effluent rates measured by the U.S. Environmental Protection Agency's (EPA) *Residential End Uses of Water Study* (EPA 2002), but lower than TPCHD's minimum design effluent flow rate of 360 gpd (TPCHD 2015). The design flow rate is intended to ensure that OSDS are sized large enough to treat the maximum anticipated daily flow. Using the design flow rate would over-estimate the long-term loading from the OSDS. Therefore, the average value was used for the loading estimates. Properties with land uses not designated "single-family residence" were also assumed to produce effluent flow rates equal to 228 gpd. These properties likely generate greater effluent flows, but are not expected to significantly affect phosphorus loading estimates as single-family residences account for 81 percent of all OSDS within the Spanaway Lake watershed upgradient of Spanaway Lake.

5.1.1.1 Estimation of Phosphorus Transport through the Vadose Zone to the Saturated Zone

The vadose zone is the unsaturated volume of aquifer between ground surface and the water table (saturated zone). For this study, OSDS effluent was assumed to flow in a completely vertical manner through the vadose zone from the OSDS drainfield to the water table without any lateral spreading. The volume of vadose zone through which effluent traveled was calculated as the product of the drainfield area and the depth of the water table below ground surface.

The modeling approach assumes that phosphorus is removed from the aqueous phase by sorption onto aquifer materials until the sorptive capacity of the aquifer materials has been reached. Sorption is the process through which charged surfaces on grains within the aquifer attract charged ions such as phosphate and remove them from the aqueous phase. Sorptive capacity is a measure of the area available to attract ions and collectively includes adsorption, precipitation, desorption, and dissolution. Water table breakthrough—the delivery of phosphorus to the saturated zone—was determined to occur once the mass of phosphorus discharged into the vadose zone exceeded the sorptive capacity of the material. This approach assumes the process is governed by a linear isotherm to predict the upper limit of sorption capacity (SC), and noted as the most rigorous approach for estimating phosphorus sorption (McCray 2005). Naturally occurring phosphate minerals, such as hydroxyapatite, can impact phosphorus sorption to soils. However, the deposits in the Spanaway area have been reworked by a glacio-fluvial process during deposition and modern soil and aquifer recharge processes. These processes provide the basis for the assumption that initial conditions, or pre-development, are at the lower end of the sorption isotherm, and negligible background phosphorus exists.

The Chambers-Clover Creek Watershed groundwater model was used to calculate depth to groundwater at each OSDS (Figure 8) (Johnson et al. 2011). Latitude and longitude of the OSDS were provided by TPCHD and elevations were assigned from a bare earth light detecting and ranging (LiDAR) digital elevation model

(DEM) from the Puget Sound LiDAR Consortium (PSLC 2002). Using the Chambers-Clover Creek Watershed model for groundwater depth resulted in some elevation discrepancies between the modeled water table and the DEM surface because of the difference in cell resolution between the model (1,000 feet x 1,000 feet) and the DEM (6 feet x 6 feet). OSDS sources with erroneous elevations represent less than 1 percent of the reported OSDS. In cases where erroneous elevations were identified (e.g., DEM surface elevation minus water table elevation resulted in negative values), an adjusted depth to groundwater of 10 feet was assumed.

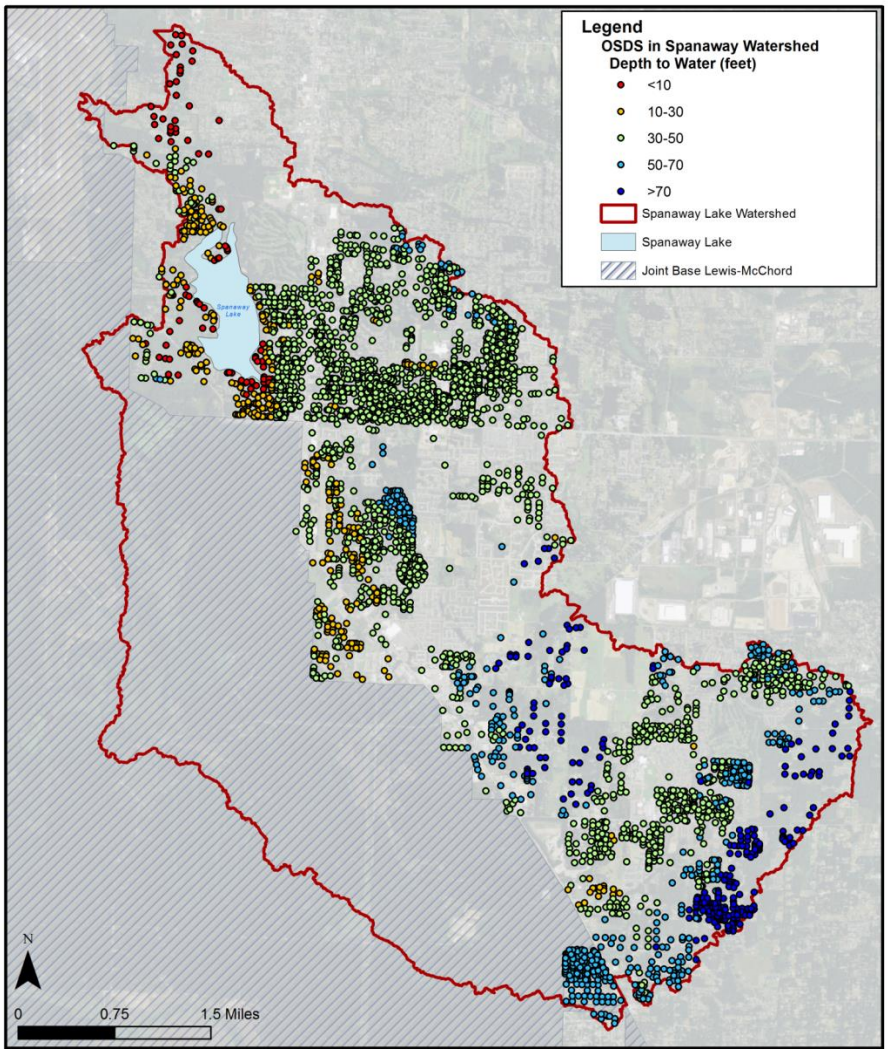

Figure 8. Depth to water estimations for OSDS in the Spanaway Lake watershed

Actual OSDS drainfield dimensions were not readily available from TPCHD; rather, initial construction sizing requirements for Pierce County were used to estimate installed drainfield size. Construction of an OSDS drainfield is dependent on soil type and number of bedrooms serviced. Missing household information from the TPCHD data set was supplemented with property information from the County Assessor, Treasurer's office (County Property Data 2016). Through communication with TPCHD, the assessment of soils through the U.S. Department of Agriculture (USDA) National Resources Conservation Service (NRCS) Soil Survey, and field reconnaissance, soils in the Spanaway Lake watershed are predominately Type 1 and 2 (Paul Thomas, BC, written communication with George Waun, TPCHD, 2016). Table 5 provides a summary of the TPCHD soil

type descriptions as well as the maximum hydraulic loading rates for residential effluent using gravity or pressure distribution OSDS.

Based on the available information, approximately two-thirds of the OSDS systems within the project area are traditional gravity systems. While drainfields are subject to clogging and settling, gravity systems are prone to these challenges to a greater extent that can result in preferential flows through smaller more permeable zones and function with reduced drainfield surface area. To assess loading under prolonged periods with reduced drainfield area, as would be the case for older gravity systems with no historical or routine maintenance, a one-half reduction in drainfield area was also considered.

Table 5. TPCHD Soil Type Descriptions and Maximum Hydraulic Loading Rate[a]

Soil type	Soil texture classifications	Loading Rate for Residential Effluent using Gravity or Pressure Distribution (gal/ft^2/day)
1	Gravelly and very gravelly coarse sands, all extremely gravelly soils excluding soil types 5 and 6, all soil types with greater than or equal to 90% rock fragments.	1.0
2	Coarse sands.	1.0
3	Medium sands, loamy coarse sands, loamy medium sands.	0.8
4	Fine sands, loamy fine sands, sandy loams, loams.	0.6
5	Very fine sands, loamy very fine sands; or silt loams, sandy clay loams, clay loams, and silty clay loams with a moderate or strong structure (excluding platy structure).	0.4
6	Other silt loams, sandy clay loams, clay loams, silty clay loams.	0.2
7 Unsuitable for treatment or dispersal	Sandy clay, clay, silty clay, strongly cemented or firm soils soil with a moderate or strong platy structure any soil with a massive structure any soil with appreciable amounts of expanding clays.	Not suitable

a. Source: (TPCHD 2014).

In this analysis, a drainfield area was estimated using the documented number of bedrooms for each household and adjusted by the designed hydraulic loading rate, as shown below:

$$D_a = \frac{B * B_r}{L_r}$$

Where:

D_a is the estimated drainfield area

B is the number of bedrooms in a household/complex

B_r is the flow rate per bedroom (120 gpd/bedroom)

L_r is the design hydraulic loading rate

The designed hydraulic loading rate for gravity or pressure distribution OSDS is 1 gallon per square foot per day (gal/ft2/day) for Type 1 and Type 2 soils in the Spanaway Lake watershed (Table 1).

When the number of bedrooms was zero, they were modified as follows using best scientific judgment:

- Single family homes = 2.0
- Condominiums = 2.0
- Commercial = 1.5

- Community system = 5.0
- Day care facility = 2.0
- Food establishment = 3.0
- Institution = 1.0
- Large multi-family = 4.0
- Mobile home park = 3.0
- Other = 3.0
- School = 4.0
- Where dwelling type was not listed, 1.0 bedroom was assigned

The model was run assuming that infiltration occurred evenly throughout the entire drainfield. However, traditional gravity drainfields are prone to clogging and/or settling over time, which can reduce the effective area of the drainfield. The hydraulic loading rate is increased because the flow must pass through a smaller area. To assess the potential effects of drainfield clogging or settling, the model was also run assuming a 50 percent reduction in drainfield size.

Sorption capacities were modeled after work done in Spokane County, which has coarse-grained aquifer material similar to the Spanaway Lake watershed. SC estimates provided a margin of safety and remain realistic to average site conditions. The following sorption capacities were used for the Spanaway Lake watershed:

- Zero to 3 feet American Society of Testing and Materials (ASTM) C-33 sand used during OSDS construction. 200 milligrams per kilogram (mg/kg)
- Three to 13 feet with an assumed increase in particle size diameter to coarse-grained sands and gravels, 150 mg/kg
- Thirteen and deeper, SC of 50 mg/kg

This layering reflects the typical construction of septic drainfields and local geology. These values are greater than those reported by McCray and conservative in that the capacity of soils to sorb phosphorus is likely overestimated (HDR 2007).

The timing of phosphorus breakthrough to groundwater was estimated for total yearly phosphorus load per system, based on estimated drainfield size (D_a), phosphorus sorption (P_a), and depth to groundwater (D_{gw}). An initial step for breakthrough calculations included the estimation of soil weights (W1, W2, and W3) for the three soil compartments (0 to 3 feet, 3 to 13 feet, and 13 feet and deeper). Soil density (S_w) was assumed to be 100 pounds per cubic foot (lbs/ft^3), which is an average density for sand textured soils:

$$W1 = D_a * D_{gw} * S_w$$

$$W2 = D_a * D_{gw} * S_w$$

$$W3 = D_a * D_{gw} * S_w$$

The SC of each interval was calculated as:

$$SC = W * (\frac{P_a}{10^6})$$

The total SC of all three intervals (ΣSC) was divided by the annual mass flow rate from the OSDS to the vadose zone ($\dot{m}_E$), to obtain the breakthrough time to the saturated zone (t_{BSZ}):

$$t_{BSZ} = \frac{\Sigma SC}{\dot{m}_E}$$

Breakthrough times for OSDS sources to groundwater in the Spanaway Lake watershed ranged from under 5 years to over 300 years, with an average time of 35 years (Figure 9). The total mass of phosphorus breakthrough to the saturated zone from system installation to present was determined by multiplying the time since breakthrough in years by the calculated phosphorus load per OSDS ($\dot{m}_E$). Assuming a 50 percent reduction in drainfield area for gravity systems results in a reduction of the maximum breakthrough time to groundwater to 171 years. Conversely, reducing the drainfield effluent concentration from 12,000 to 8,000 µg/L increases the maximum breakthrough time to groundwater to approximately 460 years.

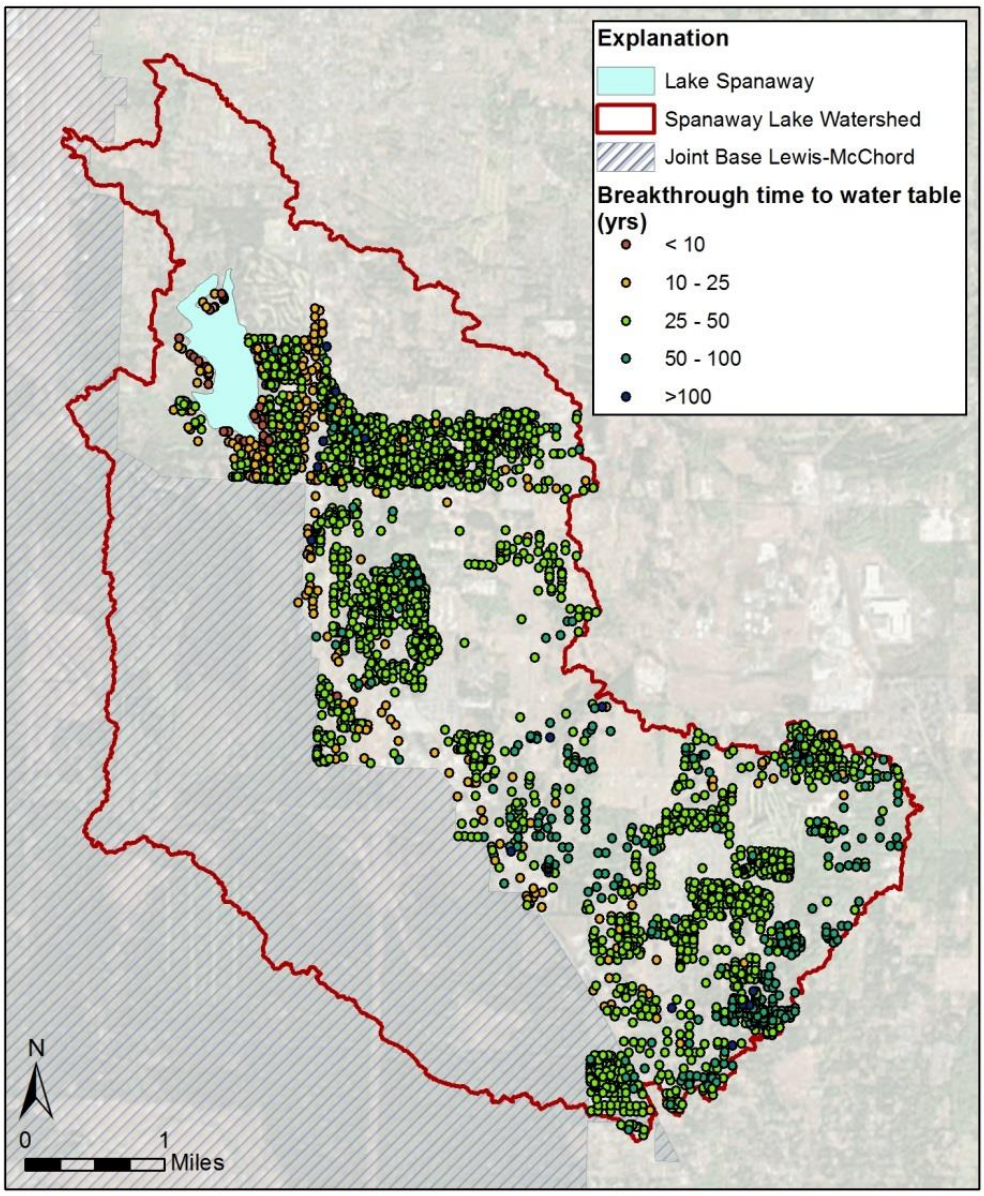

Figure 9. Phosphorus breakthrough time (years) to the saturated zone from OSDS sources

5.1.1.2 Estimation of Phosphorus Transport through the Saturated Zone

The saturated zone is the volume of the aquifer below the water table where voids are completely filled with water. Phosphorus within the saturated zone was modeled as moving perfectly laterally from the point where it crossed the water table to Spanaway Lake. Within the saturated zone, transport of phosphorus is retarded by sorption and mineralization processes along the flow path (URS and BC 2004; Stollenwerk 1996).

The distance to Spanaway Lake from each OSDS was calculated as the straight line distance between the OSDS and the point on Spanaway Lake's shoreline nearest to the OSDS. Calculations were carried out in ArcGIS using the OSDS geospatial data set provided by TPCHD and a shapefile of Spanaway Lake downloaded from the USGS National Hydrography Data Set (TPCHD 2005).

The advective groundwater velocity—the speed at which groundwater moves through the saturated zone—was estimated for the Spanaway basin using groundwater levels collected throughout 2015 and 2016. Measured water levels were used to calculate groundwater hydraulic gradients during 4 months distributed throughout the year (February, May, August, and November). To simplify the model, hydraulic gradients from all periods were averaged and then used to calculate groundwater velocities using the following equation:

$$v_{advective} = -\frac{K}{n_e} * \frac{dh}{dl}$$

Where:

$v_{advective}$ is the advective groundwater velocity (ft/day)

K is the saturated hydraulic conductivity of the aquifer (ft/day)

n_e is the effective porosity of the aquifer material (dimensionless)

dh/dl is the hydraulic gradient of groundwater in the saturated zone (dimensionless)

$v_{advective}$ was then assumed to be constant throughout the aquifer and invariant with time. The saturated hydraulic conductivity of the aquifer (K) was assumed to be 933 feet per day (ft/day), as described in the Chambers-Clover Creek groundwater model (Johnson et al. 2011). The effective porosity (n_e) of the aquifer material was assumed to be 0.18, as measured during hydraulic testing at nearby JBLM (Truex et al. 2010).

$v_{advective}$ is computationally sensitive to estimates of K. The Chambers-Clover Creek groundwater model uses a constant 933 ft/day for the uppermost aquifer (the A1 aquifer in that report) throughout the basin, but also documents measured K values between 62 and 5,065 ft/day. Because $v_{advective}$ has a strong influence on the calculated phosphorus load to Spanaway Lake, and K has a strong influence on $v_{advective}$, loading estimates could benefit from better constraint of K. Sensitivity analyses were completed to identify the potential range of loading estimates assuming the range of K values documented within the watershed.

Phosphorus does not appear to be transported through glacial soils at the same rate as ambient groundwater because of sorption and mineralization processes within the saturated zone (URS and BC 2004; Stollenwerk 1996). Instead, the front of the phosphorus plume appears to take longer to reach a downstream point than ambient groundwater because phosphorus is removed along the flow path until sorption and mineralization processes are overcome. This process is known as retardation.

To account for the slower movement of phosphorus in the saturated zone, a retardation factor (R) was estimated using time-of-travel data (URS and BC 2004):

$$R = \frac{v_{advective}}{x/t}$$

Where:

R is retardation factor

$v_{advective}$ is the advective groundwater velocity (ft/day)

x is distance traveled by the front of the phosphate plume in time t (feet)

t is the time required for the front of the phosphate plume to travel x feet (day)

The retardation factor was then used to calculate an effective velocity of phosphorus through the saturated zone as the quotient of the retardation factor and the advective groundwater velocity within the Spanaway Lake watershed.

$$v_e = \frac{v_{advective}}{R}$$

Where:

v_e is the effective velocity of phosphorus in the saturated zone (ft/day)

$v_{advective}$ is the advective groundwater velocity (ft/day)

R is retardation factor

In addition to estimating the rate of movement of phosphorus within the groundwater system, additional mass transport processes occur within the aquifer. Similar to the transport steps within the vadose zone, the sorptive capacity of the aquifer determines the fraction of mass removed through sorption to the aquifer material. Plume-spreading models generally include estimates of advection, diffusion, dispersion, sorption, precipitation, and other chemical reactions. These dynamic processes can vary broadly in both time and space, and are simplified through the use of an aquifer retention relationship.

The phosphorus load reaching Spanaway Lake was modeled using the simple retention relationship:

$$S = W * \dot{m}_{VZ} * (1 - Sr)$$

Where:

S is pounds of phosphorus to surface water

W is number of OSDS that have reached breakthrough in that year for the study area

$\dot{m}_{VZ}$ is the estimated effluent load of phosphorus from the vadose zone (lbs/year)

S_r is the soil retention factor

Two soil retention factors were used to calculate a range of impacts from OSDS to Spanaway Lake. A soil retention factor of 50 percent represents geologic material (sand, gravels, and cobbles) that would not strongly sorb phosphorus, while a factor of 70 percent would suggests strong sorption and mineralization processes. These values fall within the ranges presented by HDR and others noted therein.

5.1.1.3 Flow Weighting of Phosphorus Reaching Spanaway Lake from OSDS Sources

The phosphorus load to Spanaway Lake from the saturated zone was weighted to account for aquifer flow paths that did not intersect the lake. Examples of flow paths that might not intersect the lake include those that flow around the lake and those that flow under the lake. Because these flow paths do not deliver phosphorus to Spanaway Lake, mass carried along these flow paths was discounted using a 2-dimensional flow zone weighting process.

Linear flow weighting is the process of determining the proportion of flow likely to pass through a feature by calculating the fraction of the feature's width to the total width of the basin at a transect:

$$f_f = \frac{w_L}{w_B}$$

In which:

- f_f is flow weighting factor (the fraction of flow passing through Spanaway Lake)
- w_L is the width of Spanaway Lake at the transect line (feet)
- w_B is the width of the Spanaway basin at the transect line (feet)

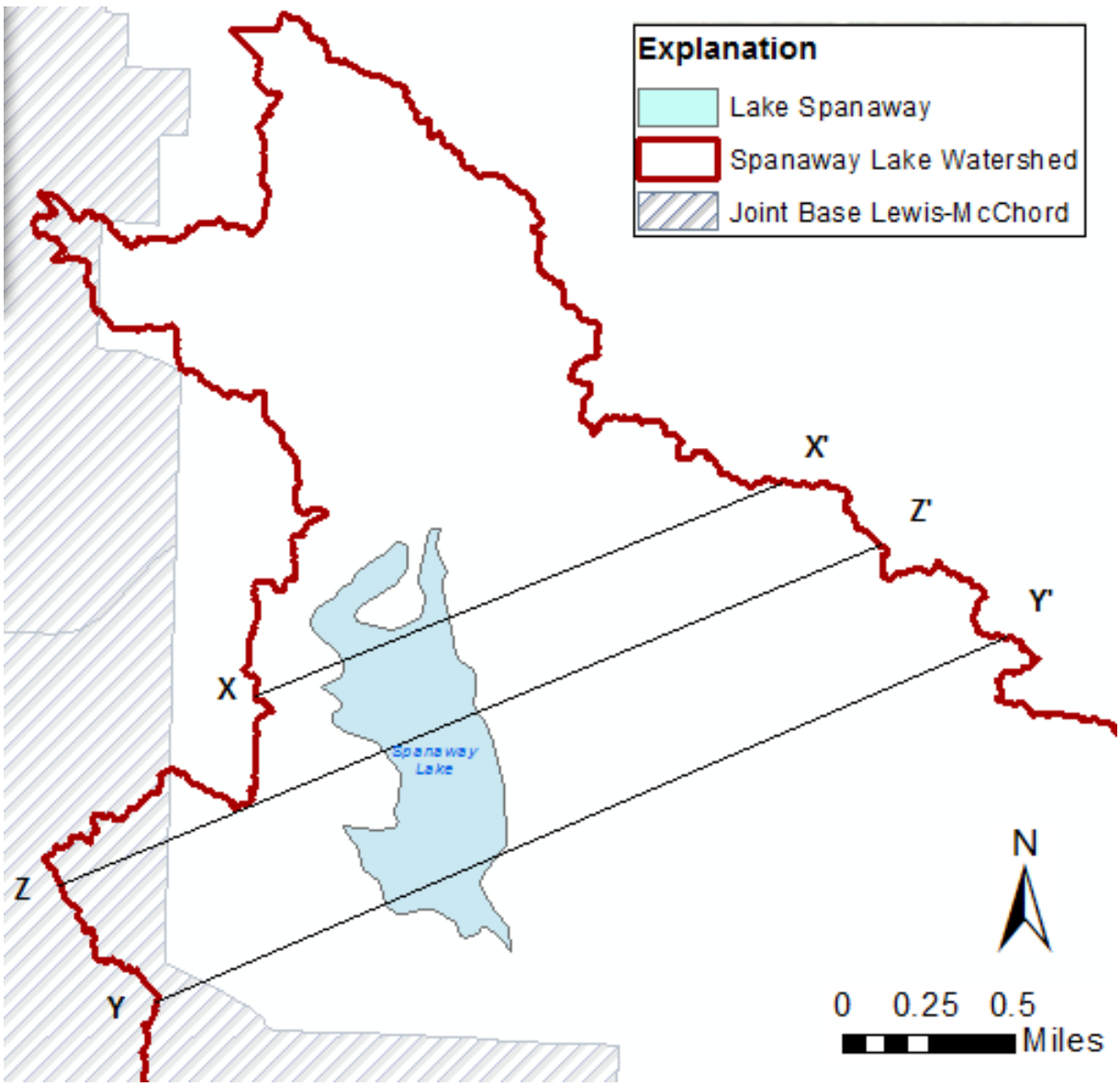

Figure 10. Flow-weighting transects

Width measurements were made perpendicular to the average flow direction simulated by the Chambers-Clover Creek groundwater model.

The flow-weighted phosphorus load to Spanaway Lake was then calculated as the product of the flow-weighting factor and the phosphorus load in the saturated zone:

$$\dot{m}_{LAKE} = f_f * \dot{m}_{SZ}$$

In which:

- $\dot{m}_{LAKE}$ is the phosphorus loading rate to Spanaway Lake (lbs/yr)
- f_f is the flow-weighting factor
- $\dot{m}_{SZ}$ is the mass flow rate of phosphorus within the saturated zone (lbs/yr)

The linear flow weighting method employed by this study makes two major assumptions about Spanaway Lake and the Spanaway basin. First, the lake is assumed to fully penetrate the saturated zone with only horizontal flow components. If the lake does not fully penetrate the saturated zone, the flow-weighting factor will overestimate the fraction of flow passing through the lake. The second assumption is that the saturated zone can be modeled as having a constant thickness across the entire basin. If the saturated zone cannot be modeled in this manner, the flow-weighting factor will underestimate the fraction of flow passing through the lake. The Chambers-Clover Creek groundwater model simulates the saturated zone as being relatively uniform along the entire transect.

5.1.1.4 Breakthrough to Spanaway Lake

Time to breakthrough to Spanaway Lake from the saturated zone was calculated as the quotient of the distance to Spanaway Lake and the effective velocity of phosphorus in the saturated zone:

$$t_{BLS} = \frac{x_{LAKE}}{v_e}$$

Where:

t_{BLS} is the time to breakthrough at Spanaway Lake (year)

x_{LAKE} is the distance between the OSDS and Spanaway Lake (feet)

v_e is the effective velocity of phosphorus in the saturated zone (ft/yr)

Breakthrough times from OSDS installation to lake interception for individual OSDS are shown in Figure 11, below.

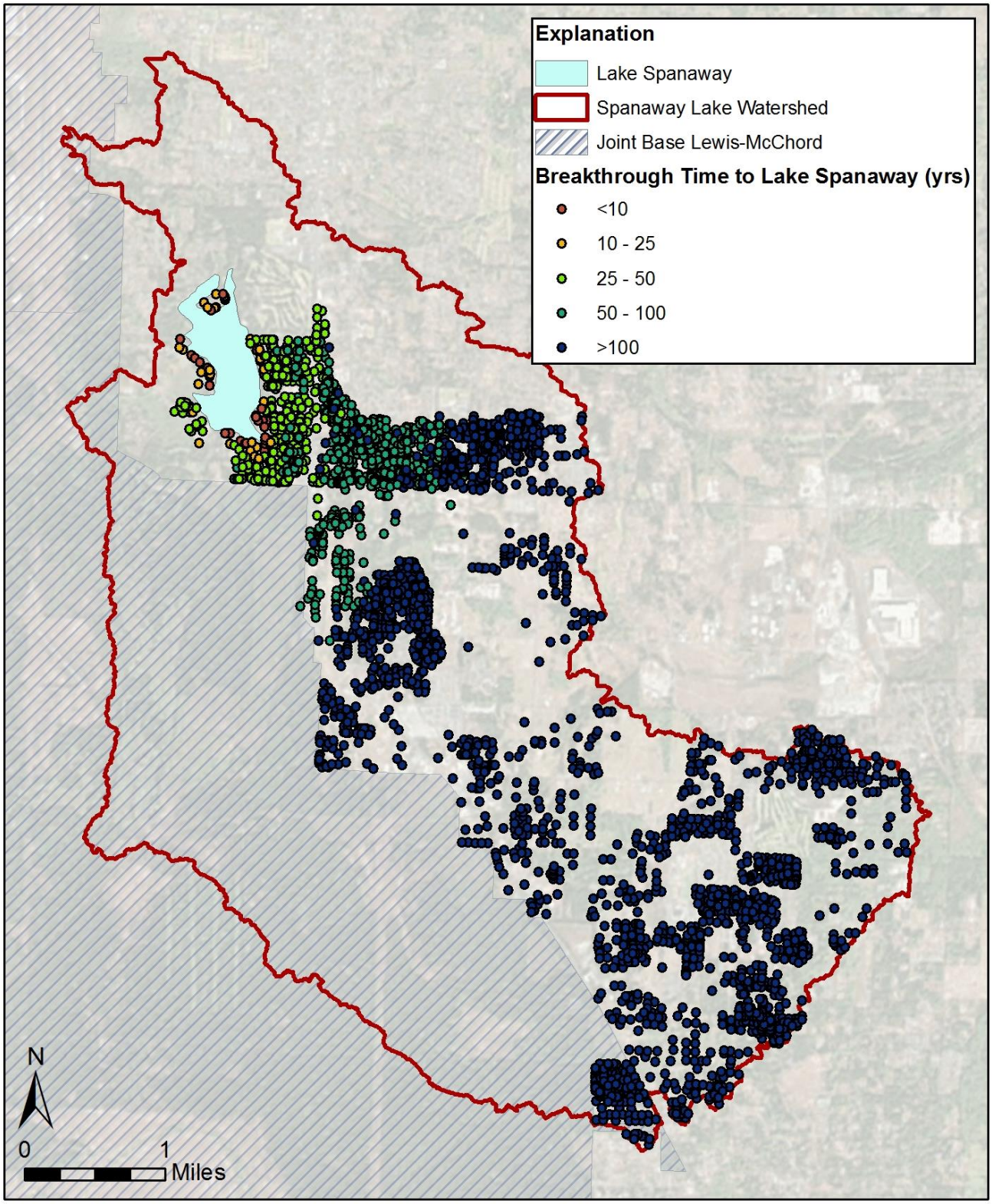

Figure 11. Phosphorus breakthrough times to Spanaway Lake from OSDS sources (years)

Breakthrough times indicate the amount of time phosphorus takes to reach Spanaway Lake following installation of the OSDS.

5.1.1.5 Summary of Phosphorus Loads to Spanaway Lake from OSDS Sources

The set of simplifying assumptions, described in previous sections, governs the modeling process to estimate the potential range of phosphorus loads to Spanaway Lake. The OSDS drainfield area and the drainfield effluent phosphorus concentrations represent variables or conditions that could vary significantly both spatially and temporally. Phosphorus loading estimates based on changes in drainfield area and effluent concentrations resulted in predictable linear relationships with the annualized loading values.

Spanaway Lake is estimated to receive 200 pounds of phosphorus in 2016 from OSDS sources. This value supposes 50 percent aquifer retention. As shown in Figure 12, 2016 load values would be 120 pounds if the aquifer retention factor is 70 percent and 400 pounds if there was no aquifer retention.

The model sensitivity to changes in OSDS drainfield effluent concentrations and drainfield area was assessed. A summary of the model results from sensitivity tests is provided in Figure 13, based on:

- A 25 percent reduction in effluent concentration (from 12,000 to 8,000 µg/L)
- A 50 percent reduction in drainfield area (based on estimated system size)

Assuming constant aquifer retention factors and a 50 percent reduction in drainfield area for gravity systems results in an increase in loading to the lake to approximately 260 pounds in 2016. A 25 percent reduction in drainfield effluent phosphorus concentration from 12,000 to 8,000 µg/L results in a decrease in the estimated 2016 phosphorus load to the lake to approximately 160 pounds.

Table 6. Annual Phosphorus Loads to Spanaway Lake from OSDS Sources

Year	Estimated Number of OSDS with Breakthrough	Flow-weighted Loading Rate to Spanaway Lake, no Aquifer Retention (lbs/yr)	Flow-weighted Loading Rate to Spanaway Lake, 50% Aquifer Retention (lbs/yr)	Flow weighted Loading Rate to Spanaway Lake, 70% aquifer retention (lbs/yr)
2000	242	282	141	85
2005	267	311	156	93
2010	300	350	175	105
2015	336	392	196	118
2020	381	444	222	133
2025	415	484	242	145

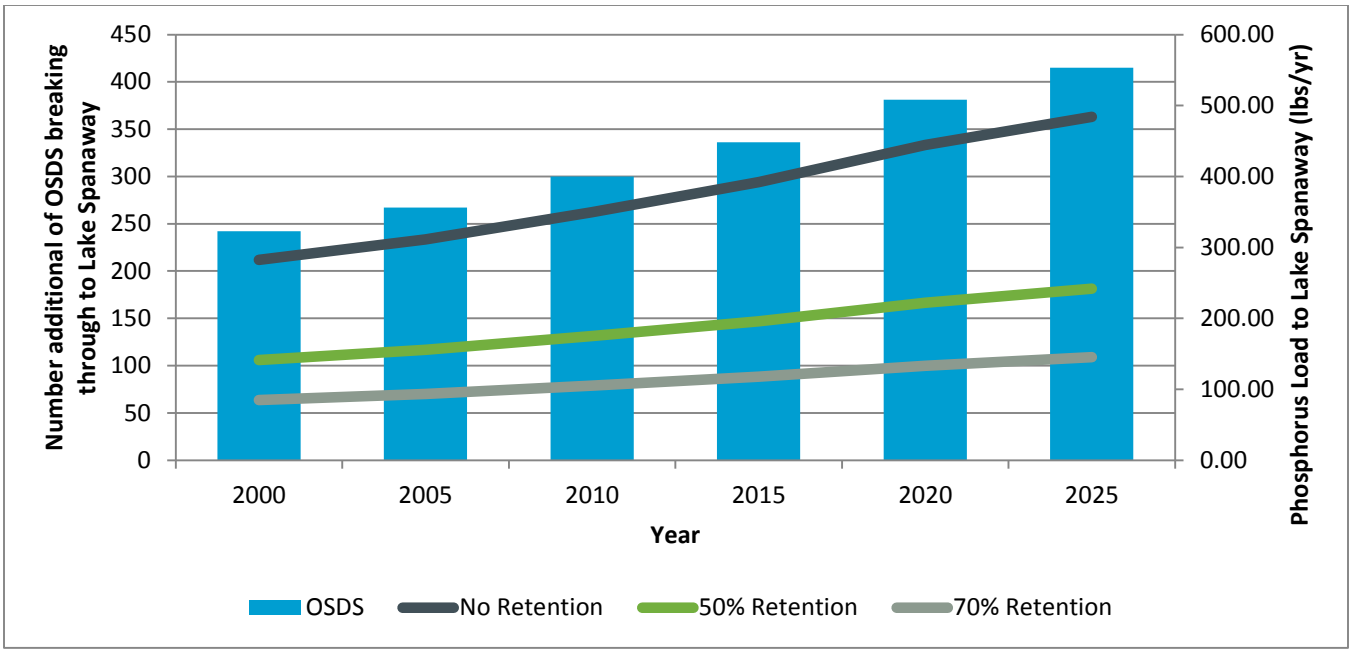

Figure 12. Annual phosphorus load to Spanaway Lake from OSDS sources

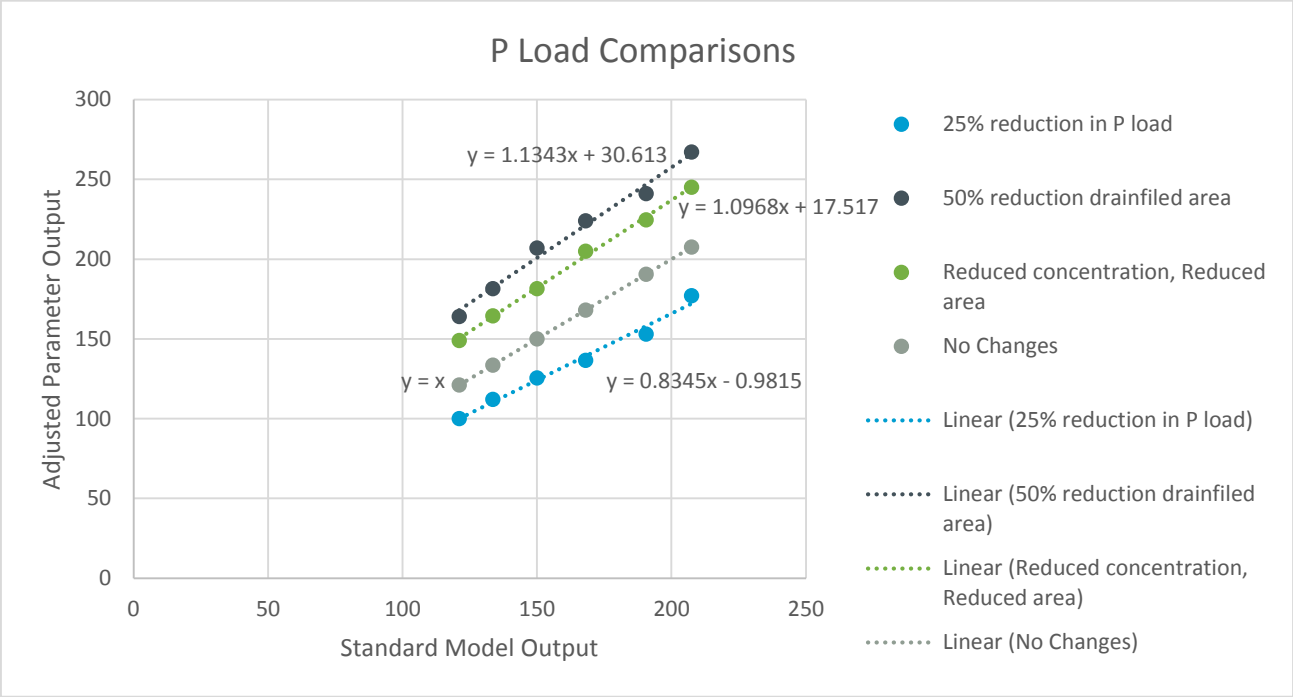

Figure 13. Summary of sensitivity test results on effluent concentration and drainfield area

Phosphorus loads to Spanaway Lake may increase as OSDS located farther from the lake continue to break through. Assuming no new OSDS are installed, estimates for 2050 indicate a load of 364 pounds (50 percent aquifer retention factor). Assuming a 25 percent reduction in effluent phosphorus concentration (from 12,000 to 8,000 µg/L) or a 50 percent decrease in drainfield areas results in estimated 2050 annual

loads of 317 and 508 pounds, respectively. Based on these results, the effective drainfield area is a critical factor in estimating the phosphorus loading to the lake. Drainfields with preferential flow through more permeable areas—which may be typical of older gravity systems—or systems with structural failures such as cracks or holes in tanks and pipes, pose the greatest level of risk.

Phosphorus retained in the vadose and saturated zones can remobilize if effluent phosphorus concentrations drop or are eliminated. This means that even if every OSDS was immediately decommissioned, groundwater phosphorus loads to Spanaway Lake could remain significant for many years as the load bound within the soils slowly releases.

5.1.2 Fecal Coliform Loads from OSDS

A wide range of FC concentrations have been reported in relevant literature. Concentrations are highly dependent on the type of system and underlying soils. Systems that include sand filters and pressurized distribution systems generally show lower FC concentrations in drainfield effluent than non-sand systems.

To estimate FC transport through the soil and aquifer toward Spanaway Lake, a similar compartmentalized modeling approach was developed:

- If the vadose zone thickness (DTW) was documented to be more than 30 feet, full attenuation is assumed to occur within the vadose zone and no FC hits the water table.
- If the vadose zone thickness is less than 30 feet, the vadose zone is compartmentalized into a 1-foot drainfield compartment and 4-foot incremental compartments thereafter to the water table. Each vadose zone compartment was assigned 1-log removal of FC.
- Once breakthrough to groundwater occurs, the aquifer zone is compartmentalized based on the distance between the OSDS and the lake, with 52-foot compartments. Aquifer compartment values were derived from literature values and regulations for riverbank filtration. California river bank filtration regulations use 1-log removal per 8 meters aquifer distance, for an alluvial aquifer system (Berger 2002; Schijven, Berger, and Miettinen 2003). However, based on the high permeability values from the Spanaway area, and the potential for increased groundwater velocities, the California values were adjusted to meet the project data.
- In all cases where dividing distance by compartment size resulted in a fractional compartment, the number of compartments was rounded down to the nearest whole number.

FC transport modeling indicates that only systems within approximately 350 feet of the lake shoreline area have the potential to contribute FC to the lake. OSDS sources within 100 feet from the lake pose the greatest risk. These systems are generally in areas with shallow groundwater, providing little soil and aquifer media to assimilate OSDS loads prior to breakthrough to the lake.

Approximately 121 OSDS systems exist within 350 feet of the lake. Of these systems, approximately 35 to 50 systems have estimate depths to groundwater less than 10 feet. These systems are likely to have FC removal efficiencies of only 2- to 4-log removals, resulting in a strong potential for FC breakthrough to the lake.

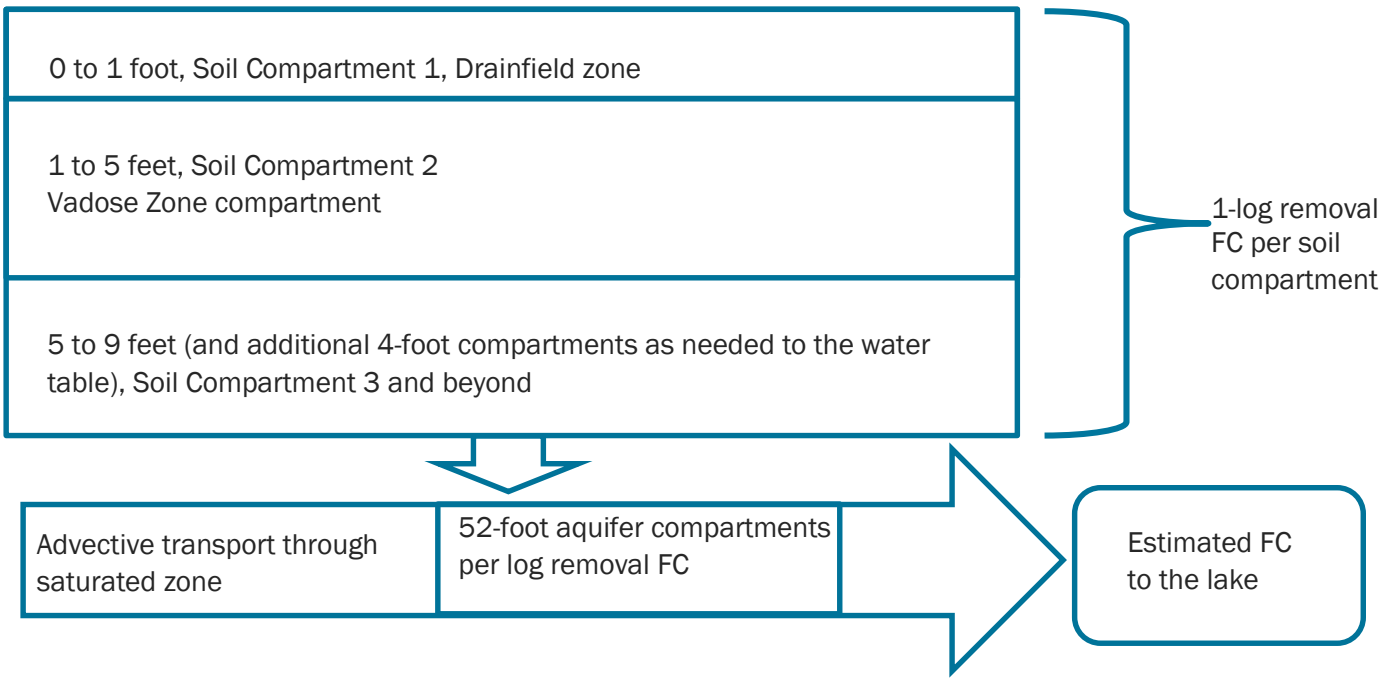

Figure 14. Schematic of FC transport

5.2 Stormwater Infiltration Facilities

Stormwater infrastructure, such as stormwater drywells and stormwater infiltration ponds, were also identified as potential sources of phosphorus moving into Spanaway Lake. Currently there are 1,535 drywells and 129 stormwater infiltration basins known to be operating in the Spanaway Lake watershed. Figure 15 below shows the locations of stormwater infrastructure discharging to groundwater within the Spanaway Lake watershed. Phosphorus and FC from stormwater reaches Spanaway Lake after entering the subsurface through infrastructure, passing through the vadose zone to the water table, then moving through the saturated zone to the lake in a similar process to phosphorus sourced from OSDS.

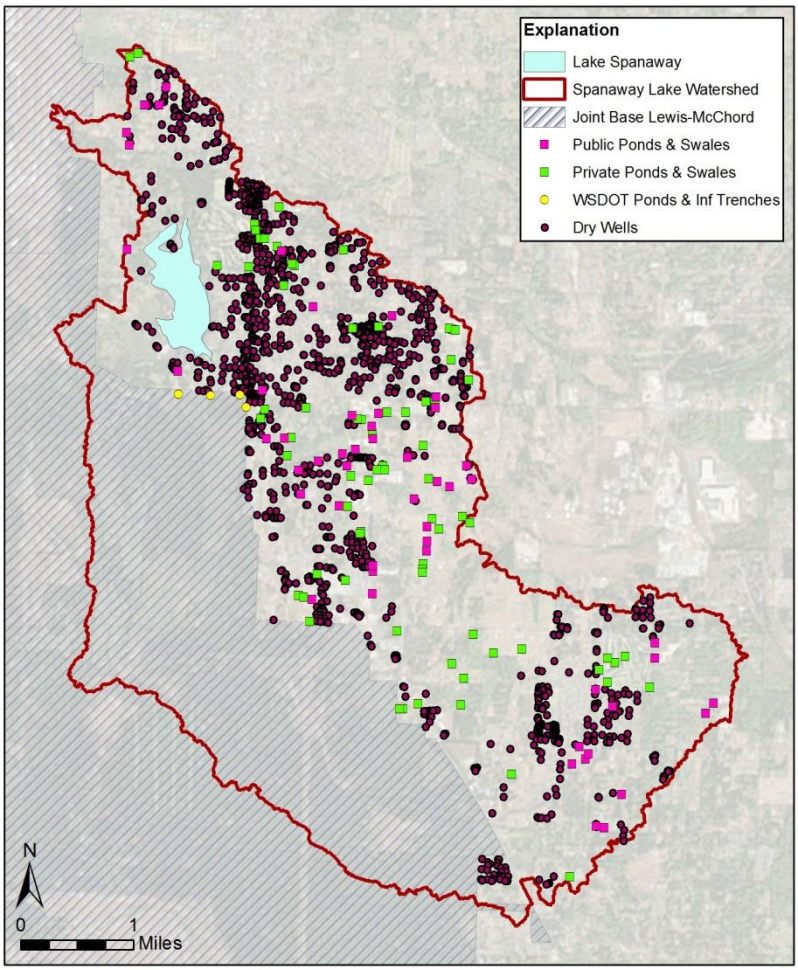

Figure 15. Locations of stormwater infrastructure discharging to groundwater in the Spanaway Lake watershed

5.2.1 Phosphorus Loading from Stormwater

The rate of phosphorus discharged from stormwater infrastructure was estimated with a similar process as OSDS sources by estimating the total effluent flow rate at each location and a constant average phosphorus concentration within the effluent described as:

$$\dot{m}_E = Q * C_P$$

In which:

- $\dot{m}_E$ = mass flow rate of phosphorus from the drywell/stormwater pond to the vadose zone (lbs/yr)
- Q = annual effluent flow rate (MG/yr)
- C_P = phosphorus concentration (lbs/gal)

The difference between the OSDS process and that used for stormwater infrastructure is the removal of the uppermost soil compartment within the loading calculations from drywells and infiltration basins.

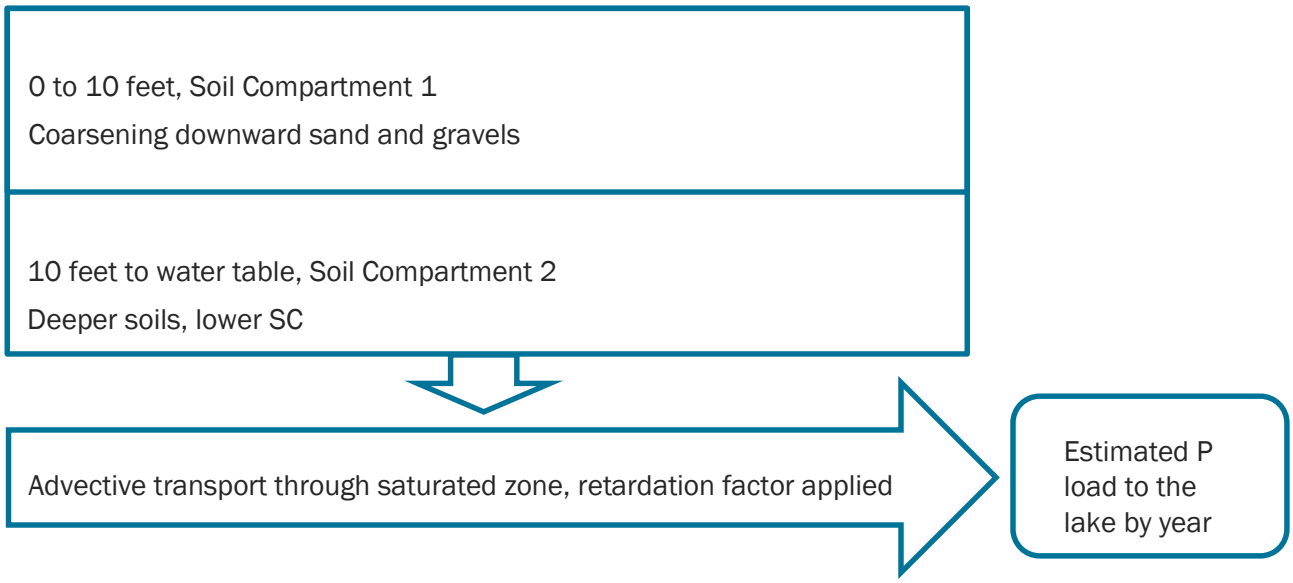

Figure 16. Conceptual model of phosphorus transport from stormwater sources to Spanaway Lake

Phosphorus in stormwater from residential areas comes primarily from fertilizer, pet waste, and yard waste captured in lawn and street runoff (Waschbusch et al. 1995). An average stormwater concentration of 0.22 parts per million (ppm) phosphorus was used for this analysis based on EMC statistics developed for SPU based on local and regional stormwater monitoring data (SPU 2015).

Stormwater runoff volumes were estimated from 2014 and 2015 precipitation data recorded at the Spanaway Golf Course. Stormwater volumes at each location were calculated by averaging monthly precipitation and runoff values during the project monitoring period from 2014 and 2015. Based on historical stormwater drainage trends, each drywell was assumed to collect runoff from 5,000 ft^2 of impervious area, though many drywells are suspected to receive runoff from larger contributing areas (Mike Milne, BC, written communication with G. Vigoren, May 11, 2016). The flow from each drywell was then calculated as the product of runoff at that location and the assumed 5,000 ft^2 contributing area. This flow was modeled as entering the vadose zone through a perforated concrete well screen 8 feet long with a 30-inch inside diameter. This construction yields an infiltration area of 533 ft^2, and is representative of drywells constructed by the County before 2000 (Mike Milne, BC written communication with G. Vigoren, May 11, 2016). Many drywells have alternate construction or have been retrofitted, but are poorly documented.

Each stormwater pond was assumed to receive runoff from a contributing area proportional to its footprint (plan-view area). The area contributing runoff to each stormwater pond was determined by the following equation:

$$A_c = \frac{A_f}{A_{DW}} * 5{,}000\ ft^2$$

Where:

A_c = impervious area contributing runoff to the stormwater basin

A_f = footprint (plan-view) area of the stormwater basin

A_{DW} = the infiltration area of a standard Pierce County dry well (533 ft^2)

The flow rate of stormwater into the vadose zone was then calculated as the product of A_c and runoff for that location. Additionally, the model was used to test impacts from increases in the drainage basin area for drywells by increasing the drainage catchment to 10,000 and 25,000 ft^2.

5.2.1.1 Estimation of Phosphorus Transport through the Vadose Zone from Stormwater Sources

Phosphorus from stormwater transported through the vadose zone was estimated in the same manner as phosphorus from OSDS sources with modifications to the calculations of drainfield area.

Drainfield area for drywells was modeled as the infiltration area for a standard County drywell (Section 2.2.2). For infiltration ponds, the drainfield area was assumed to be equal to the footprint area.

Lacking original drywell construction records and installation dates, a proxy date of 1950 was used as the starting date for phosphorus loading from all drywell sources. The use of this proxy date has little impact on loading estimates as shown in the breakthrough time predictions below.

When drainage basin area was not included within the County's stormwater infrastructure data for infiltration ponds, an alternative method was used to estimate the annual discharge. Under these conditions, the footprint area was used to back-calculate an estimated drainage basin size based on equivalent drywell area and the assumed standard drainage area for a drywell.

Phosphorus retention in the vadose zone from stormwater sources was modeled with the same process as OSDS sources, with one modification. Figure 9 shows the removal of Soil Compartment 1, which represented OSDS sands filter media, and use of only the remaining soil compartments. Again, the SCs were modeled after work done in Spokane County, which has coarse-grained material similar to that of the Spanaway Lake watershed. The following SCs were used for the Spanaway Lake watershed (HDR 2007):

- Zero to 10 feet with an assumed increase in particle size diameter to coarse-grained sands and gravels - 150 mg/kg
- Ten and deeper, SC of 50 mg/kg

This layering reflects the typical simplified model of soils beneath stormwater infiltration facilities, and average local geology.

The timing of phosphorus breakthrough to groundwater was estimated for total yearly phosphorus load per system (P_t), estimated drainfield size (D_a), phosphorus sorption (P_a), and depth to groundwater (D_{gw}). An initial step for breakthrough calculations included the estimation of soil weights (*W1, W2*) for the two soil compartments (0 to 10 feet, and 10 feet and deeper). Soil density (S_w) was assumed to be 100 lbs/ft^3, which is an average density for sand textured soils:

$$W1 = D_a * D_{gw} * S_w$$

$$W2 = D_a * D_{gw} * S_w$$

The SC of each interval was calculated as:

$$SC = W * (\frac{P_a}{10^6})$$

The total SC of all intervals (ΣSC) was divided by the annual mass flow rate from the stormwater infrastructure to the vadose zone ($\dot{m}_E$), to obtain the breakthrough time to the saturated zone (t_{BSZ}).

$$t_{BSZ} = \frac{\Sigma SC}{\dot{m}_E}$$

5.2.1.2 Phosphorus Transport through the Saturated Zone and Breakthrough to Spanaway Lake

Phosphorus travel times from drywells to Spanaway Lake vary considerably depending on the depth to groundwater and the distance to the lake. Drywells located in areas with shallow groundwater near the lake could contribute phosphorus in as little as 1.5 years, while drywells far from the lake have estimated breakthrough times exceeding 600 years.

Preferential flows in areas surrounding drywells or high groundwater periods when aquifer water levels approach the base of drywells could result in direct discharge to the water table. Under these conditions, no attenuation in the vadose zone occurs and phosphorus loads breakthrough to the lake sooner.

About 80 drywells are located in areas where the USGS CCC Groundwater Model predicts a depth to water of less than 10 feet, or even slightly above the land surface (Savoca 2010). In these cases, the phosphorus transport model assumed the depth to water was 10 feet. The actual depth to groundwater may be less than 10 feet for some of the drywells near the lake, however. For these wells, the model was run for two scenarios: 10 feet of depth to the water table and the water table at or above the bottom of the drywell. The latter scenario resulted in the shortest transport time (1.5 years) to the lake, but the estimated phosphorus loading rates are relatively low (approximately 0.25 pound per year for a drywell draining 5,000 ft^2 of impervious area).

Little information was available regarding drywell tributary areas. The base scenario assumed that each drywell received runoff from 5,000 ft^2 of impervious area, which is the current design criterion. However, older drywells could drain larger areas. To evaluate this scenario, the model was re-run assuming 25,000 ft^2 and 50,000 $ft^2$of impervious tributary area. Under these scenarios, the average breakthrough time decreased from more than 600 years to approximately 150 and 75 years, respectively.

The drywell loading estimates assumed that all drywells were installed in 1950 and consist of vertical, perforated concrete pipes with no pre-treatment systems. The model likely over-estimates P transport from drywells that have been retrofitted or replaced with two-stage systems, which have a pre-treatment sump to reduce clogging and a horizontal infiltration pipe to reduce hydraulic loading rates.

Phosphorus transport from infiltration ponds was estimated using a similar approach to the drywell evaluation. The drainage facility footprint, contributing drainage area, and stormwater phosphorus concentrations were used to estimate phosphorus breakthrough times and loads. Breakthrough from the stormwater basin nearest to the lake (approximately 760 feet) was estimated at 50 to 100 years. Based on the age of this facility, the earliest breakthrough to the lake would occur around 2045. The model predicts that stormwater infiltration ponds could contribute up to 85 pounds of phosphorus per year by 2050. Most of the infiltration ponds in the watershed have estimated phosphorus breakthrough times greater than 500 years.

In summary, stormwater drywells and infiltration ponds close to the lake, and in areas where the depth to groundwater is shallow (less than 10 feet), could contribute phosphorous to the lake within a few years, but the loading rates appear to be relatively low compared to OSDS sources.

5.2.2 Fecal Coliform Loads from Stormwater Infiltration Facilities

The OSDS evaluation described in the above section found that subsurface transport of fecal bacteria is much more limited than phosphorus transport. OSDS more than 350 feet from the lake are unlikely to contribute appreciable FC bacteria to the lake. Phosphorus loads from stormwater infiltration facilities are estimated to be considerably lower than the OSDS phosphorus loads. FC concentrations in stormwater are typically orders of magnitude lower than FC concentrations in septic tank effluent. Therefore, stormwater infiltration is not expected to be a significant source of FC bacteria to Spanaway Lake.

5.3 Phosphorus Loading via Leaching from Fertilized Areas

It is possible for phosphorus to leach below the root zone in fertilized areas, move downward through the vadose zone, and be transported to the lake via groundwater flow. Irrigation of fertilized areas increases the potential for leaching.

While leaching can be important in agricultural areas, the available data indicate it is unlikely to be a major phosphorus source for Spanaway Lake, as summarized below:

- Hydraulic loading rates are low compared to OSDS and stormwater infiltration facilities because leaching occurs over a much larger area The infiltrating water comes into contact with a much larger mass of soil material so there is more opportunity for sorption of phosphorus.
- Average phosphorus concentrations in infiltration from landscaped areas are expected to be lower than concentrations in septic system effluent.
- Unlike OSDS and stormwater infiltration systems that bypass the upper soil horizons, the infiltrating water must pass through surface soils that typically have more plant roots, larger microbial populations, more organic matter, and finer-textured soils than underlying soils.
- Phosphorus fertilizer use at the Spanaway Golf Course is limited to the greens and application rates are determined based on soil testing (Mike Milne, BC written communication with Tony Bubenas, Pierce County Parks and Recreation, July 2016). USGS groundwater contour data indicate that groundwater recharge from much of the golf course area flows northwest rather than west into the lake.
- Recent restrictions on phosphorus in turf fertilizer have likely reduced phosphorus inputs associated with residential lawns.

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Appendix F: Management Measures

Appendix F Contents:

This appendix contains fact sheets for the recommended measures for Spanaway Lake:

- Hypolimnetic oxygenation system with optional alum injector
- Maintain conveyance capacity of lake outlet
- Aquatic plant management
- Waterfowl management
- Public education and outreach
- Spanaway lake monitoring, focused monitoring, and long-term monitoring

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Fact Sheet: Hypolimnetic oxygenation system with alum injector

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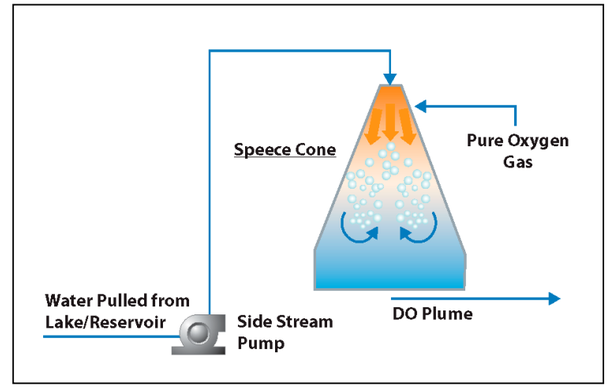
HYPOLIMNETIC OXYGENATION WITH ALUM INJECTOR	
Description	Install 1,000-pound per day hypolimnetic oxygenation system for Spanaway Lake. As a potential add-on, include alum injection to enhance phosphorus sediment. The alum system will include a liquid alum storage tank and alum feed system within the new boathouse extension. Install the Speece cone and its pump outside, adjacent to the new room, behind a masonry block enclosure, accessible through a normally locked gate. A suction pipeline from the deepest hypolimnion area will carry water through the pump into the Speece cone. A discharge pipeline terminating in a multiport diffuser will return highly oxygenated water into the hypolimnion away from the suction intake.  Schematic diagram of Speece cone
Objectives	Prevent anoxia from occurring in the lake hypolimnion, to limit nutrient cycling and reduce the lake's tendency to suffer from degraded water quality owing to algae blooms.
Initial planning level cost estimate[1]	$1,900,000
Estimated annual operation and maintenance cost[2]	$49,000
Basis for preliminary sizing	Estimated oxygen demand of about 1,000 lb/d, working from limited data for bathymetry and oxygen profiles.
Water quality benefit[3]	Maintains beneficial DO concentrations in hypolimnion to prevent nutrient cycling.
Approximate time to see water quality benefit	Improvement should start in first summer season but full benefit would likely occur after 3 to 5 years of operation.
Duration/frequency	Operates annually and indefinitely after installation. The oxygen demand would likely decrease after several years of operation. The County likely could cycle the system in the future based on in situ monitoring.
Other potential benefits	Expand cold water fisheries habitat.
Other potential impacts/costs	Requires dedication of some onshore space for LOX facility, Speece cone and pump, electrical and controls and alum storage and metering equipment. Temporary trenching needed for suction and discharge piping, followed by surface restoration.
Required infrastructure	Likely 480-volt, 3-phase power; wash-down water for alum system
Pre-design work needed	Bathymetric survey and subaqueous geotechnical exploration. Modeling to confirm benefits and refine design. Coordinating with County Parks and public notification/outreach. Permitting.
Additional Notes	The flow rate through the Speece cone is constant. Oxygen feed can be varied and the cone can be turned on and off daily or weekly to either have constant feed or to modulate oxygen delivery. All costs include 50% contingency and an allowance of 20% for engineering, legal, and administrative costs.

Basis of design/assumptions		
Item	**Units**	**Notes**
Capital Costs		
Speece cone system	$300,000	
Speece cone system installation	$220,000	Includes Speece cone installed outside behind CMU wall
Suction and discharge piping	$450,000	Includes suction and discharge piping with inlet screen and discharge diffuser
Site development	$580,000	Includes secure space for vendor supplied LOX tank and control system, behind CMU walls
Electrical/instrumentation allowance	$350,000	
Total Capital Costs For Hypolimnetic Oxygenation Only	**$1.9M**	
O&M Costs		
Operational days per year	240	Assumed 240 days of operation per year (~8 months) with continuous operation
Pump motor size (kw)	7.5	Assumes flow rate of 1 mgd
Oxygen demand (lb/d)	1,000	
Oxygen cost ($/ccf)	0.4	
Oxygen equipment O&M ($/year)	14,400	Paid monthly whether operating or not
Electricity cost ($/kWh)	0.08	
Labor effort (hours/yr)	240	Assumes $1 per hour per day
Labor cost ($/hour)	80	
Spare parts ($/year)	1,000	
Item	**Cost (dollars)**	
Electricity	$3,456	Assumes 7.5 kW pump motor with a flow rate of 1 mgd and electricity cost of $0.08/ccf operating at 240 days for 24 hours
Oxygen (gas)	$11,616	Assumes $242 for 1 ton of oxygen conversion to gas in ccf
Speece cone (O&M)	$14,400	
Labor	$19,200	
Total Annual O&M Costs	**$49,000**	
OPTIONAL Add-On to Hypolimnion Oxygenation System Costs: Alum Injector		
Capital Costs		
Chemical feed system, controls, storage tank, and WQ monitor	$100,000	Equipment and storage tank to be placed in oxygen generation building.
O&M Costs		
Labor, supplies, electricity, chemical purchase, and chemical feed system renewal and replacement.	$32,000	Assumes running the chemical feed system 240 days per year, 12 hours per day for an annual O&M cost of about $32,000/yr. This is based on an alum dose of 5 mg/L. The cost to operate the system 365 days per year, 12 hours per day is about $50k. Another option is to choose focused time of alum injection - this option would decrease the annual O&M cost to less than $32,000.
Summary: Hypolimnetic oxygenation + alum injector = $2,000,000 initial cost + $49,000/yr for Hypolimnetic oxygenation O&M + $32,000/yr for alum O&M		
Notes:		
1. Based on the planning-level information and concept development stage of this project, conceptual-level costs were estimated following the Association for the Advancement of Cost Engineering (AACE) Class 5 Cost Estimate Classification System, providing estimates in the range of -50% to +100% for the candidate actions.		
2. Planning-level estimate of annual O&M costs in 2016 dollars.		
3. Long-term lake monitoring is recommended (see Lake Monitoring fact sheet) to evaluate the effectiveness of the selected lake management measure(s).		

Fact Sheet Memo: Maintain conveyance capacity of lake outlet

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Fact Sheet Memo: Maintain conveyance capacity of lake outlet

Subject: Preliminary Evaluation of Spanaway Lake Outlet Hydraulics

Date: December 6, 2016

To: Mike Milne, Project Manager

From: Nathan Foged

Copy to: Colleen Doten, Valerie Fuchs

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Section 1: Purpose and Objectives

A preliminary hydraulic analysis of the outlet channel of Spanaway Lake was performed to evaluate potential benefits of vegetation maintenance/removal. The analysis was performed to meet the following objectives:

- Examine the sensitivity of lake water surface elevations to variations in roughness at the outlet channel
- Evaluate the potential effects of water surface elevation changes on inundated areas around the periphery of the lake
- Evaluate the potential effects of water surface elevation changes on residence time in the lake using an idealized ("plug flow") assumption

LIMITATIONS: The analysis described herein is intended to be an initial "desktop" evaluation of the outlet conditions to obtain some indication of the potential variations in lake levels. This fact sheet memorandum does not purport to predict water level changes from specific maintenance actions, but only suggests likely or possible ranges. An evaluation of specific planned actions would require survey data, field observations, and detailed roughness calculations. Furthermore, state regulations pertaining to in-channel maintenance activities should be assessed to determine how much vegetation and/or clearing could be allowed.

Section 2: Approach

Brown and Caldwell (BC) performed hydraulic modeling of upper Spanaway Creek starting approximately 3,000 feet upstream of the lake and ending approximately 4,000 feet downstream of the lake near the confluence with Morey Creek. A one-dimensional, steady-state hydraulic flow model was developed using HEC-RAS[1] software in combination with a geographic information system (GIS)-based toolbox called HEC-GeoRAS[2]. BC executed a series of 15 steady-state hydraulic simulations while incrementally varying the Manning's roughness parameter for the lake outlet channel. Simulated water surface elevations from the HEC-RAS results were used to examine potential changes in lake inundation levels and calculate the relative impact on lake residence time. The following subsections describe key steps in input data development.

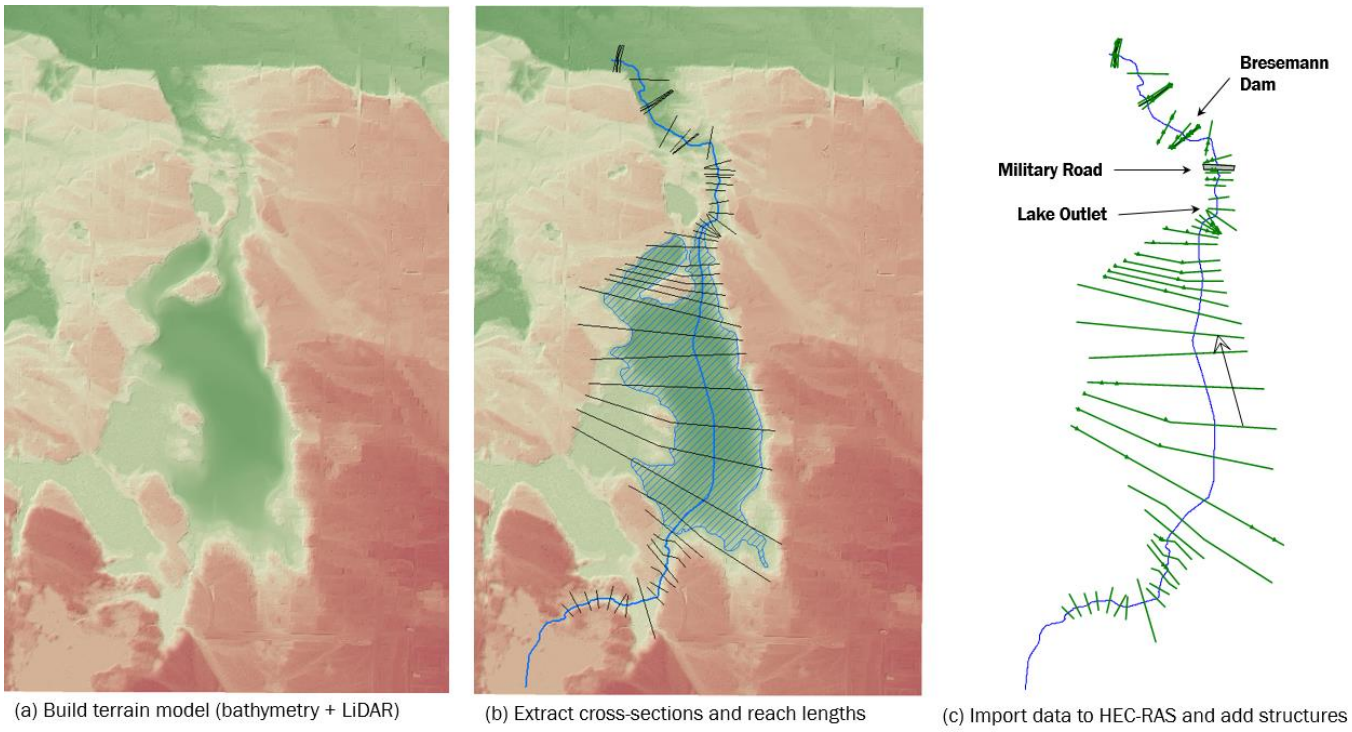
2.1 Geometric Data

For this preliminary hydraulic analysis, the physical geometry of the lake and stream channel system was developed using a combination of bathymetric contour data from the Department of Ecology, a 3-foot digital elevation model from the Puget Sound LiDAR Consortium (PSLC), and cross-section surveys

[1] HEC-RAS is a one-dimensional step backwater flow model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE): http://www.hec.usace.army.mil/software/hec-ras/.

[2] HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI): http://www.hec.usace.army.mil/software/hec-georas/.

and structures data from an existing HEC-RAS model developed for Federal Emergency Management Agency (FEMA) floodplain mapping. Figure 1 illustrates the development of geometric inputs.



(a) Build terrain model (bathymetry + LiDAR) (b) Extract cross-sections and reach lengths (c) Import data to HEC-RAS and add structures

Figure 1. Upper Spanaway Creek geometric data development using HEC-GeoRAS

2.2 Flow Data

Pierce County currently operates a streamflow monitoring station near Military Road, approximately 1,000 feet downstream of Spanaway Lake (location known as "SW1"). Water levels are logged at 15-minute intervals and converted to stream discharge using a derived rating curve. BC prepared preliminary flow data records for a 16-month period from October 2014 to May 2016. These data records were used for this analysis to calculate a flow duration curve for the Spanaway Lake outlet (Figure 2). BC also calculated average and median monthly discharges values using the same streamflow data (Figure 3). These flow data records indicate the following:

- The median daily flow for the full-time period was estimated to be 23 cubic feet per second (cfs).
- The median daily flow for just February (the highest month) was estimated to be 60 cfs.

Extreme or rare flood discharges were estimated from the FEMA Flood Insurance study, which lists the 10-, 50-, 100-, and 500-year discharges as 69, 86, 92, and 106 cfs, respectively. For each of the 15 hydraulic scenarios BC ran several flow profiles including the FEMA discharges plus lower discharges in 5 cfs increments down to 1 cfs. A total of 25 discharges were run for each of 15 Manning's roughness scenarios for a total computation set of 375 steady-state profiles.

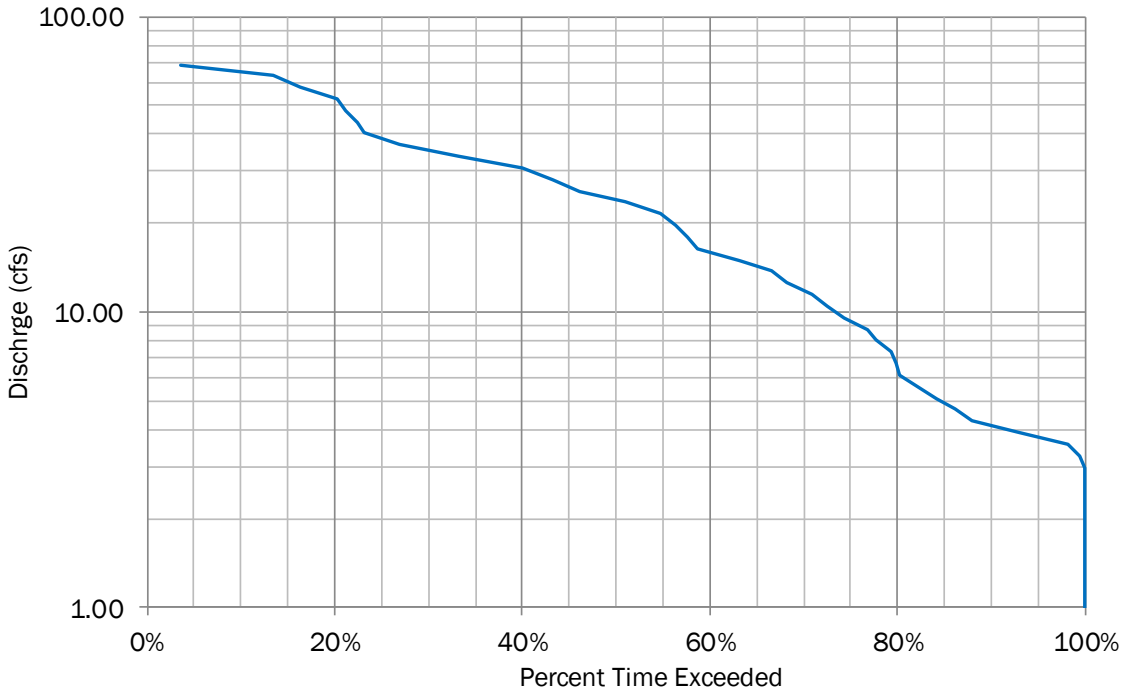


Figure 2. Flow duration curve from streamflow data collected at Military Road from October 2014 to May 2016

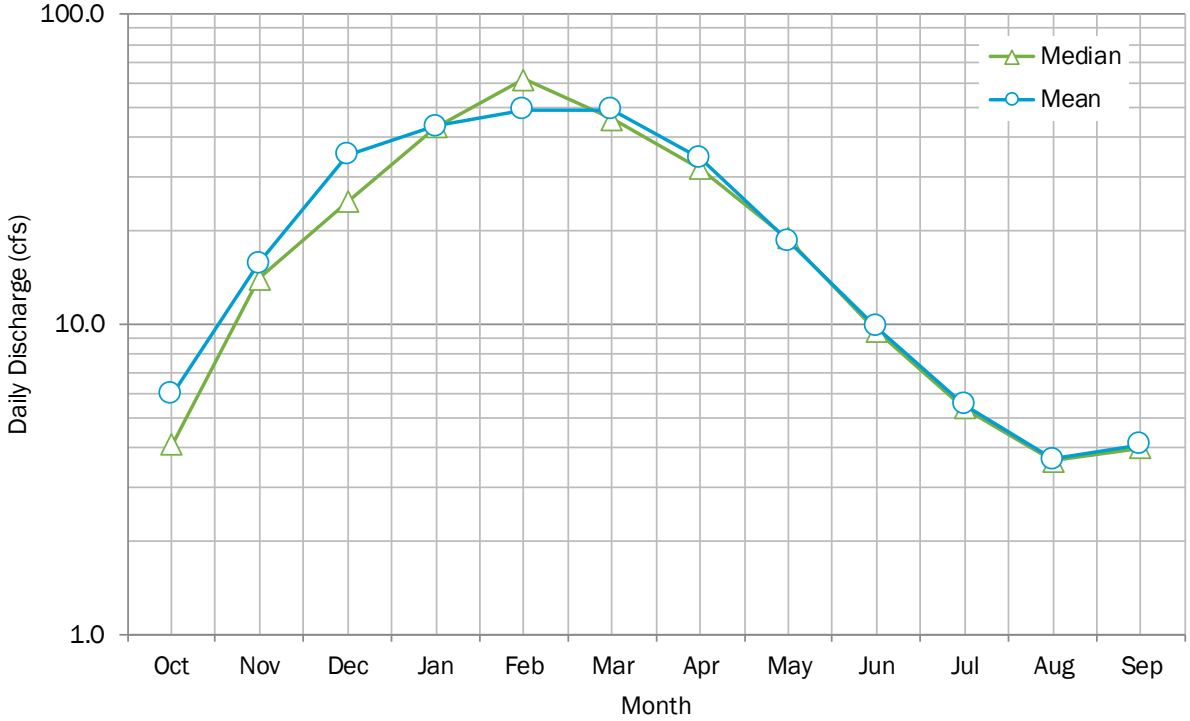


Figure 3. Monthly discharges from streamflow data collected at Military Road from October 2014 to May 2016

2.3 Manning's Roughness

BC identified a range of Manning's roughness values for the outlet channel based on observations made during previous field reconnaissance. Figure 4 shows a picture taken just downstream of the outlet during one of those site visits.

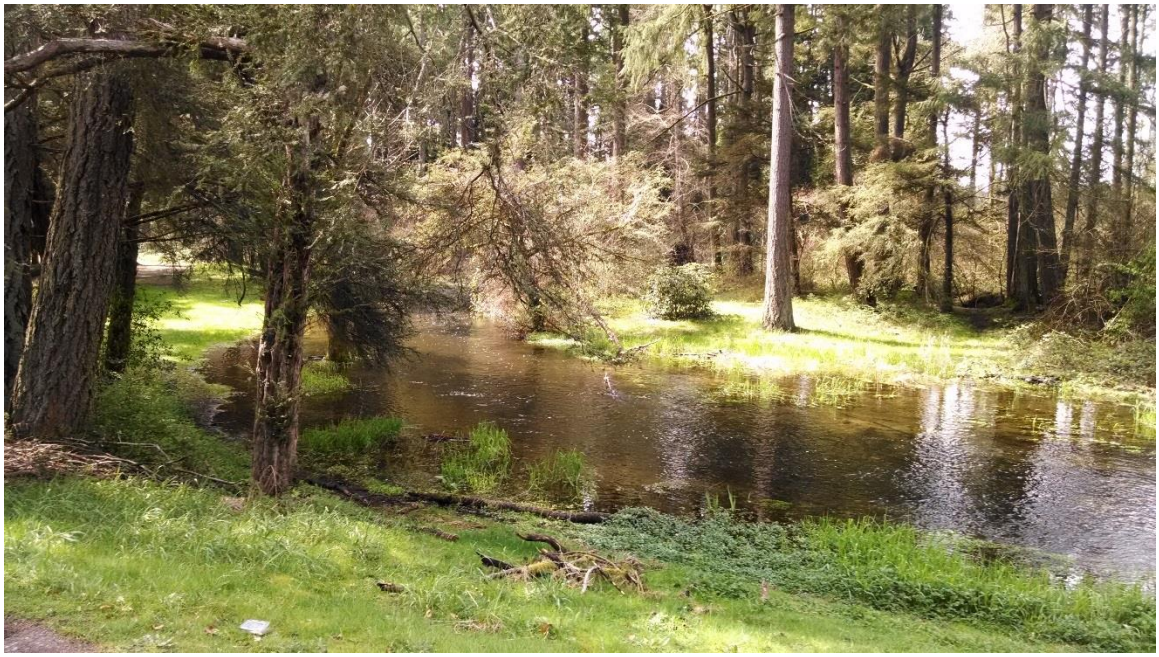


Figure 4. Photo taken between Spanaway Lake and Military Road in 2015 during previous field reconnaissance

The Manning's roughness in natural channels depends on bed material, geometric irregularities, variation in cross-section, vegetation, minor obstructions, and meandering (Chow 1959). A straight earthen channel could have a Manning's roughness as low as 0.020, while a highly irregular channel with dense woody vegetation could be as high as 0.090. These values were selected as bookends for the sensitivity analysis. However, Table 1 suggests that a more realistic range of roughness coefficients for Spanaway Creek would be from about 0.030 (very little vegetation) to about 0.070 (thick vegetation).

Table 1. Manning's Values for Low-gradient Natural Stream Channels (Chow 1959)			
Type of Channel and Description	Minimum	Normal	Maximum
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" with more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Section 3: Results

Figures 5 through 7 show water surface profile and cross-section plots from the HEC-RAS hydraulic modeling simulations with Manning's roughness coefficients ranging from 0.030 to 0.070.

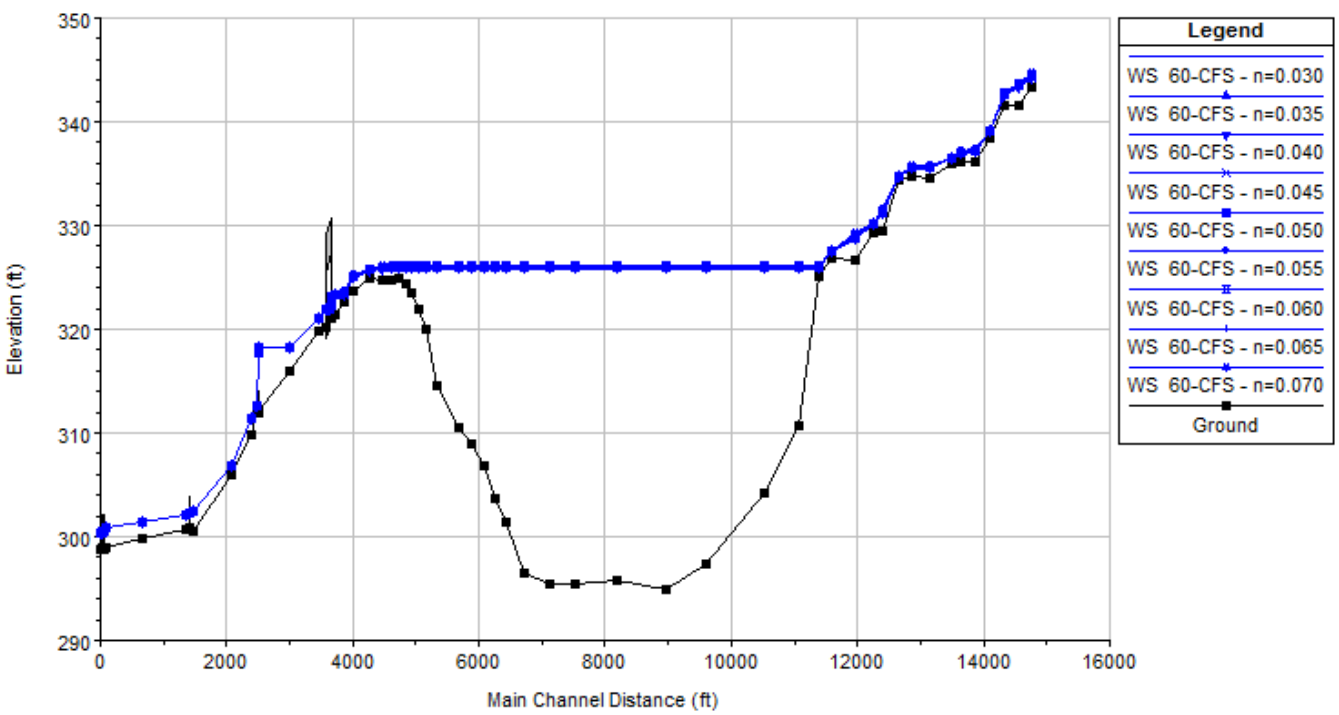


Figure 5. Water surface profiles for 60 cfs in Spanaway Creek

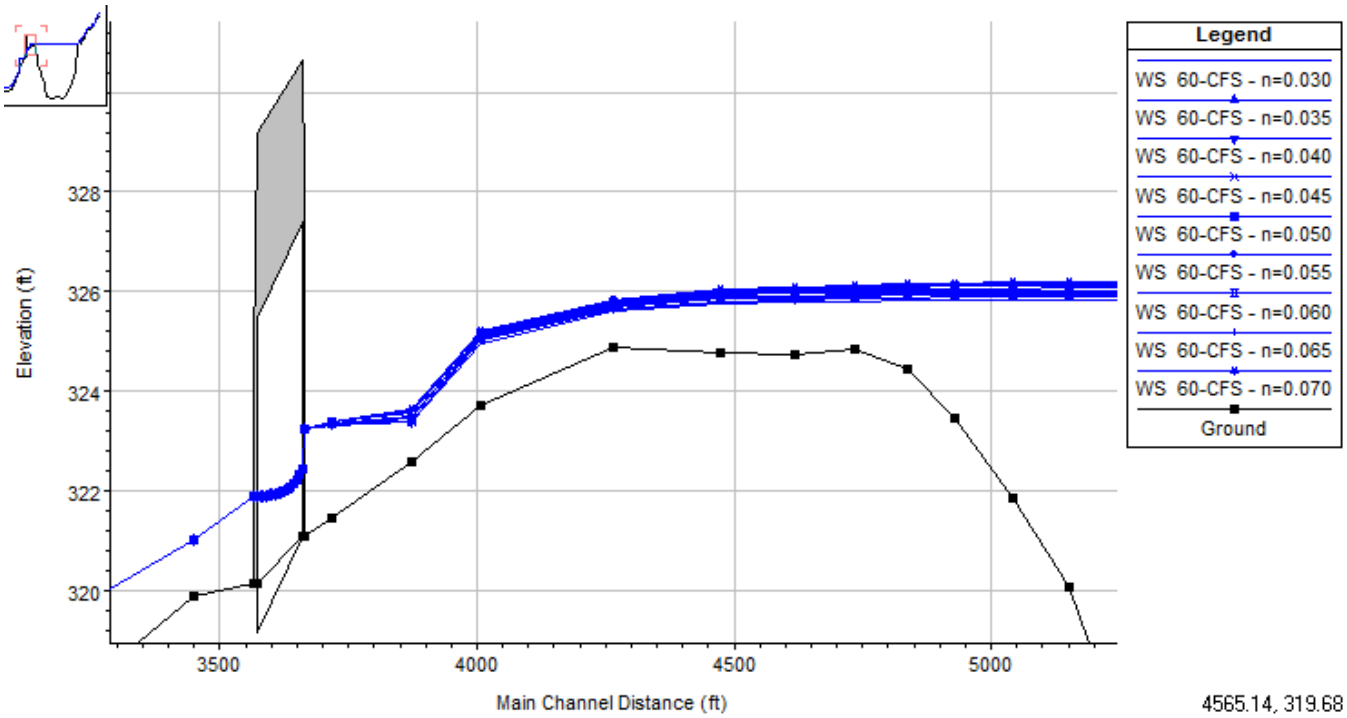


Figure 6. Water surface profiles for 60 cfs between Spanaway Lake and Military Road

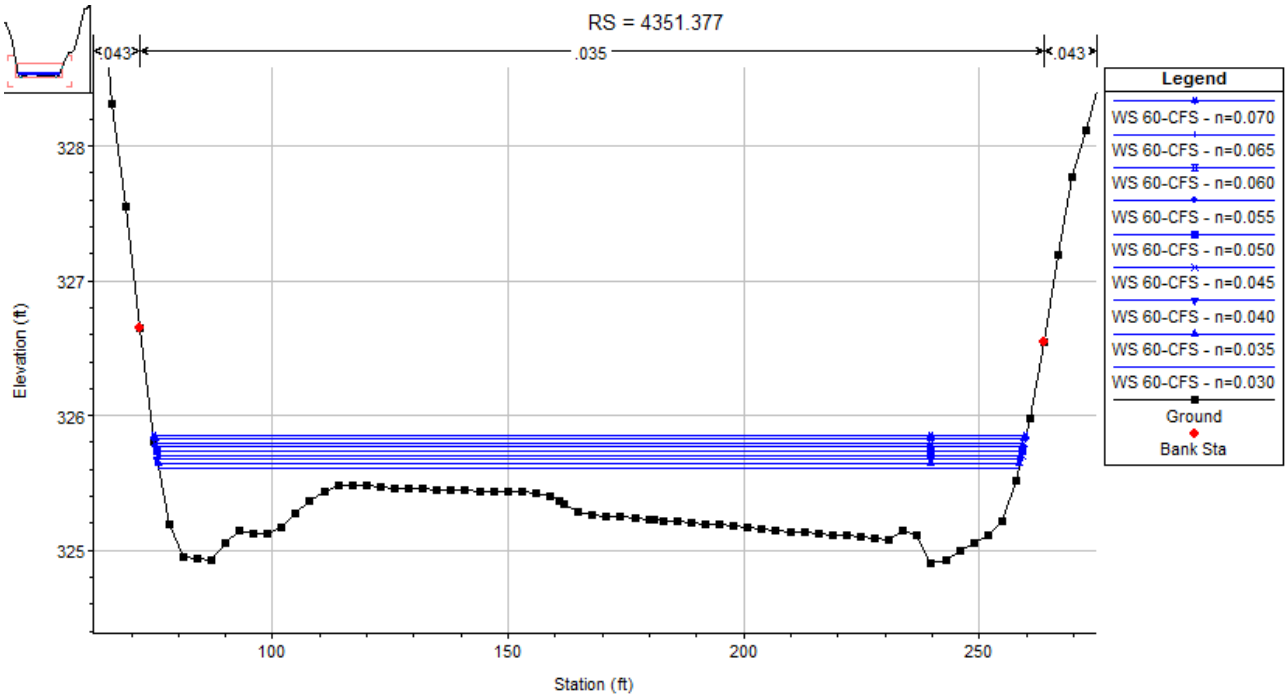


Figure 7. Water surface elevations for 60 cfs at Spanaway Lake Outlet

Hydraulic output from each of the simulations were processed and analyzed to examine the variability of water surface elevations in Spanaway Lake. Figure 8 shows the results for all discharges and the full range of Manning's roughness coefficients.

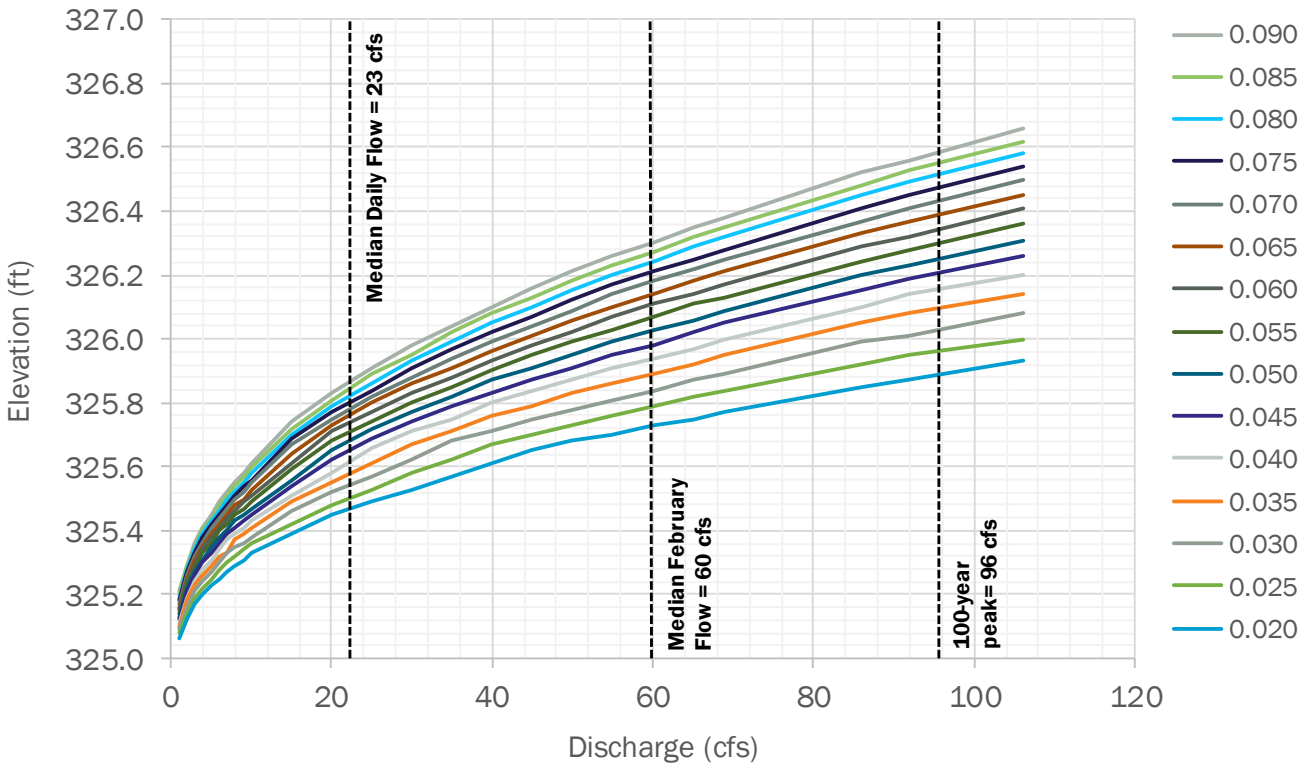


Figure 8. Variation in Spanaway Lake water surface elevation over a range of discharges

Another way to look at this variability is to isolate notable discharges and plot the variability in water surface elevations in Spanaway Lake with respect to changes in Manning's roughness (Figure 9).

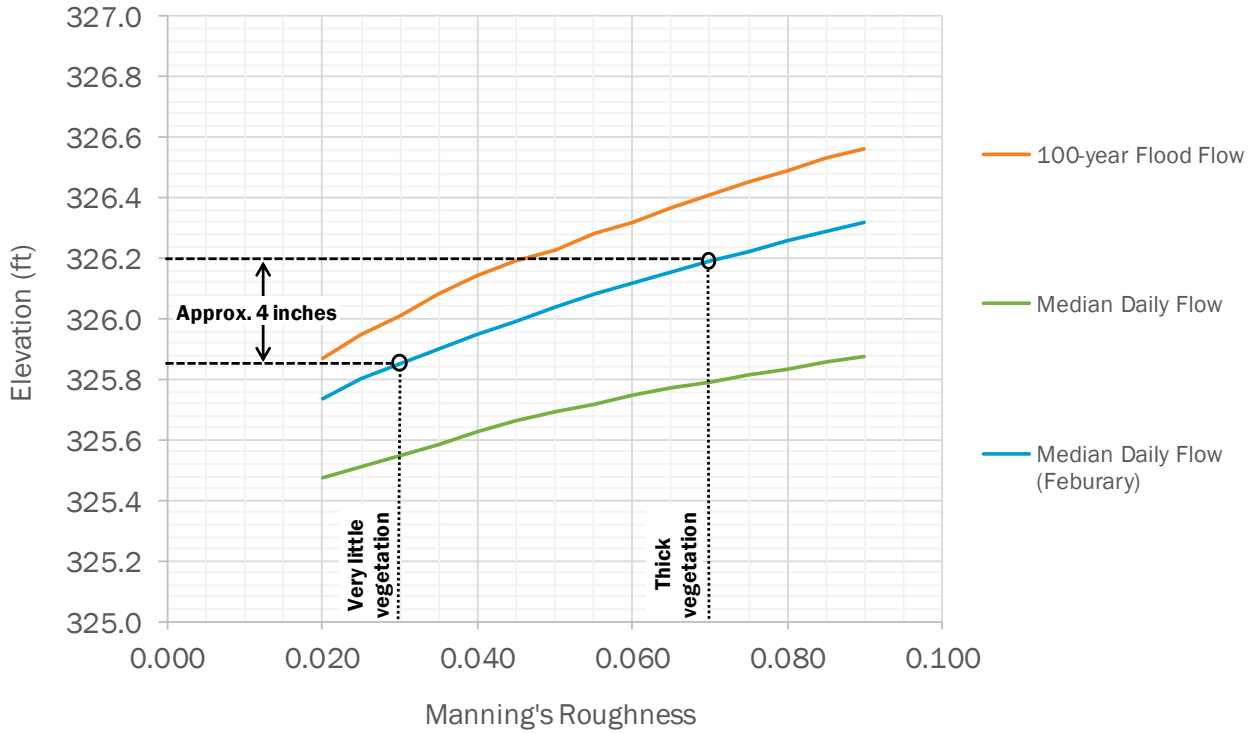


Figure 9. Variation in water Spanaway Lake water surface elevation over a range of Manning's roughness

The results for the median daily discharge for February (60 cfs) indicate that a change from thick vegetation to very little vegetation at the outlet could lower the water surface in the lake by about 4 inches.

Blockages

While Manning's roughness can account for factors other than vegetation (e.g., coarse bed material, geometric irregularities, variation in cross-section, minor obstructions), the above analysis assumes there are no large obstructions blocking the channel. Obstructions or blockages such as beaver dams could have a substantial impact on water levels, depending on the size and location of the obstruction. Profiles shown in Figure 6 suggest that blockages 600 to 1,200 feet upstream of Military Road will have a greater impact than blockages at Military Road because the latter is 3 to 4 feet lower than the outlet. Figure 10 shows an additional steady-state simulation for the median daily discharge for February (60 cfs), where the bottom 2 feet of the Military Road culvert are blocked and there is no appreciable change in lake level (Manning's roughness was kept constant at 0.045). In fact, the culvert would need to be blocked to a depth of roughly 2.5 feet to raise the water surface at the lake by about 0.1 feet during a 60 cfs discharge.

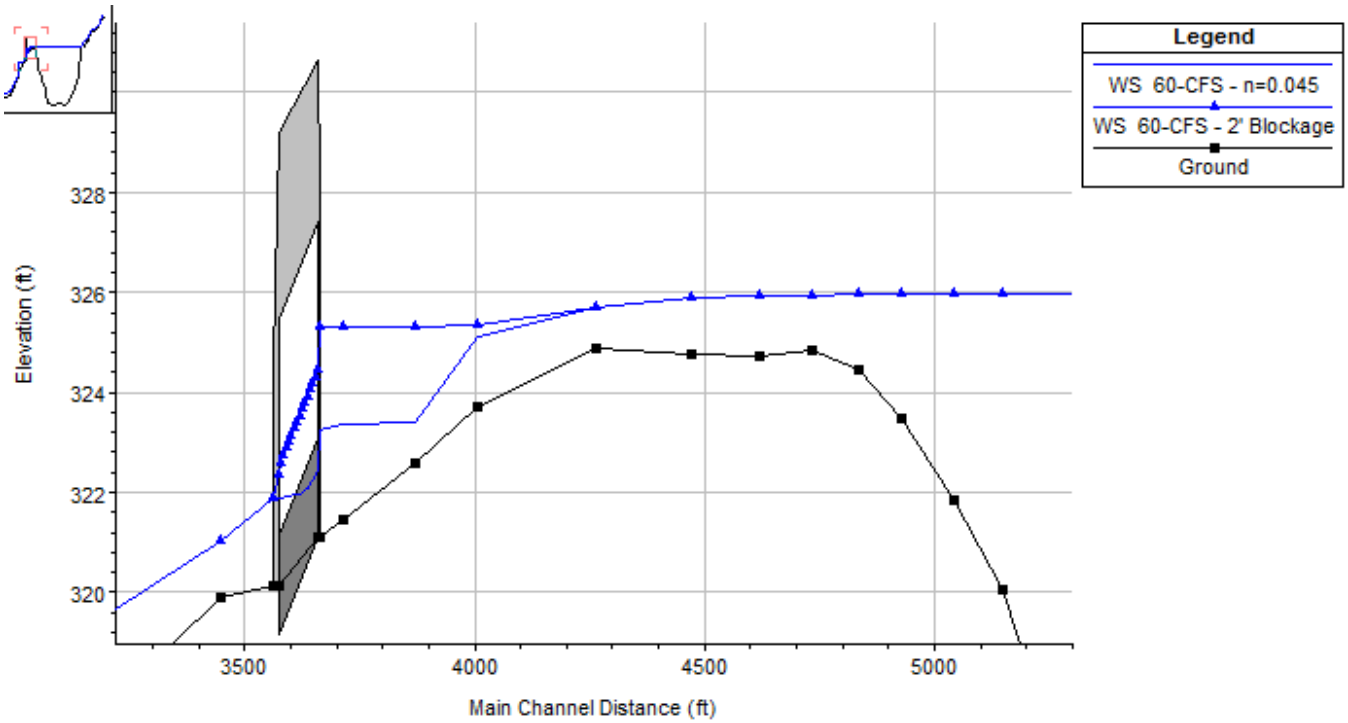


Figure 10. Water surface profiles showing 2-foot blockage at Military Road

Inundation

Continuing with the results for the 60 cfs scenarios, the project team performed inundation mapping using the digital elevation model created in ArcGIS to examine the potential change in lake area for a water surface change of 4 inches. The results indicated that the area inundated by the lake could increase by about 3 percent or roughly 8 to 10 acres. Figure 11 shows the results of the inundation analysis.

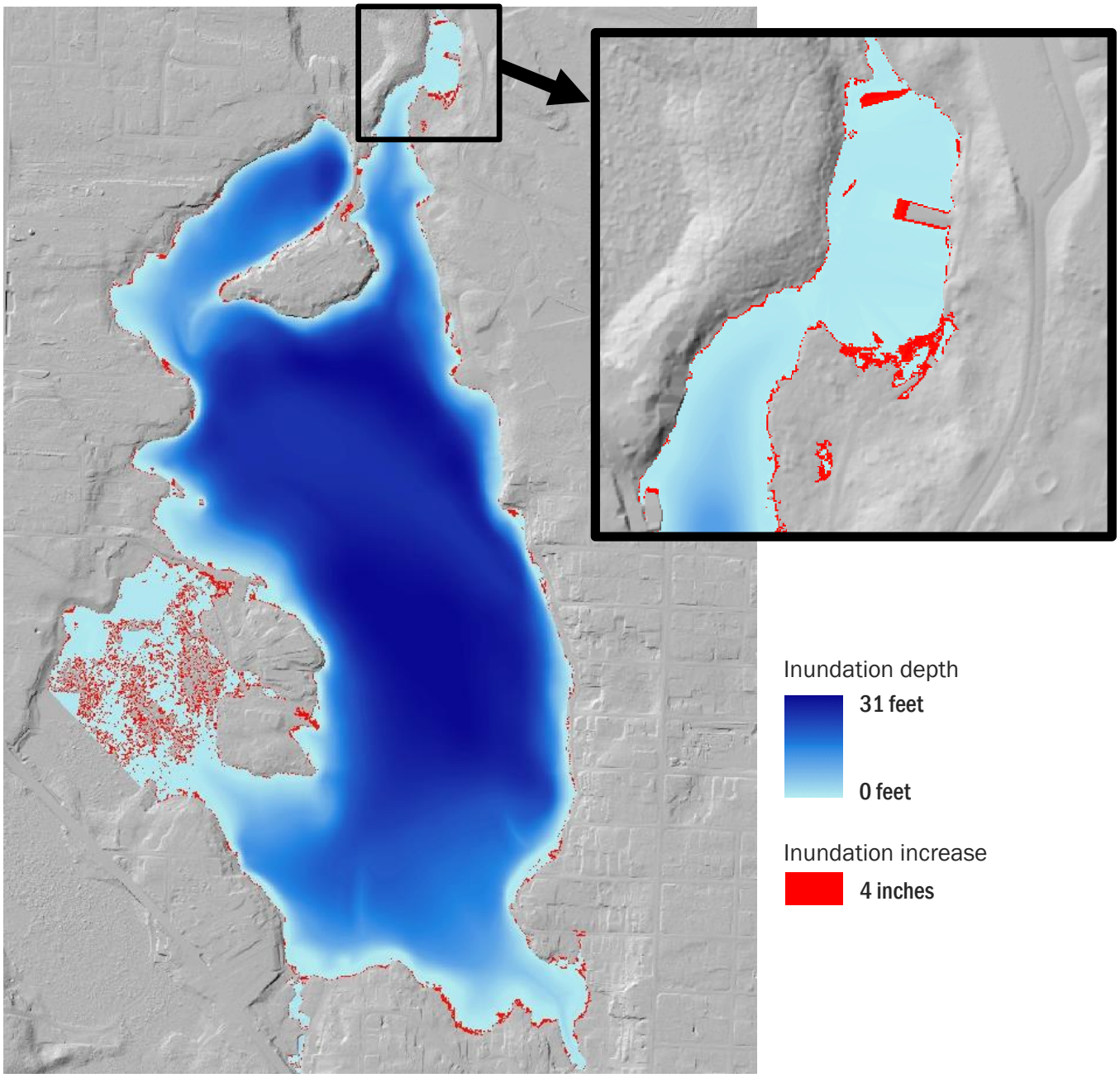


Figure 11. Inundation mapping for Spanaway Lake water surface at 60 cfs stream discharge
Inundation shown in blue represents depths for base condition; Manning's roughness at outlet = 0.030
Inundation shown in red represents increase for 4 inches higher; Manning's roughness at outlet = 0.070

An increase in the water surface elevation of the lake increases in hydraulic residence time. A theoretical residence time, T_r, based on an idealized or "plug flow" condition can be calculated as follows:

$$T_r = \frac{Volume\ of\ Lake}{Discharge}$$

Using this equation, the theoretical residence time was calculated for the full range of hydraulic conditions modeled in HEC-RAS. Figure 12 shows the relative increase in residence time starting from a base condition of Manning's roughness coefficient equal to 0.020. The results suggest that a change from thick vegetation to very little vegetation at the outlet could reduce the residence time in the lake by less than 2 percent (assuming a constant discharge of 60 cfs). This small increase in residence time is unlikely to adversely affect lake water quality.

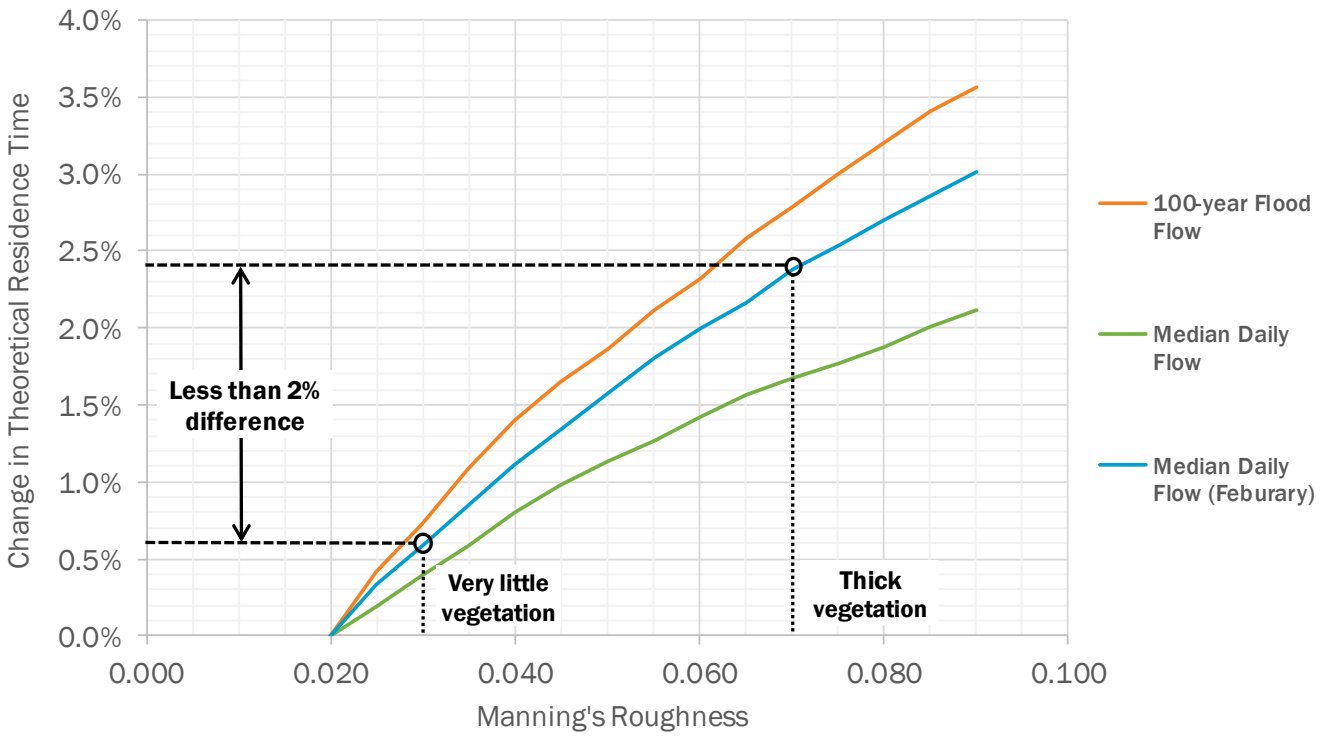


Figure 12. Change in theoretical residence time in Spanaway Lake due to water surface elevation increases associated with increased Manning's roughness at the outlet

Section 4: Conclusions

The preliminary hydraulic analysis described above indicates that lake elevations are primarily controlled by a shallow reach 600 to 1,200 feet upstream of Military Road (see Figures 6 and 10 above). Managing vegetation, debris, and minor obstructions in the lake outlet area could affect lake levels by about 4 inches, inundated area by about 3 percent, and lake volume by about 1 percent. It can also affect the amount of shoreline that is inundated. Given the small change in lake volume, this measure is expected to have little impact on hydraulic residence time. The decrease in inundated area might provide for a slight reduction in phosphorus loads from shoreline septic systems.

Substantial blockages within the channel could cause greater impacts, but it would greatly depend on the size and location of the obstruction. For example, a 2-foot blockage at the Military Road culvert would not affect lake levels because it is too far downstream.

County Parks has obtained the necessary permits and has begun implementing this measure. A bathymetric survey and a plant/debris survey of the outlet reach area should be performed to help Parks refine and focus its approach. The field survey should also look for remnants of the former bridge to assess whether they could be impeding lake outflow.

Section 5: References

United States Geological Survey in cooperation with the Washington State Department of Ecology (USGS and Ecology) (January 1976), *Reconnaissance data on lakes in Washington—Vol. 3, Kitsap, Mason, and Pierce Counties. Water Supply Bulletin 43, Volume 3*.

Fact Sheet: Aquatic plant management

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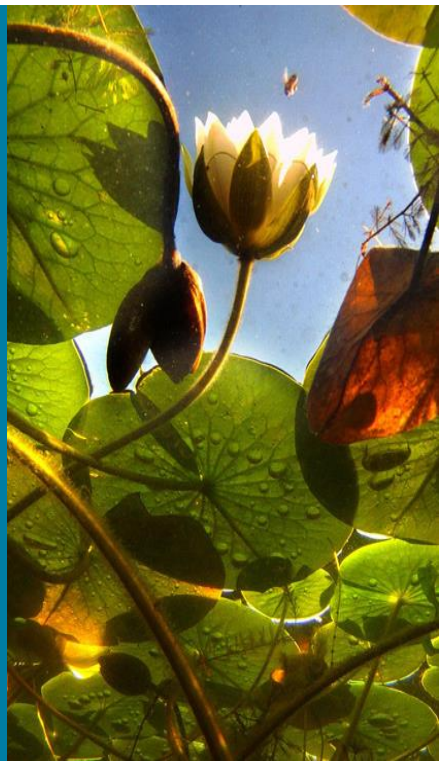
AQUATIC PLANT MANAGEMENT

Native aquatic plants are an essential component of a healthy lake ecosystem. Aquatic plants provide oxygen, food, and habitat for fish, zooplankton, waterfowl, and aquatic mammals. Fortunately, Spanaway Lake's plant community is composed mostly of beneficial native species, although two non-native, invasive species are also found in the lake (fragrant water lily and curly-leaf pondweed). Non-native plants can often spread aggressively and outcompete native species, harming lake recreation and ecology.

Aquatic vegetation management includes a variety of mechanical, chemical, and physical control methods. These methods are important lake management tools that must be used cautiously to avoid unintended consequences. For example, broad-scale control of vegetation can lead to algae blooms as plant matter decays and releases nutrients that fuel algae growth. Some methods provide short-term control, but can promote the spread of undesirable plant species.

Annual vegetation monitoring is recommended to provide the basis for informed plant management decisions, document plant community changes over time, and ensure rapid identification and response to any future non-native species infestations.



Aquatic Vegetation Harvesting

Aquatic vegetation harvesting includes techniques that range from hand-pulling of nuisance plants to large-scale mechanical cutting, collection, and offsite plant disposal. These techniques can provide effective but short-term control, immediately restoring open water in areas where plant growth impedes recreational uses such as swimming and boating. However, without careful application and management, aquatic vegetation harvesting can promote the spread and increase the future growth density of some nuisance plant species. For this reason, these techniques should be conducted only where appropriate based on a recent aquatic vegetation survey of Spanaway Lake that results in a detailed aquatic vegetation map and inventory of species in target areas.

Mechanical Harvesting

Mechanical harvesting involves the use of boats that are designed to cut and collect aquatic plants. Most harvesting machines are designed to cut plants from 4 to 8 feet below the water surface. Plants can be transported to shore for storage and disposal by the harvester, although using a separate transport barge can increase the efficiency of the cutting operation.

Mechanical harvester

This technique is most appropriate for plants that do not propagate readily from fragments. Harvesting may promote the re-growth and spread of milfoil and other aquatic species, which have the ability to propagate by fragments and can aggressively colonize new areas following disturbances due to plant management. It is important to have a detailed aquatic vegetation map and inventory of species in the target areas before conducting mechanical harvesting. This information will allow operations to focus on species and timing considerations that are best suited to harvesting, and to avoid unintended consequences such as the spread of non-native species.

Mechanical cutting is sometimes performed without collection and removal. This practice is not recommended. If not removed from the lake, decomposition of the cut plants can lead to impacts to dissolved oxygen, and also releases nutrients that can fuel nuisance algal blooms.

Re-growth of plants is expected after harvesting, just as a lawn is expected to re-grow after mowing. Some species are capable of re-growing to the water surface within several weeks of cutting. Although regular plant harvesting can sometimes shift the composition of a plant community, it typically does not reduce the density of growth in areas that have suitable depths and sediments for rooted aquatic plants.

Costs: Commercial harvesting costs vary depending on the target plant(s), density of growth, travel distance for disposal of harvested plants, and number of obstructions present. The harvesting cost per acre usually ranges from $450 to $700, including trucking and disposal. The cost per acre of harvesting is inversely proportional to the size of the area harvested; there is an economy of scale for larger projects. A cost range of $260 to $770 per acre for mechanical harvesting at typical densities and $1,200 to $2,500 per acre for very high densities of plants is suggested.

Hydroraking

A hydrorake is typically a paddle-driven boat with a York rake attachment used to rake the upper sediment layer, collecting plants and their root systems. The hydrorake is used in combination with a transport barge that brings the collected material to the shoreline for storage and disposal.

Hydrorake loading water lilies onto a barge for offshore disposal

The hydrorake is most effective at removing plants with large root systems, typically floating-leafed (such as pond lilies) and emergent species (such as cattails). Plants with slender stems and root systems that can pass between the tines of the hydrorake and re-root from fragments (such as milfoil) are not well-suited for control by this technique. By disturbing the sediment and uprooting plants, hydroraking results in a temporary increase in turbidity in the locus of operation.

Re-growth is expected following hydroraking, although the longevity of effectiveness can vary considerably depending on the species composition of the target area. For example, multi-year control of water lilies can be achieved by breaking up and removing the large rhizomes of these plants. Other species may have regrowth rates similar to those achieved by mechanical harvesting.

Costs: Costs for hydroraking range from about $1,900 to $5,000 per acre for submerged plants and $7,000 to $12,000 per acre for emergent growths, large floating mats, and dense root masses. As with mechanical harvesting, per-acre costs tend to be lower for larger projects.

Diver Hand-Harvesting/Diver-Assisted Suction Harvesting (DASH)

Hand harvesting is conducted by divers who pull targeted aquatic plants, place them in collection bags, and remove them from the lake. Plants should be pulled out with their entire root structure to minimize the potential for plant re-growth.

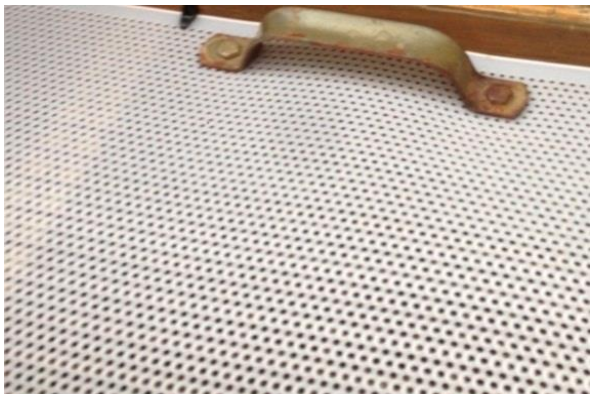
A diver feeds Eurasian milfoil into a vacuum hose.

Diver-assisted suction harvesting (DASH) is conducted by divers who pull plants and root masses by hand and feed them into a boat-mounted vacuum hose for later disposal.

The cost of hand harvesting and DASH varies widely on a per-acre basis because the rate at which divers can harvest an area varies greatly depending on the density of plant growth, stem height, and substrate composition. Water bodies with highly flocculent sediments will become turbid very quickly as plants are pulled, making it difficult for divers to see what they are doing and slowing the rate of harvesting.

Because of the labor-intensive nature of these techniques, they are most appropriate for use in very small areas where pioneer infestations have been identified, or where other plant control techniques are neither permittable nor feasible. For new and small areas of infestation, diver hand harvesting can be an effective and relatively low-cost control technique. DASH has proved to be an effective technique for somewhat larger areas. The risk of plant fragmentation associated with DASH boat operation can be reduced by incorporating controls such as the following:

1. Water and plants pumped to the collection boat should be filtered through a mesh with a maximum opening size no greater than 0.125 (1/8) inch to separate plant material from water discharged off the boat. The screen should be cleared regularly as needed to prevent clogging and allow return water flow. No plant fragments should be discharged back to the lake.



1/8-inch polyethylene mesh screen installed in a DASH boat to filter plant fragments

2. A moveable silt/fragment curtain suspended in the water from the surface to the lake bottom can be used to prevent plant fragments from spreading beyond the plant removal areas. The silt/fragment curtain should be placed to either surround the DASH work area or provide a horseshoe shape around the downstream side of the area.

Costs: Costs vary widely ($4,000 to $10,000 per acre), based on plant density, sediment type, and project area. For new infestations with moderate growth, the lower end of this cost range ($4,000 to $7,000 per acre) is expected.

Herbicides/Algaecides

Although it is a powerful tool for plant and algae control, the use of herbicides and algaecides can be controversial because of perceptions regarding toxicity to humans and non-target organisms. All aquatic herbicides approved for use in Washington are regulated by the Washington Department of Ecology (Ecology). For a more complete discussion of this complex topic, see Ecology's *Fact Sheet for the Aquatic Plant and Algae Management NPDES General Permit*.

Herbicides and algaecides (referred to in this fact sheet as herbicides) contain active ingredients that are toxic to target plants. Herbicides are typically classified as contact or systemic herbicides:

- Contact herbicides are toxic to plants by uptake in the immediate vicinity of external contact, which typically excludes the root system. Contact herbicides tend to be relatively fast-acting, and can often be used to "spot-treat" target areas, leaving other areas of a lake untreated.
- Systemic herbicides work more slowly than contact herbicides because they require uptake throughout the entire plant and its root system. Because they require longer exposure time (up to 30 to 40 days), some systemic herbicides are not well-suited to spot-treatments and may require booster applications to offset dilution during the application period. Systemic herbicides can provide more effective control of perennial plants because they kill the entire plant under favorable conditions. Re-growth from seeds should be expected following use of both contact and systemic herbicides.

Herbicides are also classified as selective or broad-spectrum, based on whether the dose and formulation of the active ingredient will control a targeted or broad range of plant species:

- Broad spectrum herbicides, as implied by the name, tend to kill a wide range of aquatic plant species. Contact herbicides tend to be broad-spectrum in their effects, but can show some selectivity based on dose and plant features.
- Selective herbicides are more effective on certain plant species than others, with the degree of selectivity dependent on dose. Even selective herbicides can kill most plant species if applied at high rates.

Ecology currently issues permits for seven aquatic herbicides and two algaecides for aquatic plant treatment for lakes, rivers, and streams. Detailed information about each active ingredient can be found at: http://www.ecy.wa.gov/programs/wq/pesticides/seis/risk_assess.html.

Any application of herbicide in Spanaway Lake should carefully consider both short-term and long-term aquatic plant management goals. Repeated herbicide treatments may alter the composition of a plant community over time by giving a competitive advantage to species that either are less susceptible to the active ingredient or are better suited to colonizing new areas that have been opened up by the treatments. Such shifts can be beneficial in some cases, although it can also result in a dominant plant community that is even more of a nuisance than the original target species. For this reason, it is important to have a complete inventory of plant species present in the target areas, and to use this information as the basis for a long-term plant management strategy.

Other Techniques

Benthic Barriers

Similar to landscaping weed control fabrics, benthic barriers control aquatic plants by blocking sunlight and providing a physical barrier that blocks growth. These sediment-covering materials include solid and porous forms of polyethylene, polypropylene, fiberglass, and nylon. Benthic barriers can provide effective control of small, dense patches of nuisance vegetation, but are not cost-effective or feasible for large areas. Benthic barriers are typically used in small recreational areas, such as beaches and boat launch areas.

Installation of a benthic barrier

Biological Control

Biological control involves the introduction of organisms such as fish, insects, and pathogens to control nuisance plants or algae. Although biological control can reduce nuisance species, it can also cause unintended impacts to non-target species. The safest biocontrol techniques use native and naturally occurring biocontrol agents. Biocontrol methods used in Washington lakes includes triploid grass carp and native milfoil weevils (*Euhrychiopsis lecontei*). Triploid (sterile) grass carp are stocked to lakes to feed on vegetation. Permits are most readily obtained if the lake or pond is small, privately owned, and has no inlet or outlet. Spanaway Lake does not meet these criteria.

Milfoil weevil

The milfoil weevil is a native plant-eating insect that provides species-specific control of Eurasian milfoil. Adult weevils and larvae feed on milfoil leaves, while the larvae also damage the plant and slow its growth by burrowing through the plant stems. Spanaway Lake does not have Eurasian milfoil at this time.

Lake Level Drawdown

Lake level drawdown

Drawdown for the control of aquatic vegetation involves lowering a lake's water level during fall and winter to expose vegetation. Drawdown can be achieved by pumping, siphoning, or releasing water from a dam. Drawdown works best when plants are exposed to cold climate winter conditions for at least 6 to 8 weeks. This exposure damages the plants by desiccation and by freezing of plant over-wintering structures and root systems. This technique is not effective on all aquatic species, and can result in increased growth of some species. However, drawdown can provide effective control of some common nuisance species (e.g., Eurasian milfoil) that rely on vegetative propagules for overwintering and expansion.

Dredging

Dredging is a costly but effective technique to deepen shallow lake areas for control of excessive aquatic vegetation. To control vegetation, dredging must either (1) remove nutrient-rich organic sediments and reach a mineral, nutrient-poor sediment or (2) deepen the lake to a "light-limiting" depth that prevents plant growth. This target depth will vary considerably based on a lake's water clarity, but is usually at least 10 feet. Dredging projects are subject to significant and expensive state and federal permitting requirements.

Dredging

In summary, for funding evaluations, the following was assumed for this measure:

- Initial cost = $12,000. This is the estimated cost to perform a plant survey and prepare a field guide for volunteers.
- Ongoing cost = $16,500. This assumes removal of aquatic plants from 5 acres per year at an average cost of $3,500 per acre.

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Fact Sheet: Waterfowl management

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WATERFOWL MANAGEMENT

Waterfowl, including geese and ducks, can be a significant source of bacteria for lakes. The sections below discuss various methods for managing waterfowl with lake water quality in mind. A survey of Spanaway Lake's waterfowl population, including resident and migratory flocks, feeding patterns, and nesting habits, would provide the necessary information to develop a management strategy.

Landscaping/Physical Barriers

Grassy areas adjacent to water (particularly open areas visible from above) are attractive to waterfowl as areas for grazing. As described below, grassy areas within and adjacent to public beaches can be modified to make the site less attractive to waterfowl.

- Plant trees and shrubs to create a visual and physical barrier between open water and grassy feeding areas. Native vegetation can also be used to obscure escape routes from predators, making the area feel less safe and less appealing to waterfowl.
- Allow grass to grow taller. Waterfowl do not like to walk through tall grass.
- Reduce open grassy areas by planting ground cover (e.g., pachysandra) or convert a lawn to a wildflower meadow. Geese do not like to eat or walk through such plantings.
- Remove grass that has encroached on the beach area and re-surface with 3 inches of screened, washed beach sand. Where possible, a 20- to 25-foot minimum width for beach sand is recommended.
- Fences and other physical barriers can be effective tools to restrict waterfowl movement. In most situations, waterfowl tend to walk, not fly, to and from water to feed. A low fence or other barrier to prevent access may discourage waterfowl from accessing a beach/day-use area.

String fencing can be an effective deterrent, particularly when geese have flightless goslings or during the molting season.

- Temporary fencing can be installed around a beach area (e.g., prior to the summer beach season or after hours) to discourage bird access to adjacent grassy areas for grazing. Sectional "string" fencing systems are designed to discourage waterfowl. These systems use narrow posts and retractable strings, creating minimal visual disruption while discouraging the passage of waterfowl. If needed, this type of fencing could be kept in place from early spring through the end of the summer beach season and used to fence an entire day use area.

Geese and ducks prefer grazing in grassy areas that offer unobstructed access from the water. The "goose buffer" shown to the right was installed at a state park. As the shrubs mature, they provide a visual and physical barrier between the lake and the grassy areas of the state park beach, while also protecting water quality by filtering stormwater runoff.

Goose buffer

Deterrents/Scaring Techniques

Feeding deterrents can be an effective way to discourage waterfowl from grazing. Several products are available to deter waterfowl from feeding on grassy areas. ReJex-iT is a non-toxic grape juice derivative that makes grass unpalatable to waterfowl. Grassy areas can be treated with a spray applicator. Repeat applications are required after rain.

Visual and audio deterrents are used to make waterfowl feel unsafe at a site, usually through the use of decoys or sounds that mimic the presence of a predator. Although these types of deterrents can be effective, results tend to diminish quickly as geese become accustomed to their presence.

Visual and audio deterrents work best in combinations with each other and with other deterrents. Visual deterrents include predator decoys (e.g., fox, coyote), kites, Mylar tapes, and balloons. Audio deterrents (e.g., recorded distress calls, predator calls, explosive noises, and propane cannons) are generally not appropriate for residential areas or park settings.

Trained border collies can be used during the spring to discourage nesting and summer to disrupt the regular feeding patterns of local flocks. Although effective, this technique is expensive and is not likely to be feasible in most areas as an ongoing management strategy.

A trained border collie can discourage resident flocks and nesting.

Depredation Permits

In extreme cases where waterfowl droppings pose a persistent threat to public health and safety, a depredation permit from the U.S. Fish and Wildlife Service may be sought to reduce a goose population by egg addling or shooting outside of the permitted hunting season. A depredation permit is not needed to harass birds (without causing nest abandonment) or to destroy inactive nests.

In extreme cases, waterfowl droppings can pose a persistent threat to public health and safety.

For more information on depredation permits, go to:

www.fws.gov/pacific/migratorybirds/permits/dprd.html

Public Outreach

Geese and ducks tend to gather in areas where humans feed them and can become a major source of bacteria. Public education signage and other forms of outreach can be used to convey the following message:

- It is important to enjoy viewing wildlife responsibly by allowing wildlife to maintain a healthy, natural diet.
- Bread and snack food is harmful to waterfowl. These foods lack the roughage and nutrients of a natural diet and can lead to malnutrition.
- 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.

In summary, for funding evaluations, the following was assumed for this measure:

- Initial cost = $5,000. This is the estimated cost to support initial survey by volunteers.
- Ongoing cost is to be determined. This measure assumes that program would be implemented primarily by private property owners and volunteers, with limited support from County staff.

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Fact Sheet: Public education and outreach

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LAKE EDUCATION PROGRAM

A lake education program will aim to inform, teach, and change traditional lakeshore property management practices to behaviors that protect lake water quality. Through this program, the community will receive information on best lake-shore management practices (such as septic tank maintenance, natural yard care, and green cleaning), incentives for participating in the program, direct technical assistance with site visits, and volunteer opportunities to benefit the lake.

The Lake Management Plan recommends ongoing lake education and awareness efforts to aid in protecting water quality over the long-term. *The initial step will be to conduct specific research to determine what the targeted audience will positively respond to in advance of implementation in order to select the best methods of communication and areas of focus for the community.* After that initial step, the specific measures that could be considered are:

LakeWise Program

The County will review and update Lake Wise materials for the County's use and in response to audience research, which could include developing and purchasing Lake Wise signage, printing copies of the PCDs Lake Book, updating the signage checklist and ordering printed materials. This program will also include direct mailing to promote Lake Wise program rollout and advertisement of workshops. The County will hold workshops in the community, one for stormwater/yard care and another for septic systems. The County will also offer incentives for participating in the Lake Wise program, such as offering Lake Wise certification signage and technical assistance visits. These technical assistance visits can include:

- Verify LakeWise checklist activities completed
- SWM drainage/stormwater site visits
- Install pet waste stations

This part of the program, including audience research, is estimated to have a one-time cost of $30,000 and an annual cost of $9,000 for the County.

Conduct Shoreline Visits

The County, in collaboration with the Pierce Conservation District, will conduct shoreline site visits and identify best management practices (BMPs) and potential shoreline restoration projects. This effort can include developing an inventory and prioritizations of sites to be funded by future projects, offering planting plans to homeowners and giving away pet waste equipment. This part of the program is estimated to cost the County approximately $10,000 per year.

Assess Education/Outreach Effectiveness

This part of the program will assess the educational and outreach effectiveness with pre- and post-workshop questionnaires or via direct mailing. This part of the program is estimated to cost the County approximately $2,000 per year.

Coordinate with Other Programs

The education and outreach program will need to be coordinated with two other programs proposed as part of the Lake Management Plan; the establishment of the Spanaway Lake Committee and ongoing lake monitoring. The education and outreach program will be used to communicate Committee activities, advertise volunteer monitoring opportunities, and share monitoring program findings. This part of the program is estimated to cost the County approximately $2,000 per year.

In summary: Public education and outreach cost = $30,000 first year costs + $23,000/yr.

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Fact Sheet: Spanaway Lake monitoring, focused monitoring and long-term monitoring

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SPANAWAY LAKE MONITORING: FOCUSED AND LONG-TERM

With proper training and a modest investment in sampling equipment, volunteers can conduct lake monitoring that contributes to the scientific understanding of lake conditions, provides historical context for water quality trends, and allows for early detection and response to new threats such as invasive, non-native plant species.

Water Quality Monitoring

Continued monitoring of in-lake and tributary phosphorus concentrations will provide the most direct means of evaluating the effectiveness of measures to reduce phosphorus loading and associated algae blooms in Spanaway Lake.

Kemmerer grab sampler

- A monthly monitoring program should extend from early spring through late fall, in order to document seasonal variations that occur when the lake stratifies thermally in the summer.
- Sampling should focus on perennial tributaries and the lake's "deep hole" locations. Deep hole sampling should include samples from the lake surface, middle, and bottom using a grab sampler, which will allow for a more precise understanding of internal "phosphorus recycling" that occurs in the summer, when low dissolved oxygen levels (anoxia) cause bottom sediments to release phosphorus into the water and fuel algae.

Secchi disk

- Deep hole sampling should be combined with "in situ" measurements of temperature and dissolved oxygen using a water quality probe. This data will supplement understanding of the summer anoxia conditions that lead to phosphorus recycling and will also measure conditions that affect habitat quality for fish and other aquatic biota.
- Water clarity measurements with a Secchi disk provide an easy and inexpensive way to track conditions associated with algal abundance.

Annual costs for equipment rental and laboratory analytical fees are estimated at $3,500 - $4,500, assuming a 7 month (April-October) monitoring season. A less intensive program (3 times per year in late May, mid-July, and late September) would cost $1,500 - $1,900. A more intensive one-time effort to determine internal phosphorus loading would require sampling deep hole sampling (assumes 2 sampling stations) twice per month from April-October, at an estimated cost of $7,000 - $9,000.

Sediment Sampling

Ekman dredge sampler

Sediment grab sampling can be conducted with a clamshell-style Ekman dredge sampler or similar device. This kind of sampling allows for lab analysis of the top layer of lake sediments. Nutrient analysis of sediment can be used to estimate the rate at which it releases phosphorus into the water during periods when dissolved oxygen levels are low. One-time sampling of this type could be conducted during other deep hole sampling activities, with equipment rental and lab costs estimated at $300.

Sediment depth mapping is also conducted in lakes to determine the volume and type of organic substrate that is present, often to support the development of cost estimates and designs for lake dredging to restore depth. Costs for such investigations vary based on area being mapped and the extent of lab analysis required for sediments. Dredging is not recommended for Spanaway Lake at this time.

Aquatic Vegetation Monitoring

Annual vegetation monitoring is recommended to provide the basis for informed plant management decisions, document plant community changes over time, and to ensure rapid identification and response to future non-native species infestations that may occur. To aide volunteer aquatic plant monitoring efforts, the Washington Department of Ecology (Ecology) has developed the *Aquatic Plant Identification Manual for Washington's Freshwater Plants*, available at www.ecy.wa.gov/Programs/wq/plants/plantid2/. A variety of additional DOE resources related to aquatic plant monitoring can be found at: www.ecy.wa.gov/programs/eap/lakes/aquaticplants/.

If conducted by a consultant, the cost for an inventory and mapping of the lake's aquatic vegetation is estimated at $7,000 - $8,500, including recommendations for vegetation management. This kind of survey could potentially be conducted every 3-5 years and supplemented with annual volunteer monitoring by trained volunteers.

Wildlife Inventories

Wildlife investigations for lakes can include a wide range of biota, such as mammals, fisheries, waterfowl, and macroinvertebrates. These investigations are conducted for a variety of reasons, but are often in support of a specific management goal (e.g., fisheries inventory in support of maintaining a sport fishing population) or regulatory requirement (e.g., rare species investigation to determine potential impacts associated with aquatic vegetation control).

The Spanaway Lake Management Plan has identified the need for a better understanding of the lake's waterfowl population. Waterfowl, including geese, ducks, and cormorants, can have an impact on lake water quality in areas where droppings from large flocks may contribute significant amounts of nutrients and bacteria. An inventory of Spanaway Lake's waterfowl population, including resident and migratory flocks, feeding patterns, and nesting habits, would provide the necessary information to determine if problem areas exist and develop a management strategy. The cost for a baseline waterfowl population inventory is estimated at $6,000 - $8,000, although this work could also be performed by volunteers.

Algae Monitoring

In recent years, an increase in the occurrence of nuisance algae blooms has been one of the most notable and visible symptoms of the nutrient enrichment and declining water quality of Spanaway Lake. Continued monitoring of the abundance and composition of the lake's algal community will provide a useful metric for understanding water quality trends in response to implementation of the measures recommended in Spanaway Lake Management Plan. The estimated cost for lab analysis of algae (species identification and enumeration) during the summer months (June-September) is approximately $1,000.

Bathymetry

A detailed bathymetric map (map of lake depths) provides important information that helps to explain a variety of lake conditions and supports the scientific basis for management recommendations. For example, bathymetry data is used to determine the likely zones for rooted aquatic plant growth, to calculate lake volume and "turnover rate" (the frequency with which the lake's water is fully replaced by new incoming water) as needed for water quality modeling, and to determine the depth zones where summer anoxia may occur.

Bathymetry data for Lake Spanaway is currently very limited. A one-time effort to develop a more detailed bathymetric map is highly recommended. This could be done by a consultant or by volunteers using a boat-mounted depth-finder with global positioning system (GPS) function. If conducted by a consultant, an estimated cost range of $12,000 - $14,000 is anticipated.

In summary, the costs for this management measures are as follows:

- Focused: One-time monitoring costs to fill data gaps = $13,000 for bathymetric survey, $2,000 for equipment, $7,000 to $9,000 for internal phosphorus load sampling, plus $1,000-$2,000 for sediment sampling = $26,000
- Long-term monitoring cost = $27,000 for labor (FTE) plus $6,000 for equipment rental and lab costs = $33,000/yr. The $6,000 estimate assumes:
    - Monthly monitoring from early spring through late fall

- Sampling in Coffee Creek and the lake's "deep hole" locations, including samples from the lake surface, middle, and bottom using a grab sampler
- Deep hole sampling combined with "in situ" measurements of temperature and dissolved oxygen using a water quality probe.
- Water clarity measurements with a Secchi disk to track conditions associated with algal abundance.
- Algae sampling during summer.