

**DRAFT APPENDIX C:
SPANAWAY LAKE WATERSHED-SCALE PLAN
WATERSHED CHARACTERIZATION**

AUGUST 2017



piercecountywa.org/swm

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DRAFT APPENDIX C:

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List of Abbreviations

°C	degree(s) Celsius	ND	non-detect
°F	degree(s) Fahrenheit	NLCD	National Land Cover Database
7-DAD _{Max}	7-day average of daily maximum temperature	NPDES	National Pollutant Discharge Elimination System
µg	microgram(s)	NRCS	Natural Resources Conservation Service
BC	Brown and Caldwell	OSDS	onsite sewage disposal system
BCG	Biological Condition Gradient	Permit	Phase I Municipal Stormwater Permit for Western Washington
B-IBI	Benthic Index of Biotic Integrity	PSRC	Puget Sound Regional Council
cfs	cubic foot/feet per second	PSSB	Puget Sound Stream Benthos
cfu	colony-forming unit(s)	QAPP	Quality Assurance Project Plan
County	Pierce County	RCW	Revised Code of Washington
DO	dissolved oxygen	RSMP	Regional Stormwater Monitoring Program
Ecology	Washington State Department of Ecology	SOW	scope of work
EPA	U.S. Environmental Protection Agency	SSURGO	Soil Survey Geographic (database)
EPT	Ephemeroptera-Trichoptera-Plecoptera	State	Washington State
GIS	geographic information system	STI	straight-to-implementation
H&H	hydrologic and hydraulic	SWM	(Pierce County) Surface Water Management
HPC	high pulse count	TMDL	total maximum daily load
HPD	high pulse duration	TP	total phosphorus
HPR	high pulse range	TPCHD	Tacoma-Pierce County Health Department
HRT	hydraulic residence time	TSS	total suspended solids
HRU	hydrologic response unit	UGA	urban growth area
HSPF	Hydrological Simulation Program-Fortran	USGS	U.S. Geological Survey
ID	identifier	WAC	Washington Administrative Code
JBLM	Joint Base Lewis-McChord	WDFW	Washington Department of Fish and Wildlife
L	liter(s)	WERF	Water Environment Research Foundation
LMP	Lake Management Plan	WQI	water quality improvement
LPC	low pulse count	WRIA	Water Resource Inventory Area
LPD	low pulse duration	WSP	Watershed-scale Stormwater Management Plan
mg	milligram(s)		
mL	milliliter(s)		
MS4	municipal separate storm sewer system		
NA	not applicable		

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SECTION 1: INTRODUCTION

The Phase I Municipal Stormwater Permit (Permit) covers discharges from large and medium National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer systems (MS4s), including Pierce County (County). Special Condition S5.C.5.c of the Permit requires watershed-scale stormwater planning to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support “existing uses” and “designated uses.” For the County, the Permit requires watershed-scale stormwater planning in the Clover Creek watershed or an alternative watershed that meets the following criteria:

- Has a drainage area of at least 10 square miles [S5.C.5.c.i(1)]
- Is partially or wholly within the County’s existing MS4 service area with discharges to the stream [S5.C.5.c.i(2)]
- Has a stream system that has been impacted by development but retains some anadromous fish resources [S5.C.5.c.i(3)]
- Is targeted to accept significant population growth and associated development, and is partially, if not fully, within the urban growth area (UGA) established under Revised Code of Washington (RCW) Chapter 36.70A, or a potential future expansion of the UGA [S5.C.5.c.i(4)]

The County selected the Spanaway Lake watershed, which is a tributary to Clover Creek. Figure 1-1 shows the Spanaway Lake Watershed-scale Stormwater Management Plan (WSP) planning area.

The County sent the Washington State (State) Department of Ecology (Ecology) a draft scope of work (SOW) for developing the Spanaway Lake WSP. The County revised the SOW in response to Ecology comments on the draft. Ecology approved the County’s revised SOW in August 2014.

The SOW called for an assessment of hydrologic, biologic, and water quality conditions and the status of the aquatic community within the Spanaway Lake WSP area. The County reviewed available data and determined that additional monitoring was needed to support WSP development. The County developed a *Quality Assurance Project Plan* (QAPP) to guide WSP monitoring. Appendix A of the WSP contains the QAPP.

The QAPP called for monitoring streamflow, surface water quality, groundwater quality, and benthic macroinvertebrates in the Spanaway Lake WSP area. The monitoring focused on the parameters identified in Special Condition S5.C.5.c and the Ecology-approved SOW, i.e., streamflow, water temperature, dissolved copper, dissolved zinc, fecal coliform bacteria, and benthic macroinvertebrates.

The County performed the Spanaway Lake WSP monitoring between October 2014 and March 2016. This appendix describes the monitoring results. Section 2 provides a brief overview of the WSP planning area. Section 3 summarizes the WSP monitoring methods. Section 4 presents the WSP monitoring results, key findings in light of the WSP objectives, and relevant data from Ecology's October 2016 *Clover Creek Assessment* report (Ecology 2016a).

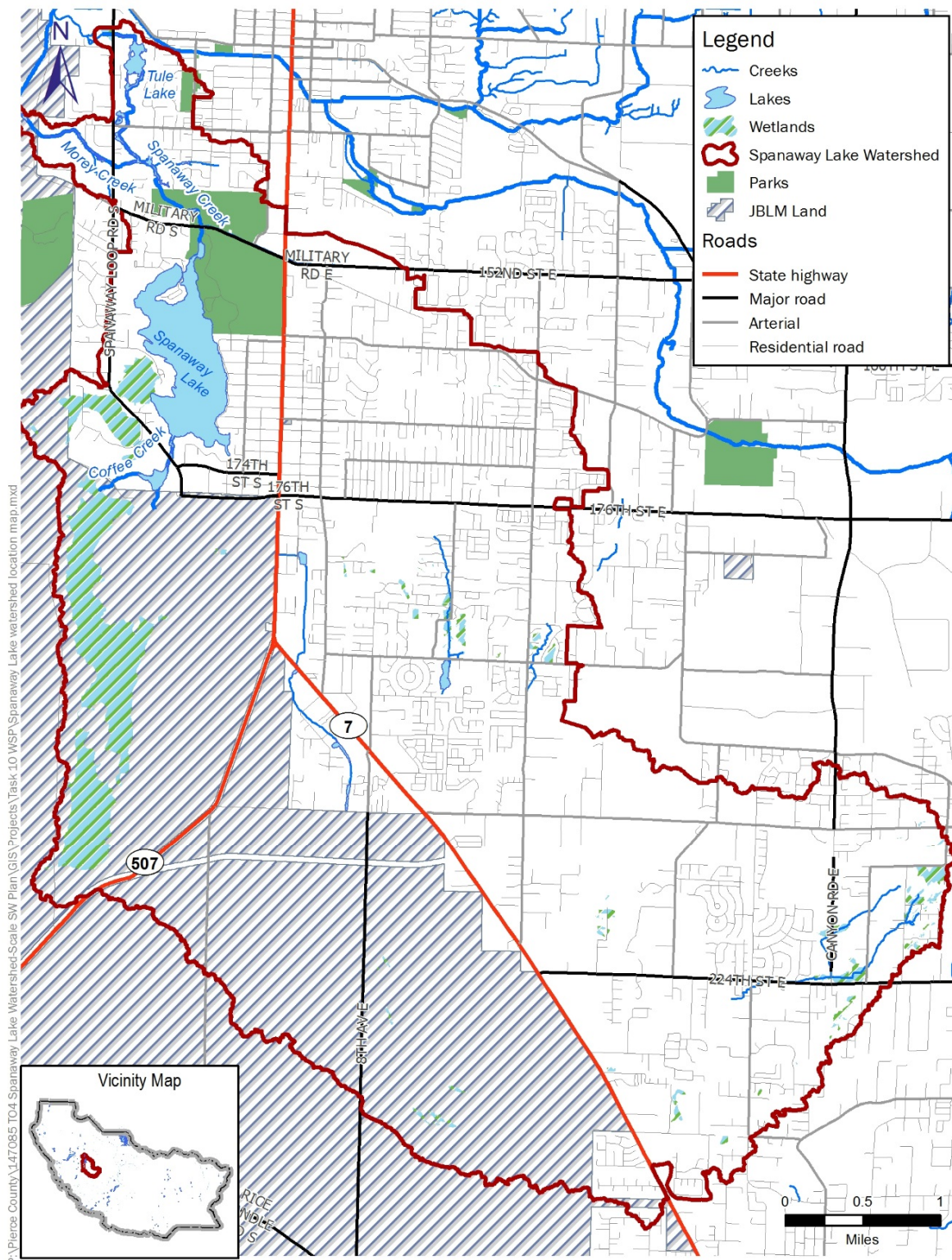


Figure 1-1. Spanaway Lake watershed

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SECTION 2: WSP PLANNING AREA DESCRIPTION

This section describes the salient Spanaway Lake WSP planning area relevant to the four Permit criteria. Additionally, a series of watershed maps were prepared to identify the existing distribution and totals of general soil types, vegetative land cover, impervious land covers, MS4s, and non-regulated public stormwater systems (if applicable). The maps also identify areas that appear especially vulnerable to hydrologic and water quality impacts. These maps focus on the types of information necessary for construction of a rainfall/runoff model representation of the watershed. The following specific figures were developed to comply with Permit SOW Task 2 [S5.C.s.c.ii(2)]: Spanaway Lake watershed-scale stormwater planning area, existing land use/land cover, soils hydrologic response units (HRUs), sub-basins and reaches, historical land use/land cover, and future land use/land cover. These figures are provided in the *Model Development and Calibration* report (WSP Appendix D).

2.1 Geology, Soils, and Hydrology

The Spanaway WSP area is underlain by northwest-thickening, unconsolidated, highly permeable glacial (till and outwash) deposits which overlie sedimentary and volcanic bedrock deposits (USGS 2011). Most unconsolidated deposits in the Spanaway Lake WSP area are referred to as the Steilacoom gravel, Qgo(sq) (Figure 2-1). The Steilacoom gravel is a porous gravel/cobble deposit 30-50 feet thick which offers little resistance to infiltration or rainwater and contaminants (Troost 2014). The gravel/cobble unconsolidated deposits in Pierce County and the Spanaway Lake WSP area are the result of repeated jökulhlaups, which is an Icelandic-term used to describe any large and abrupt release of water from a subglacial or proglacial lake/reservoir (Troost 2014). Attachment A includes geologic cross sections throughout Spanaway Lake as well as the boring logs and well construction details.

Roughly 80 percent of the Spanaway Lake WSP area is covered with deep, highly permeable glacial outwash soils that produce little runoff (Figure 2-2). Prior to development, much of the WSP area was covered with prairie vegetation (Figure 2-3).

Surface water bodies in the WSP area include Spanaway Lake, Coffee Creek, Spanaway Creek, Morey Creek, Tule Lake, and a large wetland system on JBLM property south (upstream) of Coffee Creek (Figure 1-1).

Most of the WSP planning area is underlain by a very transmissive unconfined aquifer. Groundwater discharge appears to be the main source of inflow to Spanaway Lake as well as Coffee Creek, which flows into Spanaway Lake. The reach of Spanaway Creek just downstream of the lake has also been observed to gain flow from groundwater (Ecology 2016a). Spanaway Creek has substantial baseflow throughout the year, with flow rates rising and falling in response to groundwater and lake elevations.

Spanaway and Tule lakes provide substantial detention, further attenuating wet weather flows in the creeks downstream. Consequently, the creeks in the watershed tend to respond slowly to precipitation.

The creeks in the Spanaway Lake watershed are characterized by low gradients, with slopes less than 1 percent. Approximately 1 mile downstream of Spanaway Lake, Morey Creek branches off the mainstem of Spanaway Creek and flows west about 1 mile before discharging into Clover Creek. Most of the flow remains in the Spanaway Creek channel, which flows north through Tule Lake before discharging into Clover Creek about 1 mile upstream of its confluence with Morey Creek (nhc 2002; nhc 2005a; nhc 2005b; Pierce County 2005).

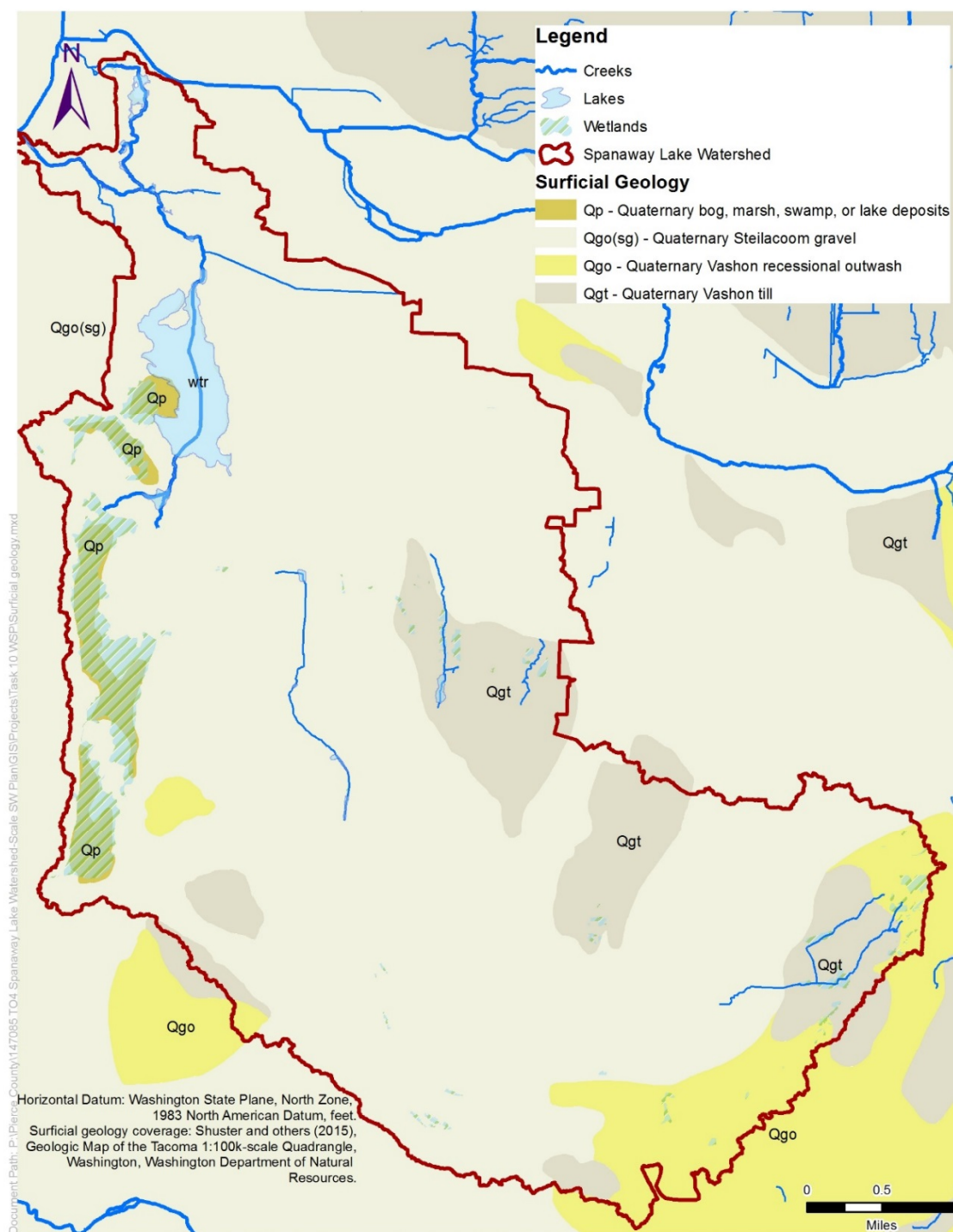


Figure 2-1. Surficial geology of Spanaway Lake WSP area

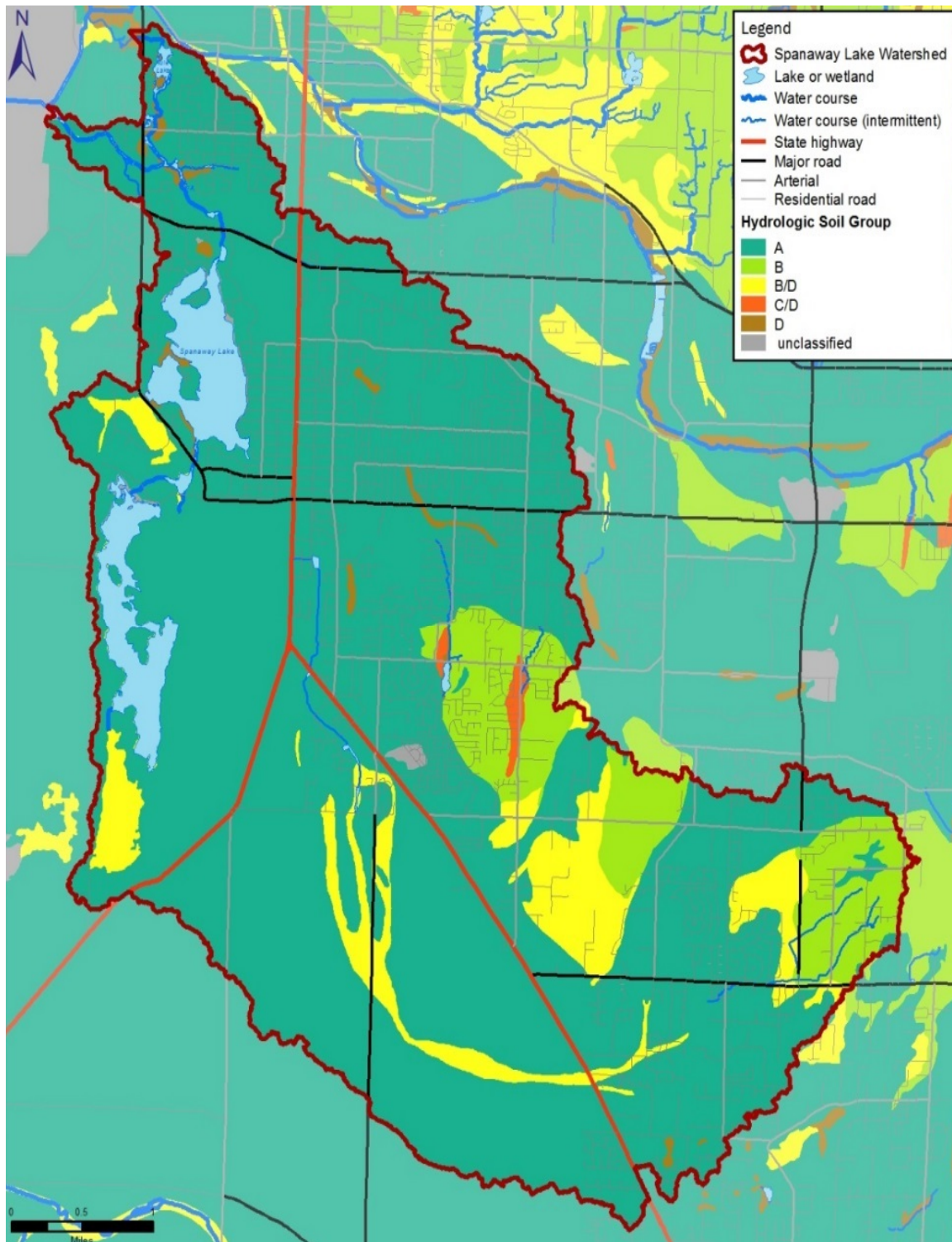


Figure 2-2. Hydrologic soil groups in Spanaway Lake watershed

Source: NRCS 2001.

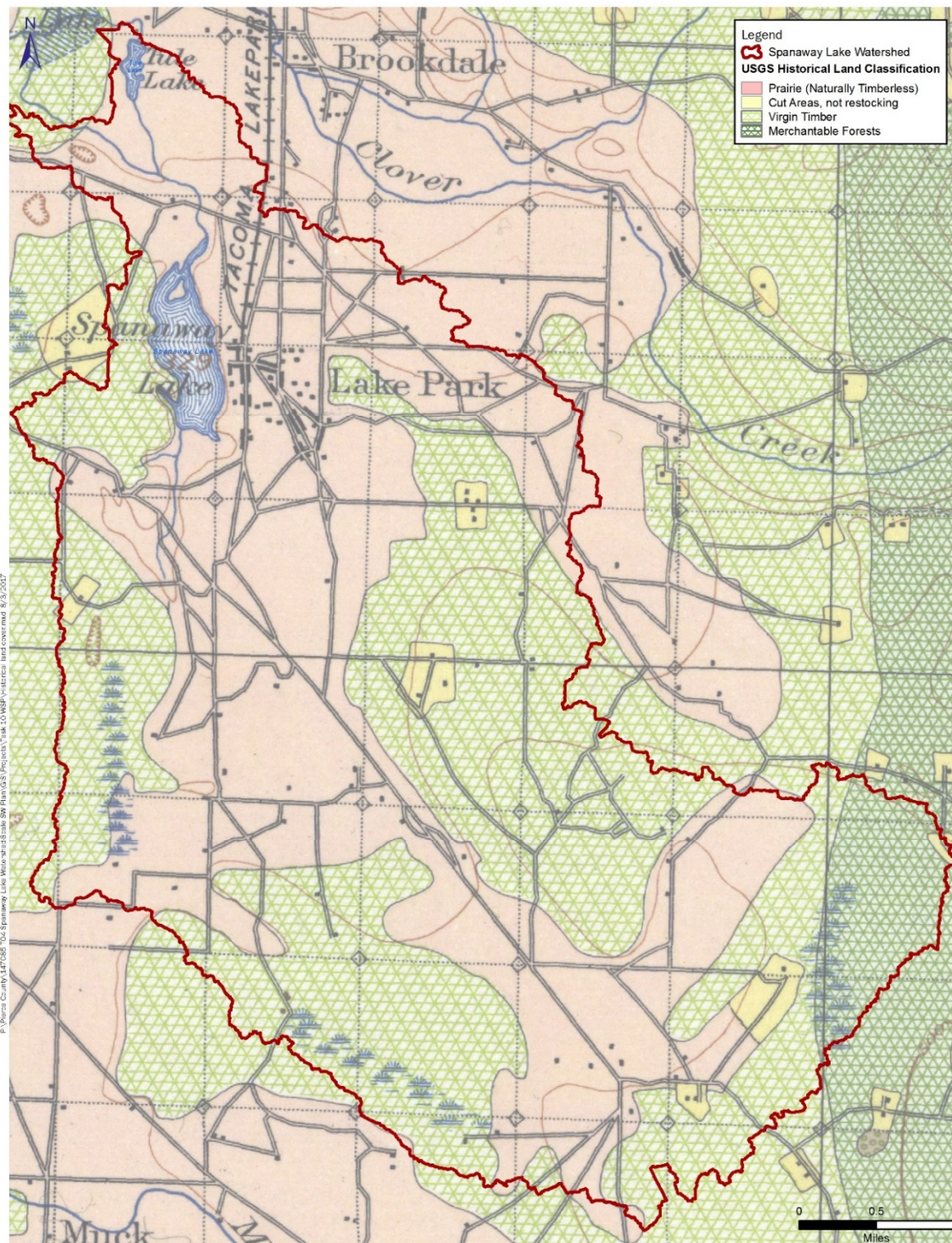


Figure 2-3. Historical land cover in Spanaway Lake watershed

Source: Gannett, USGS 1897.

2.2 Stormwater Drainage System

Nearly all stormwater runoff from impervious cover in the WSP area is infiltrated or dispersed onto adjacent pervious areas. The WSP area encompasses more than 1,400 infiltration facilities including drywells, infiltration basins, and infiltration trenches (Figure 2-4). Because of the highly permeable soils and ubiquitous infiltration facilities, the WSP area has only one significant MS4 conveyance system that discharges directly into a surface water body. This system receives stormwater runoff from approximately 176 acres and discharges into Spanaway Creek on the north side of Military Road. Numerous infiltration facilities have been installed in the catchment area for this outfall to reduce wet weather flows. The County recently installed a media filter just upstream of the outfall to treat the remaining flow prior to discharge.

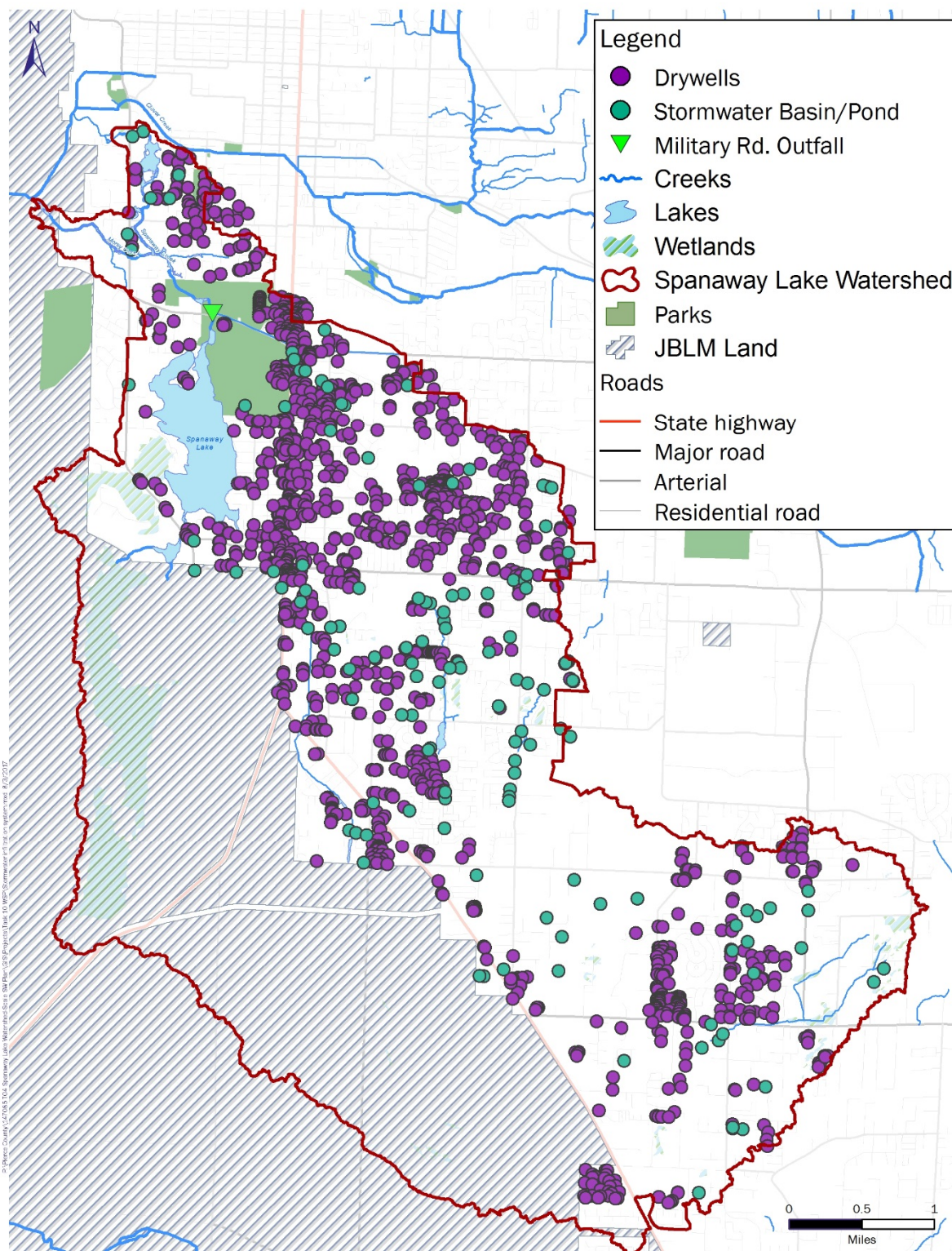


Figure 2-4. Stormwater infiltration systems and drywells in Spanaway Lake watershed

2.3 Land Use

Approximately 44,000 people currently live in Spanaway Lake watershed (PSRC 2017). Residential and commercial land uses cover approximately 10,000 acres, parks and golf course cover approximately 70,000 acres, and public facilities cover approximately 3,000 acres (see Figure 2-5). Most of the WSP area is served by onsite wastewater treatment systems (Figure 2-6).

About 67 percent of the watershed is under County jurisdiction and the remainder is within JBLM. Municipal stormwater discharges in the County portion of the watershed are regulated by the Phase I Permits issued by Ecology to the County and to the Washington State Department of Transportation (WSDOT). Coffee Creek, Spanaway Lake, Spanaway Creek, and Morey Creek downstream of the lake are within the County's MS4 service area.

The JBLM portion of the Spanaway Lake watershed is undeveloped. Stormwater discharges within the developed portions of JBLM are regulated under a municipal NPDES permit issued by the U.S. Environmental Protection Agency (EPA) Region 10.

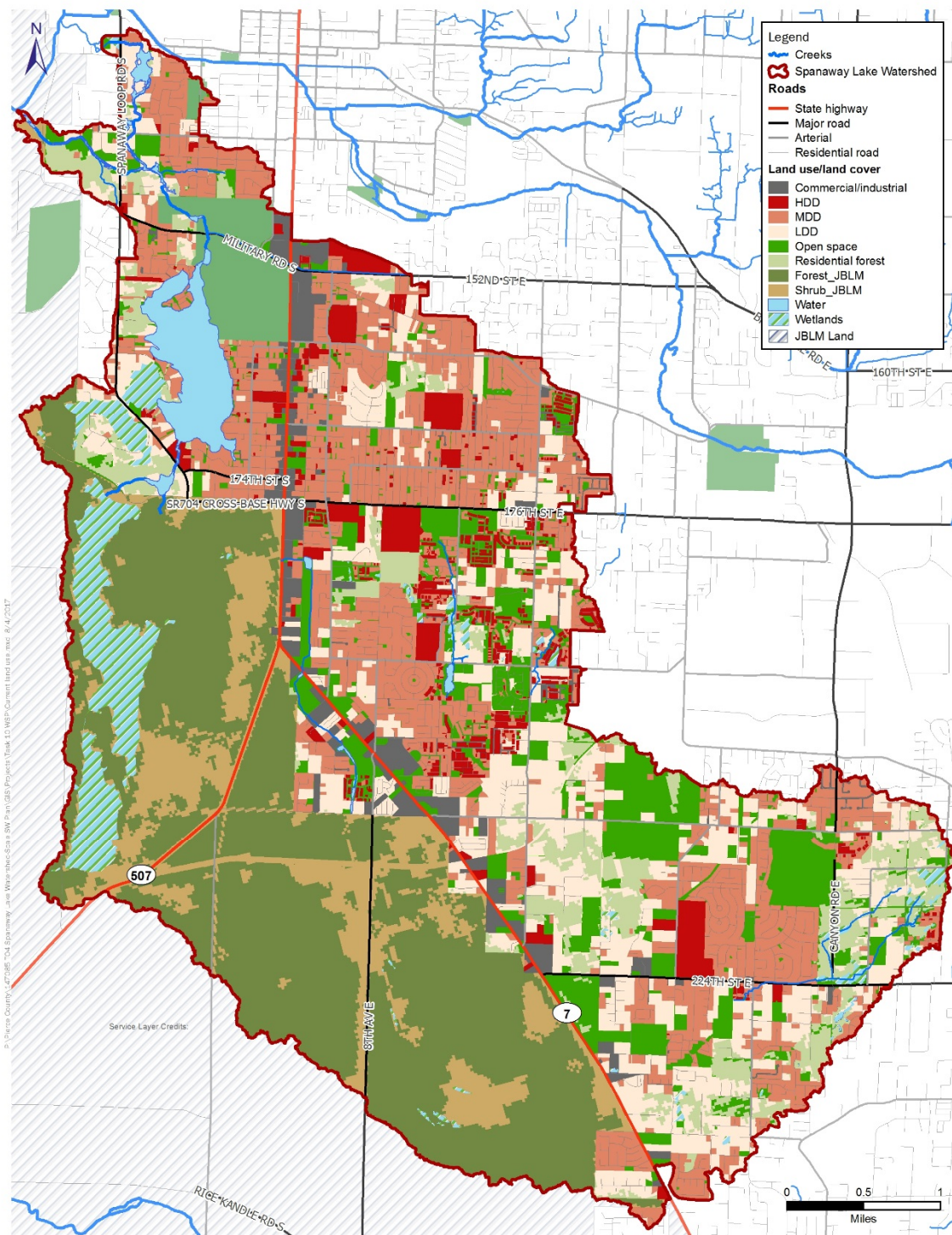


Figure 2-5. Current land use in Spanaway Lake watershed

Source: BC 2017 and Pierce County GIS database

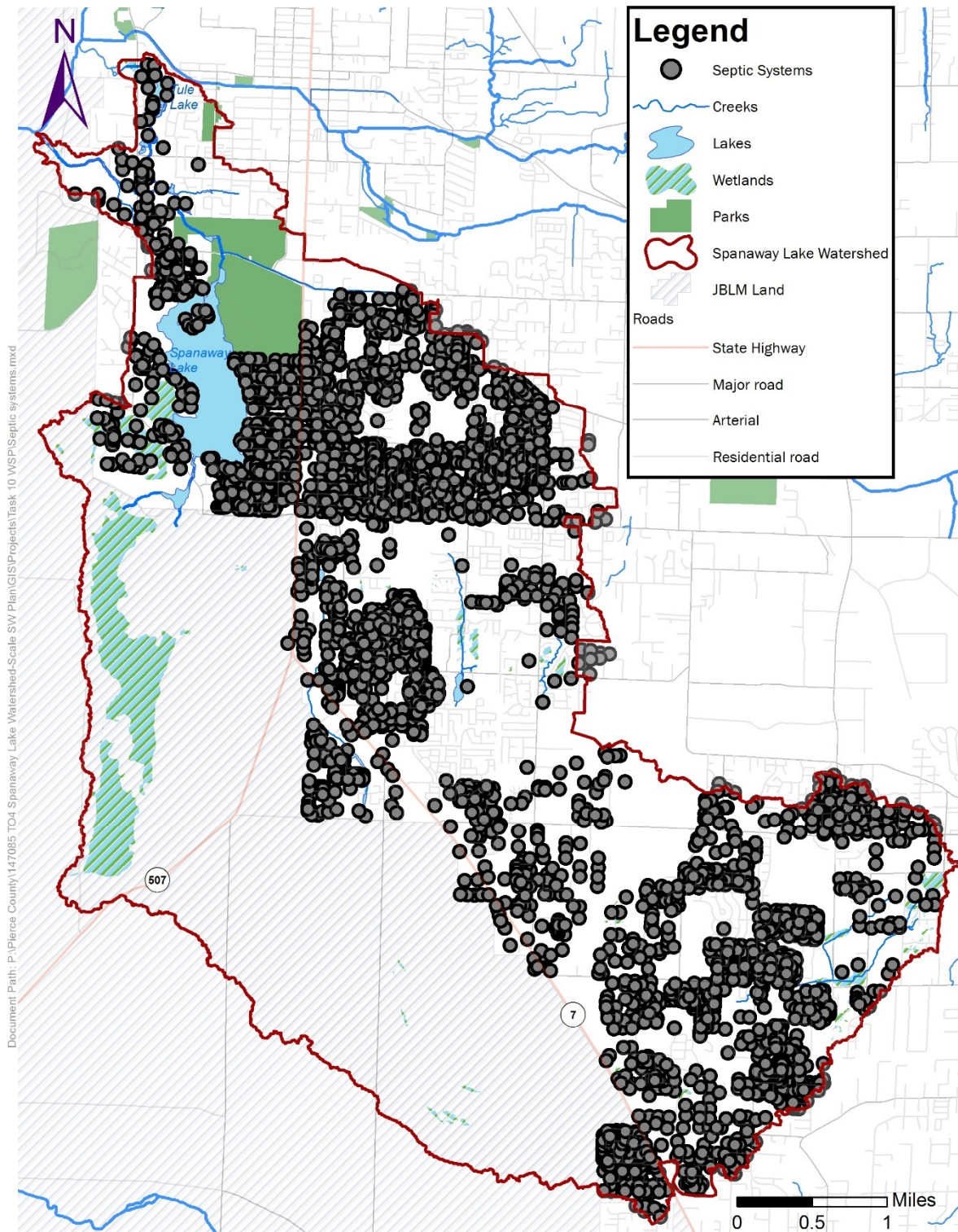


Figure 2-6. Septic systems in Spanaway Lake watershed

2.4 Future Growth

The northern portion of the watershed is in the Parkland/Spanaway/Midland unincorporated area, which is part of the UGA for the City of Tacoma. The southeast portion of the Spanaway Lake watershed, about 5.4 mi² (23 percent of the area), is outside of the Tacoma UGA, but within the Pierce County Comprehensive UGA. The southeast region of the watershed includes portions of the Frederickson and Graham communities. The WSP area population is expected to increase to about 50,000 by 2030 and 50,500 by 2040 (PSRC 2017).

2.5 Designated Uses and Water Quality Criteria

WAC 173-201A-600 provides use designations for freshwater bodies in Washington State. Spanaway and Morey creeks have the following designated uses:

- Salmonid spawning, rearing, and migration
- Primary contact recreation
- Domestic, industrial, agricultural, and stock water supply
- Wildlife habitat, harvesting, commerce/navigation, boating and aesthetics

Spanaway Lake and Coffee Creek have the designated uses listed above, except that they are designated for Extraordinary Primary Contact Recreation rather than Primary Contact Recreation.

According to Special Condition S5.C.5.c in the Permit, the WSP must evaluate water temperature, dissolved copper, dissolved zinc, fecal coliform bacteria, and benthic macroinvertebrates. The following sections summarize the applicable water quality criteria for water temperature, dissolved copper and zinc, fecal coliform bacteria, and benthic macroinvertebrates.

Water Temperature Criteria

The WSP water bodies are designated for salmonid spawning, rearing, and migration. To protect these uses, the 7-day average of the daily maximum temperatures (7-DADMax) shall not exceed 17.5 degrees Celsius (°C) (63.5 degrees Fahrenheit [°F]) more than once every 10 years on average. For lakes and other water bodies that exceed 17.5°C 7-DADMax because of natural conditions, human actions considered cumulatively may not increase the 7-DADMax by more than 0.3°C (0.54°F).

Copper and Zinc Criteria

To protect aquatic life, all water bodies in the WSP area have the same criteria for copper and zinc (Ecology 2016c). Copper and zinc toxicity generally increases as water hardness decreases. Therefore, the copper and zinc criteria depend on hardness and must be calculated for each

sample using the formulas listed below. The criteria apply to the dissolved form of these metals. These criteria may not be exceeded more than once every 3 years on the average.

- **Acute criterion for copper:** The 1-hour average concentration of dissolved copper may not exceed the value calculated using this formula: $(0.960) (e^{(0.9422[\ln(\text{hardness})] - 1.464)})$
- **Chronic criterion for copper:** The 4-day average concentration of dissolved copper may not exceed the value calculated using this formula: $(0.960) (e^{(0.8545[\ln(\text{hardness})] - 1.465)})$
- **Acute criterion for zinc:** The 1-hour average concentration of dissolved zinc may not exceed the value calculated using this formula: $(0.978) (e^{(0.8473[\ln(\text{hardness})] + 0.8604)})$
- **Chronic criterion for zinc:** The 4-day average concentration of dissolved zinc may not exceed the value calculated using this formula: $(0.986) (e^{(0.8473[\ln(\text{hardness})] + 0.7614)})$

Fecal Coliform Bacteria Criteria

Spanaway Lake and Coffee Creek are designated for Extraordinary Primary Contact Recreation use. To protect these uses, the geometric mean fecal coliform concentration may not exceed 50 colony-forming units (cfu) per 100 milliliters (mL), and no more than 10 percent of samples may exceed 100 cfu/100 mL.

The water bodies downstream of Spanaway Lake are designated for Primary Contact Recreation. In these water bodies, the geometric mean fecal coliform concentration may not exceed 100 cfu/100 mL, and no more than 10 percent can exceed 200 cfu/100 mL.

Table 2-1 below provides a summary of the numerical water quality standards applicable to the water bodies within the Spanaway Lake watershed.

Benthic Macroinvertebrate Criteria

The State water quality standards do not include numeric criteria for benthic macroinvertebrates. Under Ecology's current Water Quality Policy 1-11, water bodies with B-IBI scores of 38 or higher on the 10–50 scale are placed in Category 1 (meets criteria), while water bodies with B-IBI scores less than 27 are placed in Category 5 (impaired). Water bodies with B-IBI scores between 38 and 27 are placed in Category 2 (waters of concern) (Ecology 2012). Ecology is now updating Water Quality Policy 1-11; consequently, the B-IBI assessment criteria may change. Ecology's WSP guidance suggests that for water bodies where B-IBI scores are limited by natural conditions, 90% of the pre-development B-IBI score would be an appropriate target (Ecology 2016c).



Table 2-1. Water Quality Standards for Permit-Mandated Constituents in Spanaway Lake Watershed

Parameter	Numeric Criteria
Temperature ^a	<ul style="list-style-type: none"> Salmonid rearing and migration only. “7-DADMax” or “7-day average of the daily maximum temperatures” is the arithmetic average of seven consecutive measures of daily maximum temperatures. For this location, the criterion is 7-DADMax of 17.5°C (63.5°F).
Dissolved copper	<ul style="list-style-type: none"> Acute^b: (0.960) ($e^{(0.9422[\ln(\text{hardness})] - 1.464)}$) Chronic^c: (0.960) ($e^{(0.8545[\ln(\text{hardness})] - 1.465)}$)
Dissolved zinc	<ul style="list-style-type: none"> Acute^b: (0.978) ($e^{(0.8473[\ln(\text{hardness})] + 0.8604)}$) Chronic^c: (0.986) ($e^{(0.8473[\ln(\text{hardness})] + 0.7614)}$)
Fecal coliform bacteria	<ul style="list-style-type: none"> Locations upstream of Spanaway Lake and within Spanaway Lake (WSP1, SW-2, LW-1, LW-2, and LW-3): Extraordinary Contact--geometric mean value < 50 cfu/100 mL, with < 10% exceeding 100 cfu/100 mL Locations downstream of Spanaway Lake (SW-1, WSP2, WSP3, and WSP4): Primary Contact--geometric mean value < 100 cfu/100 mL, with < 10% exceeding 200 cfu/100 mL

a. Acute criteria, 1-hour average concentration not to be exceeded more than once every 3 years on the average.

b. Chronic criteria, 4-day average concentration not to be exceeded more than once every 3 years on the average.

c. Temperature (7-DADMax) not to exceed the criteria more than once every 10 years on average.

2.6 Current Water Quality Assessment

Every 2 years, Ecology performs a water quality assessment to identify water bodies that are not meeting their applicable water quality standards. Ecology’s 2016 Water Quality Assessment lists Spanaway Lake as impaired (Category 5) for fecal coliform bacteria and a water of concern (Category 2) for phosphorus. Spanaway Creek, immediately downstream of the lake, is listed as impaired (Category 5) for temperature and a water of concern (Category 2) for pH. Morey Creek is listed as impaired (Category 5) for dissolved oxygen (DO). Tule Lake is listed as a water of concern (Category 2) for temperature.

Category 5 water bodies typically require development and implementation of total maximum daily loads (TMDLs) or equivalent water quality improvement (WQI) plans.

2.7 Fish Populations

Limited information is available regarding fish populations in the Spanaway Lake WSP area. In May 2000, WDFW surveyed the Spanaway Lake fish population. WDFW used electrofishing, gill nets, and trap nets to capture 1,702 fish in 11 different taxa: yellow perch (*Perca flavescens*)

and rock bass (*Ambloplites rupestris*) were the most abundant species. Largemouth bass (*Micropterus salmoides*), rainbow trout (*Onchorynchus mykiss*), common carp (*Cyprinus carpio*), smallmouth bass (*M. dolomieu*), coho salmon (*O. kisutch*), pumpkinseed (*Lepomis gibbosus*), sculpin (family Cottidae), brown bullhead (*Ameiurus nebulosus*), and cutthroat trout (*O. clarki*) were also found. The WDFW analysis of the Spanaway Lake fish population was limited by the single sample and low sample counts of many of the key species such as largemouth bass and smallmouth bass. Relative weights of most species were high or average, possibly indicating low competition, an adequate food supply, low-density population, or a combination of these factors (Caromile 2002).

In August 2016, fish were removed from a section of Spanaway Creek downstream of 138th Street S, near the intersection with Spanaway Loop Road S. The fish were removed prior to pilot testing of the “Sand Wand” water jet and suction sediment removal system. Seine and dip nets were used to remove fish from the creek so they would not be harmed during sediment removal. Lamprey, cutthroat trout, rainbow trout, bass, perch, dace, and sculpin were identified during the fish removal portion of the pilot testing, but numbers of each species were not recorded (Winecka 2016). Figure 2-7 shows a few of the fish collected from Spanaway Creek in August 2016 prior to the “Sand Wand” pilot testing program.

Other sources of data consulted were the WDFW geographic information system (GIS) data set for salmonid distribution (“SalmonScape”), fish species and populations identified in the Chambers-Clover Creek Watershed 1995 and 2003 WRIA 12 limiting-factors reports, and historical accounts.



Figure 2-7. Fish collected from Spanaway Creek in August 2016

Historical accounts indicate that salmon (probably coho and chum), steelhead, rainbow trout, and large cutthroat trout were observed and caught from Spanaway Creek during the 1940s through the 1960s (Tobiason 2003). Ecology's 1995 WRIA 12 report said that coho and chum salmon were the primary anadromous species present in the Chambers-Clover Creek system (Ecology 1995). The 2003 WRIA 12 Salmonid Habitat limiting-factors report noted that coho were present throughout the entire length of Morey Creek, and coho were potentially present in Spanaway Creek (Runge et al. 2003). Current distribution as indicated by the WDFW fish presence GIS indicates that coho salmon spawning has been documented in Morey Creek, and coho presence has been documented in the Tule Lake area. A 1996 study reported that Spanaway Lake, Spanaway Creek, and Morey Creek contained trout (Pierce County 2005).

In 2007, Pierce County Surface Water Management (SWM) built a bypass channel to encourage anadromous fish passage around Bresemann Dam, which is located about 2,200 feet downstream of Spanaway Lake. In 2010, the County and JBLM completed a bypass channel around the 12-foot-high Morey Creek Dam, allowing fish access to Morey Creek, Spanaway Creek, and Spanaway Lake. This project, as well the Bresemann Dam bypass, was one of several fish passage projects conducted by SWM as part of the Clover Creek Basin Plan and intended to protect and enhance anadromous fish passage throughout the watershed.

The Clover Creek watershed downstream of the Spanaway Lake WSP area contains a number of barriers to fish passage. A dam built in 1852 at the mouth of Chambers Creek was a complete barrier to all migrating fish until the recent construction of a fish ladder. Several sections of Clover Creek have been confined to culverts, most notably under the JBLM runways. Railroad crossings and small private dams also impede fish passage (Runge et al. 2003).

Table 2-2 summarizes the fish species reported to be present in the Spanaway Lake WSP area.

Table 2-2. Summary of Reported Fish Species and Sources in Spanaway Lake watershed	
Fish Species	Source
Yellow perch	Caromile 2002; Winecka 2016
Rock bass	Caromile 2002; Winecka 2016
Largemouth bass	Caromile 2002; Winecka 2016
Rainbow trout	Caromile 2002; Winecka 2016; Tobiason 2003
Common carp	Caromile 2002
Smallmouth bass	Caromile 2002; Winecka 2016
Coho salmon	Caromile 2002; Tobiason 2003; Ecology 1995; Runge et al. 2003; Pierce County 2005
Chum salmon	Tobiason 2003; Ecology 1995
Pumpkinseed	Caromile 2002
Sculpin	Caromile 2002; Winecka 2016

Table 2-2. Summary of Reported Fish Species and Sources in Spanaway Lake watershed

Fish Species	Source
Brown bullhead	Caromile 2002
Cutthroat trout	Caromile 2002; Winecka 2016; Tobiason 2003
Lamprey	Winecka 2016
Dace	Winecka 2016
Steelhead	Tobiason 2003

2.8 Recent Water Quality Studies

The sections below provide a summary of two recent water quality studies pertinent to the Spanaway Lake WSP project: the Spanaway LMP and the Clover Creek Watershed Assessment.

2.8.1 Spanaway Lake Management Plan

Spanaway Lake has a long history of health advisories triggered by cyanobacteria (blue-green algae) blooms. The lake is on Ecology's current 303(d) list because of elevated fecal indicator bacteria (*E. coli*) concentrations near swimming areas.

In 2013, the County received a budget allocation from the Washington State Legislature to develop an LMP for Spanaway Lake. The LMP focused on cyanobacteria and fecal indicator bacteria. The first phase of LMP development involved monitoring surface water discharge into and out of the lake, lake and groundwater elevations, lake water quality, creek water quality, groundwater quality, and lakebed sediment. The LMP monitoring was conducted in accordance with an Ecology-approved QAPP. The LMP monitoring results were used to develop a nutrient budget for the lake, identify key nutrient sources, and support evaluation of lake management measures.

The County used the LMP monitoring results for streamflow, water temperature, and fecal coliform bacteria to support WSP development. In addition, the County expanded the LMP parameter list to include copper and zinc analyses for use in WSP development. Section 5 of this plan discusses the LMP monitoring results relevant to this WSP.

2.8.2 Clover Creek Watershed Assessment

In October 2016, Ecology published the *Clover Creek Watershed Fecal Coliform, Dissolved Oxygen, and Temperature Source Assessment Report* (Ecology 2016a). Ecology conducted the study because water quality data showed that some water bodies in the Clover Creek watershed do not meet State criteria (WAC 173-201A) for fecal coliform, DO, and/or

temperature. The assessment was originally intended as a TMDL study. However, Ecology subsequently decided to adopt a straight-to-implementation (STI) approach with the County playing a key role.

The Clover Creek assessment included monitoring five sites within the Spanaway Lake WSP area between March 2013 and February 2014. The sites were located on Spanaway and Morey creeks downstream of Spanaway Lake. Ecology's monitoring included fecal coliform, temperature, and benthic macroinvertebrates. Section 5.6 discusses the Clover Creek assessment monitoring results that are relevant to the Spanaway Lake WSP.

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SECTION 3: MONITORING LOCATIONS AND METHODS

Pierce County Water Quality Section's Monitoring and Assessment staff performed a variety of monitoring activities to support development of the Spanaway Lake WSP, including the following:

- Installation of streamflow gages at five locations
- 20 rounds of instantaneous flow measurements from October 2014 to May 2016
- 19 rounds of routine monthly sampling and 3x6 rounds of storm event sampling at key surface water locations
- Installation of six groundwater monitoring wells in the watershed upgradient of the lake
- Collections of soil samples during well drilling to evaluate major anions and cations in aquifer material
- 5 rounds of quarterly groundwater sampling and 14 rounds of monthly groundwater level monitoring
- One round of benthic macroinvertebrate sampling at four locations
- Analysis of creek and groundwater samples for copper, zinc, fecal coliform bacteria, hardness, and temperature

The County also analyzed groundwater samples from six LMP wells installed near Spanaway Lake for copper, zinc, and temperature, in addition to the LMP parameters. In addition, the County analyzed LMP lake water samples for copper, zinc, and hardness to provide data for the WSP.

This section summarizes the Spanaway Lake WSP monitoring activities. The Spanaway Lake WSP QAPP (Appendix B) contains more detailed information on the monitoring program.

3.1 Creek Monitoring

Monthly grab samples were collected at the six creek locations (including two LMP sites and four WSP sites) shown on Figure 3-1. All six locations were also sampled during six wet weather events. Three grab samples were collected at each location during each wet weather event. Samples were analyzed for total and dissolved copper and zinc, fecal coliform bacteria, total suspended solids (TSS), hardness, and other parameters. Appendix B contains detailed descriptions of the monitoring locations and methods. Samples were analyzed for the parameters listed in Table 3-1.

In addition to the constituents listed in Table 3-1, continuous temperature and level measurements were collected at five surface water monitoring locations. The County installed level/flow gages at SW-1, SW-2, WSP2, WSP3, and WSP4. County staff performed instantaneous depth and velocity measurements over a range of flows at each of the gaged sites to develop

stage-discharge relationships. The measurements were then used to calculate streamflow based on the rating curves developed by the County. The County was unable to obtain useful flow data at WSP3 (Spanaway Creek below Tule lake), however. WSP3 is located in a brushy wetland area with persistent beaver activity, so it was not possible to develop a meaningful stage-discharge relationship for this site. The County was unable to find a more conducive location for flow monitoring in this reach.

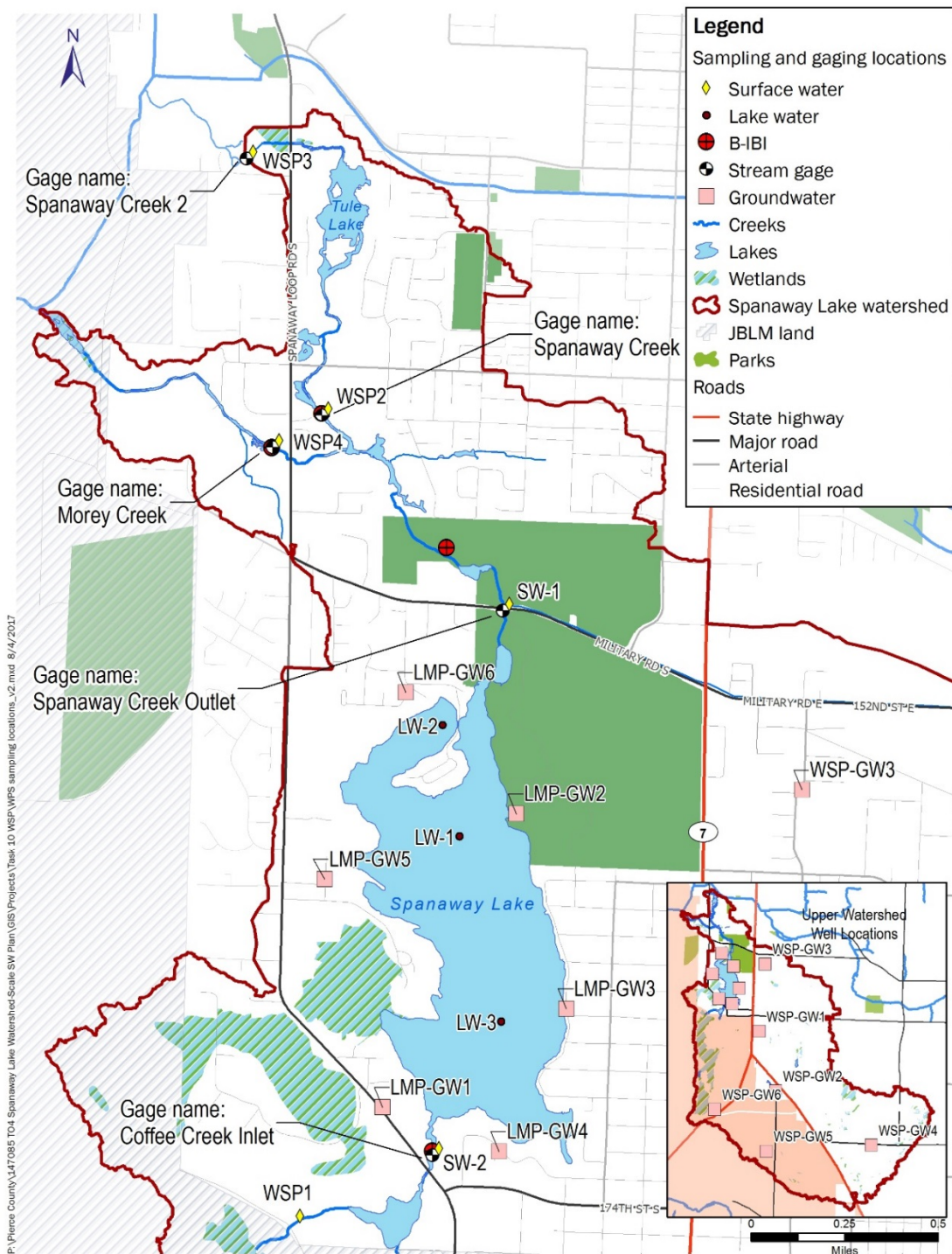


Figure 3-1. Spanaway Lake WSP sampling locations

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Table 3-1. Sampling Locations and Parameters in Spanaway Lake Watershed																	
Sample Type	Location	Flow Measurements	TSS	Fecal Coliform	Temperature ^a	pH ^a	DO ^a	Conductivity ^a	Turbidity ^a	Major Anions and Cations ^b	Total Copper	Dissolved Copper	Total Zinc	Dissolved Zinc	Hardness	B-IBI	Sediment Particle Size
Surface water	SW-1	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	SW-2	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	WSP1		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		
	WSP2	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	WSP3		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓		
	WSP4	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Lake water	LW-1		X	X	X	X	X	X									
	LW-2		X	X	X	X	X	X									
	LW-3		X	X	X	X	X	X									
Groundwater	LMP-GW1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	LMP-GW2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	LMP-GW3		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	LMP-GW4		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	LMP-GW5		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	LMP-GW6		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW1		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW2		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW3		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW4		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW5		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
	WSP-GW6		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Borehole soils ^{b,c}	WSP-GW1									✓							
	WSP-GW2									✓							
	WSP-GW3									✓							
	WSP-GW4									✓							
	WSP-GW5									✓							
	WSP-GW6									✓							

Note: WSP monitoring was coordinated with LMP monitoring to promote efficiency. Therefore, this table lists some of the parameters that were monitored for the LMP as well as the WSP projects.

✓ Denotes parameters monitored for the WSP project; X denotes parameters monitored for the LMP project.

- a. These parameters were monitored for groundwater during well purging to determine when to begin groundwater sample collection. These parameters were also monitored during creek sampling to provide supplementary information on ambient water quality. Surface water samples were also analyzed for turbidity in the lab.
- b. Major anions and cations were analyzed in the borehole soil samples collected during drilling and the first round of groundwater samples. (Borehole samples were collected at the monitoring well locations shown in Figure 3-1.)
- c. Core sediment samples collected from borings during well drilling were collected from approximate depth interval of well screen.

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3.2 Lake Monitoring

Three locations were monitored in Spanaway Lake (LW-1, LW-2, and LW-3), as shown on Figure 3-1. Location LW-1 was in the deepest portion of the lake, LW-2 was in the northern portion of the lake, and LW-3 was near the middle of the southern portion of the lake. Grab samples were collected at each location using a Kemmerer sampler. The samples were analyzed for copper, zinc, hardness, and fecal coliform bacteria, in addition to nutrients and other parameters relevant to the LMP. The County also performed water quality profiling in the deepest part of the lake (LW-1) once or twice per month, using a datasonde to measure pH, DO, conductivity, and temperature at 1.5-foot depth intervals throughout the water column. The County also installed a pressure transducer and data logger to measure lake water levels and a thermistor to measure lake water temperature throughout the study period.

3.3 Groundwater Monitoring

The County installed six groundwater monitoring wells to support the WSP. The County selected the locations of the WSP wells based on review of regional groundwater data and field investigations. The WSP wells were sited to complement the six shoreline-area monitoring wells installed for the LMP. All WSP and LMP wells were completed in the surficial aquifer. Figure 3-1 shows the WSP and LMP monitoring well locations. Attachment A contains the borehole logs and well construction details.

WSP-GW1 through WSP-GW4 are located on County property adjacent to County stormwater facilities upgradient (south and southeast) of Spanaway Lake. WSP-GW5 and WSP-GW6 are located on JBLM upgradient of the large wetland complex that feeds Coffee Creek.

The WSP wells were installed using sonic drilling technology by a licensed drilling contractor under the direction of a licensed hydrogeologist. After well installation, the ground surface and top-of-casing measuring points were surveyed by a licensed surveyor. The wells were developed to remove any fines entrained during construction.

Groundwater levels were measured in the WSP and LMP monitoring wells monthly for 1 year. All 12 wells were sampled quarterly for 1 year and analyzed for the following water quality parameters: copper, zinc, hardness, and fecal coliform bacteria. Groundwater temperature was measured in the field.

3.4 Benthic Macroinvertebrate Sampling

The County collected and analyzed benthic macroinvertebrate samples as required by the Permit. County staff collected the benthic macroinvertebrate samples in late July through late

August 2015 at the locations identified in the 2015 project QAPP (Brown and Caldwell [BC] 2015). Figure 3-2 shows the benthic sampling locations.

County staff followed Ecology guidelines for the collection of freshwater macroinvertebrate data in streams (Adams 2012). County staff used a Surber Sampler net to collect stream invertebrates from 8 square feet of area of the stream bottom (Carla Vincent, personal communication to Laura Reed, April 2017). The goal was to collect at least 500 organisms for each sample. All sites achieved their goal for minimum number of organisms collected (number of organisms collected: SW-1 = 531; SW-2 = 557; WSP2 = 544; and WSP4 = 543). Rhithron Associates Inc. analyzed the samples to the lowest practicable level of taxa resolution, the “fine” level.

To aid in interpreting the benthic sample results, County staff collected creek bed sediment samples for particle size analysis. Pebble counts were also performed.

Two changes from the QAPP were related to benthic invertebrate sampling. Because of unfavorable channel conditions at the SW-1 sampling location (logjams and debris), benthic sampling was performed slightly further downstream, below the Bresemann Dam, to represent conditions downstream of the lake outlet. The sample was referenced as site code SW-1 on the chain of custody and maintains this reference in this report. An additional benthic sampling site (WSP2) was added on Spanaway Creek just downstream of the split with Morey Creek to represent this reach. The Morey Creek sample (WSP4) was collected over 2 days (August 19 and 20, 2015) and then composited from two sample jars to one composite sample when analyzed (Carla Vincent, personal communication to Laura Reed, April 2017).

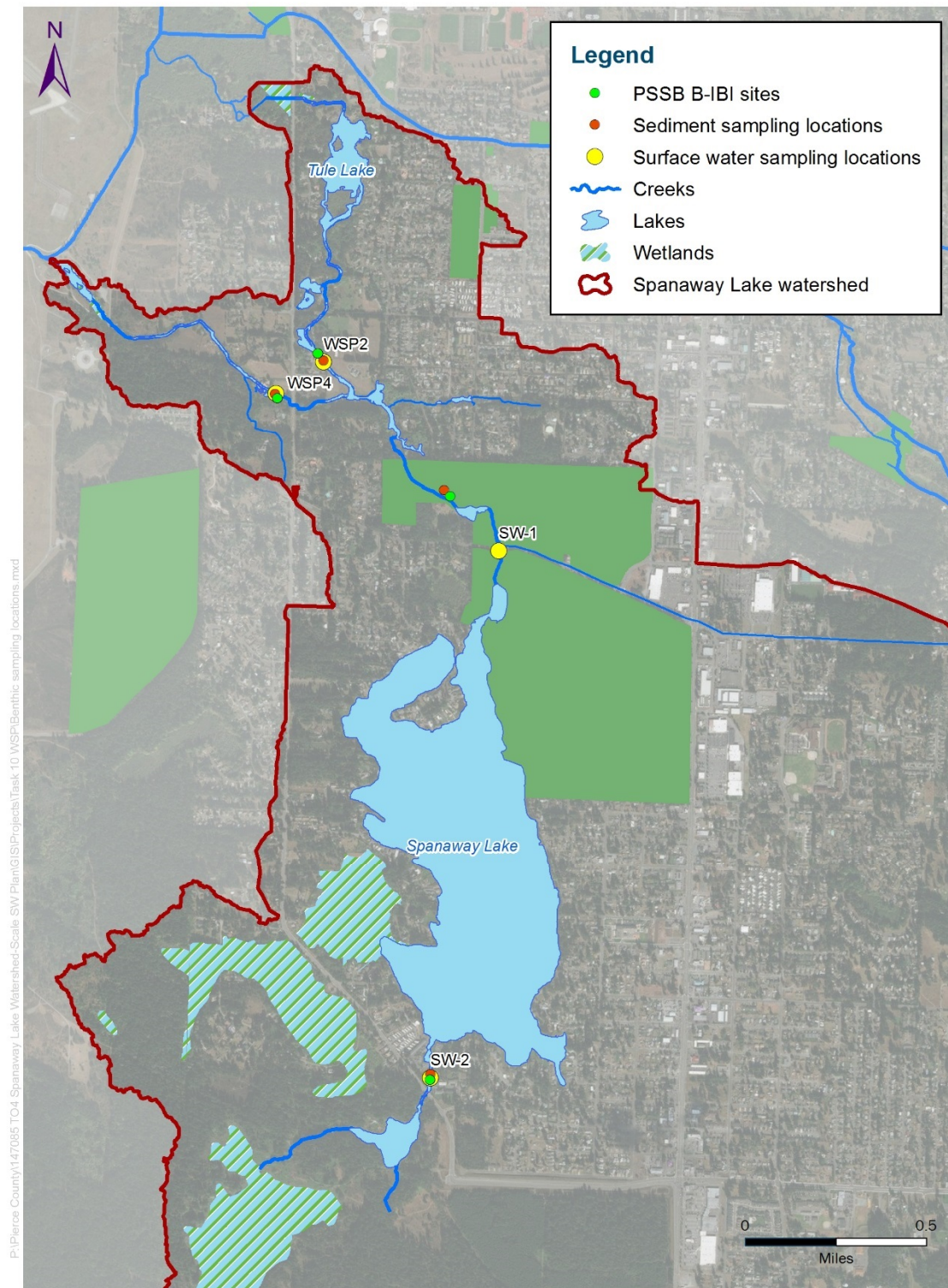


Figure 3-2. Spanaway Lake WSP benthic sampling locations

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SECTION 4: MONITORING RESULTS

This section summarizes the Spanaway Lake WSP monitoring results. It also discusses water quality and other relevant data collected by Ecology for the Clover Creek Assessment study (Ecology 2016a).

4.1 Spanaway Lake WSP Monitoring Results

This section provides a summary of the WSP monitoring results for streamflow, water temperature, copper and zinc, fecal coliform bacteria, and benthic macroinvertebrates. As discussed in Section 2.8, the County developed an LMP to address the water quality issues in Spanaway Lake, which has a history of water quality problems associated with excess cyanobacteria growth and elevated fecal coliform concentrations. The LMP's primary focus was on phosphorus, with fecal indicator bacteria as a secondary focus. The LMP monitoring included flow measurement, upstream and downstream of the lake, and water quality monitoring for fecal coliform and temperature. To support WSP development, the County analyzed the LMP surface water and groundwater samples for copper and zinc as well as LMP parameters.

4.1.1 Streamflow

The County collected streamflow data between summer 2014 and spring 2016 at four sites within the WSP Planning Area (SW-1, SW-2, WSP2, and WSP4), as shown in Figure 3-1 above. U.S. Geological Survey (USGS) flow data were also collected at the SW-1 site between September 2014 and November 2015, as shown in Figure 4-1 below.

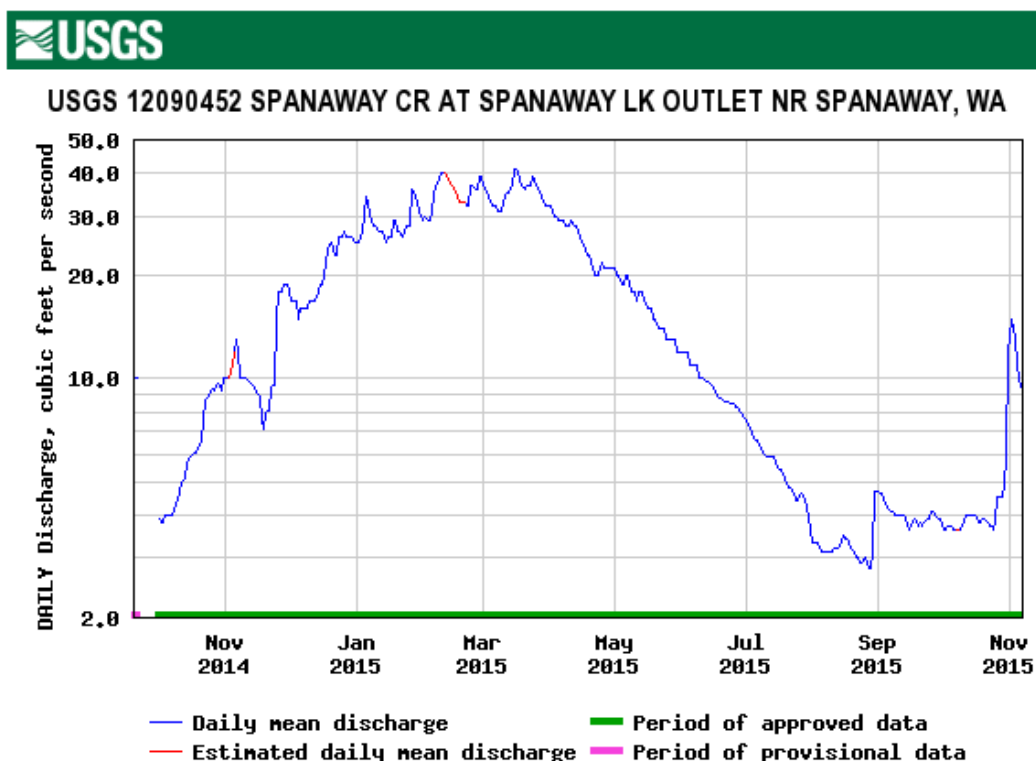


Figure 4-1. USGS flow data at SW-1 from September 2014–November 2015

Figures 4-2 and 4-3 show the flow patterns at locations SW-1 (Spanaway Creek below the lake) and SW-2 (Coffee Creek) during selected October, November, and December 2015 storms. As can be seen in these figures, flow at SW-2 at Coffee Creek coming into the lake is much more muted in response to rain events than flow leaving the lake at SW-1. This relatively small change in flow is expected for a stream system that is predominantly groundwater-fed and a tributary basin with significant storage in wetland and marsh areas. At SW-1, there was a substantial increase in winter baseflows, which would be expected based on the large amount of connection to the groundwater seen in Spanaway Lake.

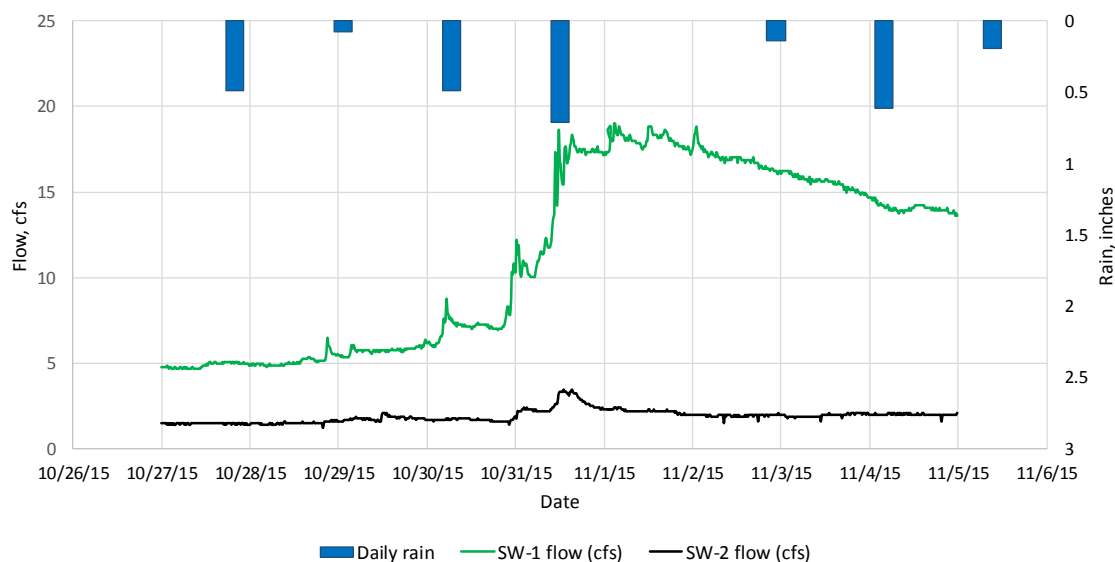


Figure 4-2. Flow patterns at SW-1 and SW-2 during October and November 2015 storms

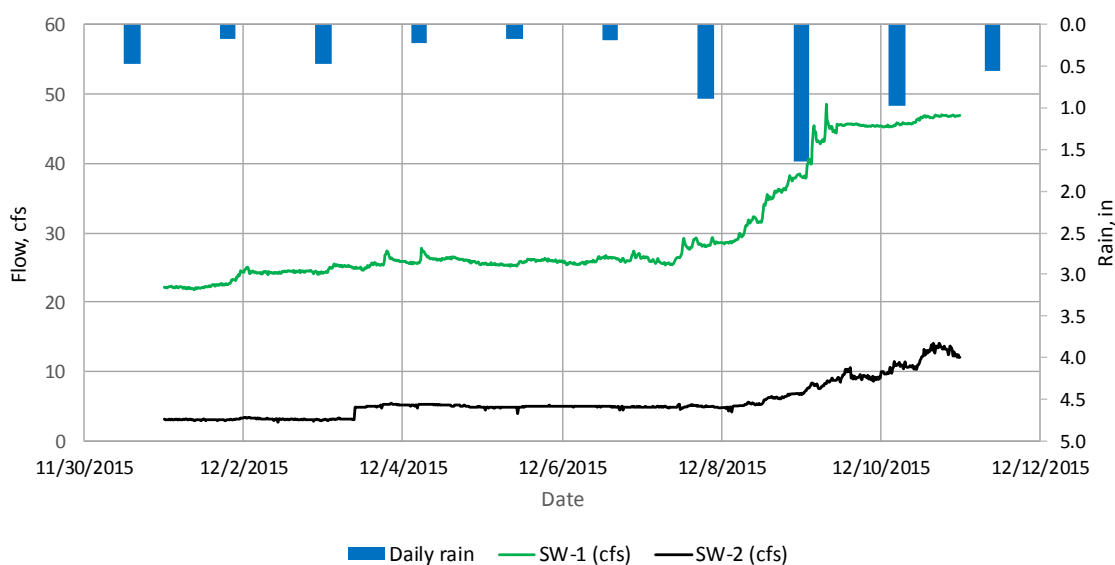


Figure 4-3. Flow patterns at SW-1 and SW-2 during December 2015 storms

Table 4-1 provides a summary of the continuous flow measurements collected at SW-1, SW-2, WSP2, WSP3, and WSP4 throughout the entire duration of the monitoring period (summer 2014–spring 2016) and Figures 4-4 through 4-8 show the observed flow patterns. The yellow dashed line represents the low flow threshold (0.5 average day flow for the calendar year). The

green dashed line (“2 mean day Q”) is the high flow threshold, or twice the average daily flow per water year. Both thresholds were selected based on the DeGasperi et al. (2009) paper *Linking Hydrologic Alteration to Biological Impairment in Urbanizing Streams of the Puget Lowland, Washington, USA*. They are included because increased frequency of low-flow and high-flow “pulses” (periods when the flow moves in and out of these zones) is negatively correlated with the biotic integrity of streams.

Table 4-1. Continuous Stream Discharge Measurements in the Spanaway Lake Watershed

Location	Upstream of Spanaway Lake	Military Road Downstream of Spanaway Lake	Spanaway Creek Downstream of Split from Morey Creek	Morey Creek	Spanaway Creek Downstream of Tule Lake
WSP site ID	SW-2	SW-1	WSP2	WSP4	WSP3
Drainage area (acres)	2,265	3,207	3,355	3,318	3,596
Flow monitoring start date	7/24/2014	10/13/2014	10/22/2014	10/22/2014	12/2/2014
Flow monitoring end date	5/10/2016	5/9/2014	5/10/2016	5/5/2016	12/6/2015
Total number of days in monitoring period	657	575	567	562	370
Average daily flow (cfs)	8.4	27	26	8.7	5.7
Minimum daily flow (cfs)	0.7	2.6	1.7	0.0	0.0
Maximum daily flow (cfs)	33	72	58	39	16

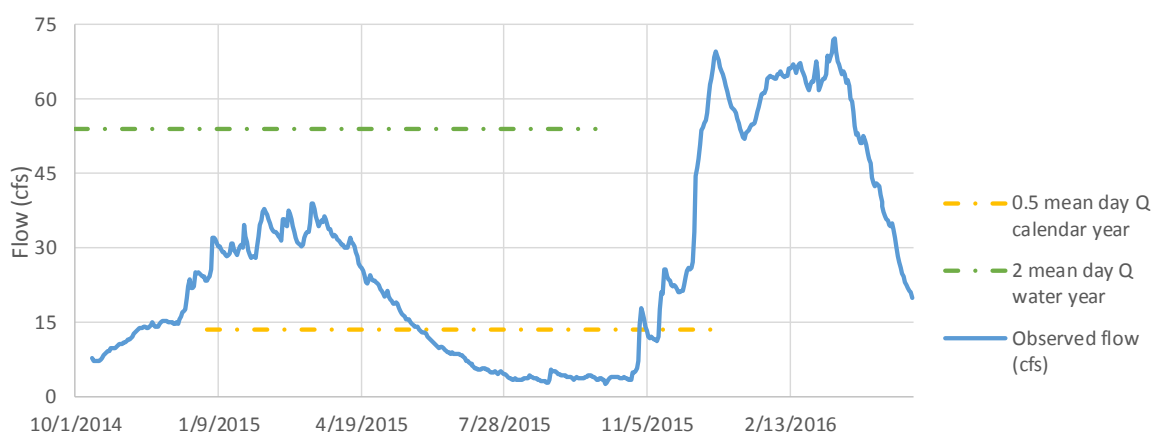


Figure 4-4. Flow pattern at SW-1



Figure 4-5. Flow pattern at SW-2

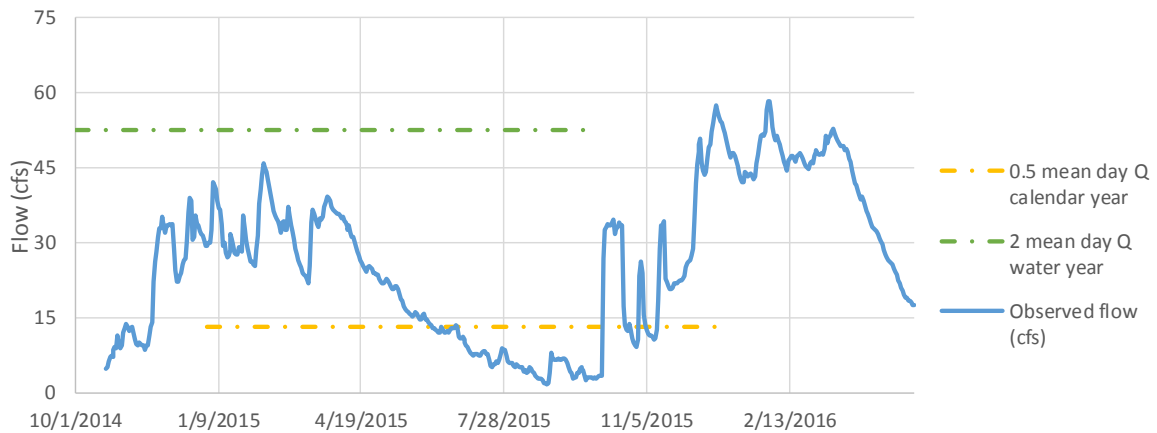


Figure 4-6. Flow pattern at WSP2

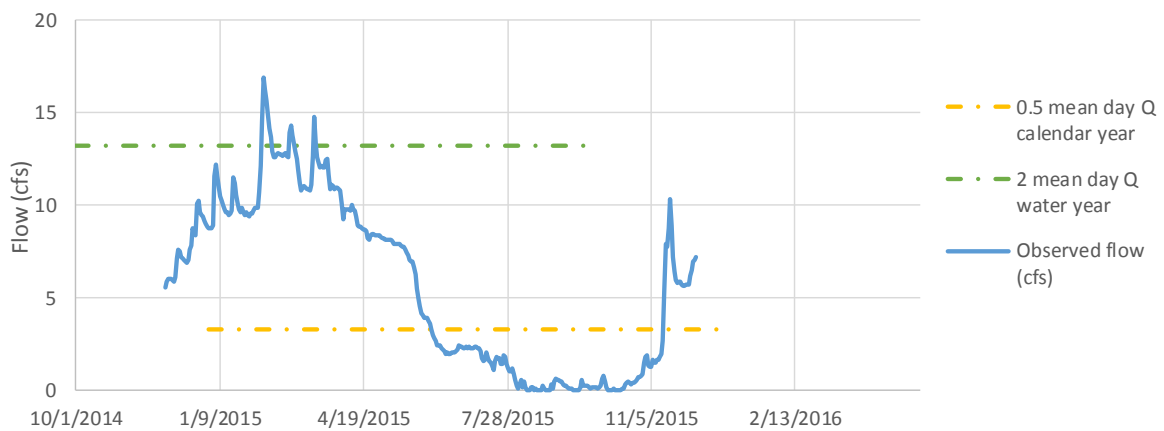


Figure 4-7. Flow pattern at WSP3

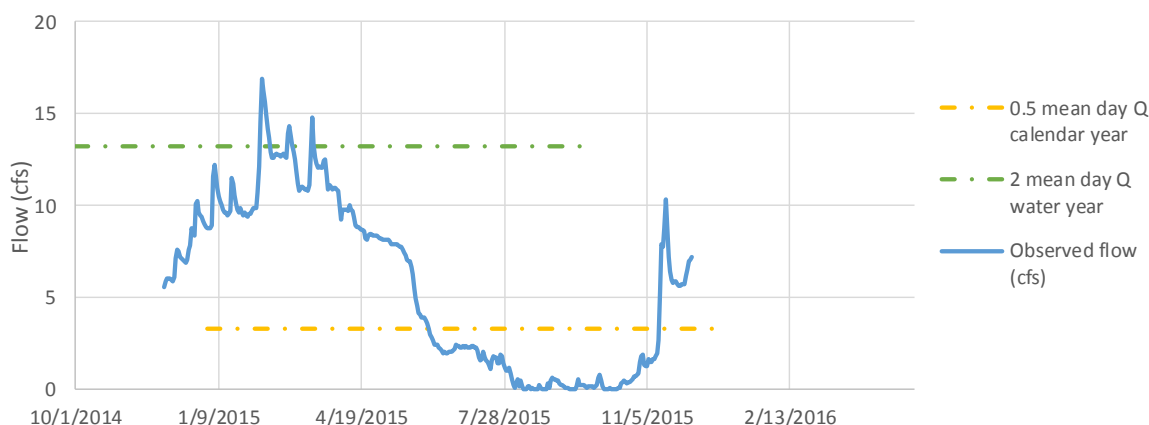


Figure 4-8. Flow pattern at WSP4

Unfortunately, the flow data collected from WSP3, the site downstream of Tule Lake on Spanaway Creek, proved to be unusable for model calibration because of equipment issues and impounded water conditions in the area around the gage. Flow data from the other four flow gages were used to calibrate the hydrologic and hydraulic (H&H) model for the Spanaway Lake WSP.

4.1.2 Water Temperature

Continuous stream water temperature data were recorded by the stream level sensors used for level and flow measurement (KPSI sensors) at a 15-minute time step at six sites—SW-1, SW-2, WSP2, WSP3, and WSP4—and at the lake level site on Enchanted Island. Temperature data recorded by the KPSI level sensors were stored and transmitted by Hobo logging instruments to the County as raw data. During the routine and storm sampling events, instantaneous field temperature measurements were also collected using a YSI meter. During post-processing by County staff, the continuous temperature data set recorded by the KPSI level sensors was adjusted to match the instantaneous YSI field measurements. This adjusted final data set was sent to BC for comparison to State water quality standards (Ecology 2016b). The WSP water bodies are designated for salmonid spawning, rearing, and migration. To protect these uses, the 7-day average of the daily maximum temperatures (7-DADMax) shall not exceed 17.5°C more than once every 10 years on average. For lakes and other water bodies that exceed 17.5°C 7-DADMax because of natural conditions, human actions considered cumulatively may not increase the 7-DADMax by more than 0.3°C (0.54°F).

A small number of clearly erroneous temperature measurements were identified and removed from the data set. The 15-minute time step measurements of temperature data were then used to calculate the 7-DADMax. Each 7-DADMax was calculated by averaging that day's daily

maximum temperature with the daily maximum temperatures of the 3 days prior and the 3 days after that date per Ecology protocols (Ecology 2016b).

Instantaneous readings of temperature taken during the routine surface water sampling events ranged from 4.5°C to 31.3°C between the five creek sites (SW-1, SW-2, WSP2, WSP3 and WSP4). Table 4-2 provides a summary of the 7-DADMax water temperatures at each monitoring location during the monitoring period. Figure 4-9 shows the 7-DADMax temperature for each monitoring location, including the water quality criteria limit (red line).

WSP Site ID	Location	Monitoring Period	Number of Days > 17.5°C
SW-1	Spanaway Creek at lake outlet	October 2014–May 2016	161
SW-2	Coffee Creek at lake inlet	July 2014–May 2016	29
WSP2	Spanaway Creek at 141st St. S	October 2014–May 2016	126
WSP3	Spanaway Creek below Tule Lake outlet	December 2014–May 2016	122
WSP4	Morey Creek	October 2014–May 2016	110

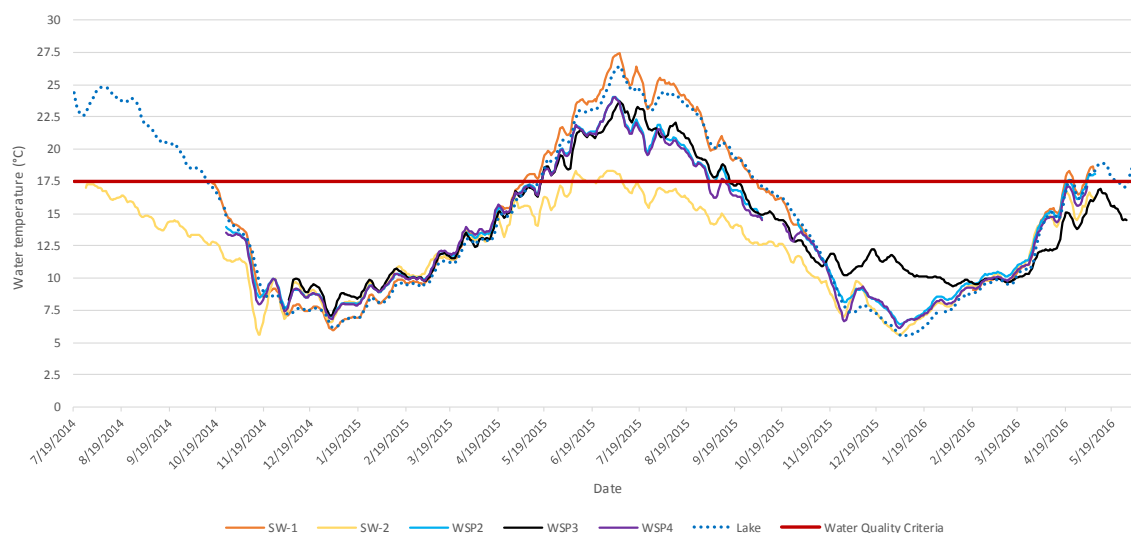


Figure 4-9. 7-day averages of daily maximum water temperatures in Spanaway Lake watershed

4.1.2.1 Causes for Elevated Water Temperature in the Spanaway Lake WSP Area

Warming in Spanaway Lake is the primary cause for the higher water temperatures at SW-1, WSP2, WSP3, and WSP4 during the summer. Warmer temperatures in Spanaway Lake are attributable to its long hydraulic residence time (HRT) and large open water area. Warming in Tule Lake could also contribute to the elevated temperatures at WSP3.

Spanaway Lake is a natural lake with no man-made control structures. (Bresemann Dam, located on Spanaway Creek in the park downstream of Military Road, is too low in elevation to affect lake levels [BC 2016]). Groundwater is the main source of water to the lake. Hydrological Simulation Program-Fortran (HSPF) model simulations for SW-1 indicate that existing 7-DADMax values are within 0.3°C of historical (pre-developed conditions). This suggests that the elevated water temperatures at SW-1 are primarily due to natural warming in the lake.

While natural lake warming is probably the main contributor to the elevated water temperatures observed at WSP2, WSP3, and WSP4, decreased riparian shade is probably a contributing factor. Ecology's Clover Creek Assessment found that only about 20 percent of the channel near WSP2 was effectively shaded (Ecology 2016a). The HSPF model simulations indicate that existing 7-DADMax values at WSP2, WSP3, and WSP4 are often more than 0.3°C higher than historical conditions.

As shown in Figure 4-9 above, the 7-DADMax at Coffee Creek (SW-2) was slightly above 17.5°C for about 29 days during the WSP monitoring period. Groundwater is the main source of flow in Coffee Creek during the summer months. It is possible that limited riparian shade contributed to the exceedances. Historical maps (Figure 2-3 above) indicate that prairie (rather than forest) covered the Coffee Creek area, so it is possible that riparian shade was limited under pre-developed conditions.

4.1.3 Copper and Zinc

This section provides a summary of hardness, dissolved metals, and total recoverable metals in the creek and lake water samples.

4.1.3.1 Hardness in Creek Water and Lake Water Samples

The State metals criteria vary as a function of hardness to account for its effect on dissolved metal toxicity. Hardness is a measure of the concentration of many dissolved ions in water, but principally calcium and magnesium. Metals toxicity generally decreases with increasing hardness (USGS 2007). Hardness data were collected at all sampling locations. Their ranges are shown in Table 4-3.

Table 4-3. Hardness Ranges in Creek and Lake Water Samples (mg/L)

Monitoring Location	WSP Site ID	Minimum	Average	Maximum
Routine water sampling from creeks	Marsh	19.2	29.9	41.5
	SW-1	32.3	43.9	56.8
	SW-2	23.7	40.2	53.6
	WSP1	26.5	33.2	47.3
	WSP2	33.2	44.5	59.4
	WSP3	25.8	42.9	55.8
	WSP4	30.9	43.7	57.0
Storm event water sampling from creeks	Marsh	19.7	27.8	34.5
	SW-1	31.0	43.8	51.5
	SW-2	22.8	38.9	46.1
	WSP1	39.0	43.0	48.0
	WSP2	30.1	42.1	50.3
	WSP3	29.6	43.2	52.6
	WSP4	30.2	41.9	51.3
Lake water samples	LW-1	39.8	51.5	68.2
	LW-1E	25.5	42.1	55.5
	LW-1H	23.4	40.1	49.5
	LW-2	40.3	49.7	63.6
	LW-2E	24.3	39.9	48.2
	LW-3	18.4	43.9	64.0
	LW-3E	25.5	40.3	51.5
	LW-3H	38.5	38.8	39.0

4.1.3.2 Dissolved Metals in Creek Water and Lake Water Samples

The hardness values were used to calculate the corresponding dissolved copper and dissolved zinc water quality criteria for each discrete surface water and lake water sample location, as summarized below. Note that the acute criteria pertain to a 1-hour average and the chronic criteria for a 4-day average. All the samples collected during this study were grab samples collected at one point in time.

Table 4-4 provides a summary of the surface water and creek water dissolved copper monitoring statistics and Table 4-5 provides a summary of surface water and lake water results with detectable dissolved copper concentrations.

Table 4-4. Dissolved Copper ($\mu\text{g/L}$) in Creek and Lake Water Samples in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples	Percent Exceeding Criteria
Routine water sampling from creeks	Marsh	<0.50 U	<0.50 U	<0.50 U	<0.50 U	16	0
	SW-1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18	0
	SW-2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18	0
	WSP1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	13	0
	WSP2	<0.50 U	0.33	0.25	1.7	18	0
	WSP3	<0.50 U	0.34	0.25	1.7	17	0
	WSP4	<0.50 U	0.33	0.25	1.7	18	0
Storm event water sampling from creeks	Marsh	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)	0
	SW-1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)	0
	SW-2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)	0
	WSP1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	6 (2 storms)	0
	WSP2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)	0
	WSP3	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)	0
	WSP4	<0.50 U	0.31	0.25	1.3	18 (6 storms)	0
Lake water samples	LW-1	<0.50 U	0.54	0.25	2.3	7	0
	LW-1E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	12	0
	LW-1H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	12	0
	LW-2	<0.50 U	0.94	0.25	5.1	7	0
	LW-2E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10	0
	LW-2H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2	0
	LW-3	<0.50 U	1.3	0.25	7.5	7	14
	LW-3E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10	0
	LW-3H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2	0

U = compound was analyzed and not detected.

Statistics calculated using half the detection limit (0.5 $\mu\text{g/L}$).

Percent exceedance calculated based on the hardness of that sample.

Table 4-5. Summary of Creek and Lake Water Results with Detectable Dissolved Copper Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Dissolved Copper (µg/L)	Freshwater Chronic Copper Criteria	Freshwater Acute Copper Criteria
Routine water sampling from creeks	WSP2	11/13/2014	56.0	1.7	6.9	9.9
	WSP3	11/13/2014	54.8	1.7	6.8	9.7
	WSP4	11/13/2014	54.8	1.7	6.8	9.7
Storm event water sampling from creeks	WSP4c	10/31/2015	43.8	1.3	5.6	7.8
Lake water samples	LW-1	11/20/2014	47.0	4.2 ^a	6.0	8.4
	LW-2	11/20/2014	45.7	5.1	5.8	8.1
	LW-3	11/20/2014	47.1	7.5 ^b	6.0	8.4

Notes:

During each storm event, three grab samples were collected at 12-hour intervals from each creek. The first stormwater samples were labeled with an "a," the second sample with a "b," and the third sample with a "c."

- a. 11/20/2014 dissolved copper results for LW-1 (2.3 µg/L) averaged with its duplicate sample (6.1 µg/L).
- b. Grab sample concentration. However, the chronic criteria apply to a 4-day average concentration rather than a grab sample concentration.

Table 4-6 provides a summary of the surface water and creek water dissolved zinc monitoring statistics and Table 4-7 provides a summary of surface water and lake water results with detectable dissolved zinc concentrations.

Table 4-6. Dissolved Zinc ($\mu\text{g/L}$) in Creek and Lake Water Samples in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples	Percent Exceeding Criteria
Routine water sampling from creeks	Marsh	<0.50 U	0.28	0.25	0.25	16	0
	SW-1	<0.50 U	0.30	0.25	0.80	18	0
	SW-2	<0.50 U	0.35	0.25	2.0	18	0
	WSP1	<0.50 U	0.35	0.25	1.5	13	0
	WSP2	<0.50 U	0.28	0.25	0.80	18	0
	WSP3	<0.50 U	0.25	0.25	0.25	17	0
	WSP4	<0.50 U	0.27	0.25	0.60	18	0
Storm event water sampling from creeks	Marsh	<0.50 U	0.41	0.25	2.1	18 (6 storms)	0
	SW-1	<0.50 U	0.39	0.25	2.5	18 (6 storms)	0
	SW-2	<0.50 U	0.30	0.25	1.1	18 (6 storms)	0
	WSP1	<0.50 U	0.53	0.25	1.9	6 (2 storms)	0
	WSP2	<0.50 U	0.55	0.25	2.2	18 (6 storms)	0
	WSP3	<0.50 U	0.38	0.25	1.2	18 (6 storms)	0
	WSP4	<0.50 U	0.52	0.25	2.1	18 (6 storms)	0
Lake water samples	LW-1	<0.50 U	0.99	1.1	2.0	7	0
	LW-1E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	12	0
	LW-1H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	12	0
	LW-2	<0.50 U	0.96	0.50	2.0	7	0
	LW-2E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10	0
	LW-2H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2	0
	LW-3	0.50	0.80	0.60	1.5	7	0
	LW-3E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10	0
	LW-3H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2	0

Notes:

U = compound was analyzed and not detected.

Statistics calculated using half the detection limit (0.5 $\mu\text{g/L}$).

Percent exceedance calculated based on the hardness of that sample.

Table 4-7. Creek and Lake Water Samples with Detectable Dissolved Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Dissolved Zinc (µg/L)	Freshwater Chronic Zinc Criteria	Freshwater Acute Zinc Criteria	Percent of Samples That Exceed Criteria
Routine water sampling from creeks	Marsh	12/7/2015	24.6	0.8	31.8	34.9	0
	SW-1	12/7/2015	45.1	0.6	53.2	58.3	
	SW-1	2/8/2016	39.3	0.8	47.4	51.9	
	SW-2	2/19/2015	34.6	2.0	42.5	46.6	
	WSP1	2/19/2015	31.2	1.5	39.0	42.7	
	WSP2	2/19/2015	43.4	0.8	51.5	56.4	
	WSP4	2/9/2016	41.8	0.6	49.9	54.7	
Storm event water sampling from creeks	Marsha	12/20/2014	29.2	2.1	36.8	40.3	0
	Marshb	12/21/2014	26.3	0.9	33.7	36.9	
	Marshc	12/21/2014	27.0	0.7	34.5	37.7	
	SW-1a	12/20/2014	51.5	2.5	59.6	65.2	
	SW-1c	10/31/2015	47.2	0.6	55.3	60.6	
	SW-2a	12/20/2014	45.9	1.1	54.0	59.2	
	WSP1c	10/31/2015	45.5	1.9	53.6	58.7	
	WSP2a	12/20/2014	50.3	2.2	58.4	63.9	
	WSP2b	12/20/2014	46.5	0.6	54.6	59.8	
	WSP2b	10/31/2015	41.8	1.1	49.9	54.7	
	WSP2c	12/21/2014	48.7	0.8	56.8	62.2	
	WSP2c	2/10/2015	41.0	0.8	49.1	53.8	
	WSP2c	10/31/2015	39.5	1.4	47.6	52.1	
	WSP3a	12/20/2014	50.9	0.8	59.0	64.6	
	WSP3b	12/20/2014	47.2	0.6	55.3	60.6	
	WSP3c	12/21/2014	52.6	0.8	60.6	66.4	
	WSP3c	2/10/2015	43.0	1.2	51.1	56.0	
	WSP4a	12/20/2014	51.3	2.1	59.4	65.0	
	WSP4b	12/20/2014	45.8	1.0	53.9	59.1	
	WSP4c	12/21/2014	47.9	1.2	56.0	61.3	
	WSP4c	10/31/2015	43.8	1.5	51.9	56.9	
Lake water samples	LW-1	11/20/2014	47.0	2.0	55.1	60.4	0
	LW-1	12/17/2014	52.0	0.7	60.1	65.8	

Table 4-7. Creek and Lake Water Samples with Detectable Dissolved Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Dissolved Zinc (µg/L)	Freshwater Chronic Zinc Criteria	Freshwater Acute Zinc Criteria	Percent of Samples That Exceed Criteria
	LW-1	1/15/2015	68.2	1.1	75.6	82.8	
	LW-1	2/26/2015	39.8	1.2	47.9	52.4	
	LW-1	3/26/2015	59.5	1.4	67.3	73.7	
	LW-2	11/20/2014	45.7	1.2	53.8	58.9	
	LW-2	2/26/2015	42.0	2.0	50.1	54.9	
	LW-2	3/26/2015	53.6	1.5	61.6	67.5	
	LW-3	12/17/2014	51.8	0.7	59.9	65.5	
	LW-3	2/26/2015	41.1	1.0	49.2	53.9	
	LW-3	3/26/2015	43.3	1.5	51.4	56.3	

Notes:

During each storm event, three grab samples were collected at 12-hour intervals from each creek. The first stormwater samples were labeled with an "a," the second sample with a "b," and the third sample with a "c."

Routine Water Sampling from Creeks. As shown in Table 4-4, none of the routine surface water samples from creeks exceeded the State criteria for dissolved copper. Of all the routine surface water samples collected from creeks, only three samples contained dissolved copper above the detection limit of 0.5 microgram per liter (µg/L). As summarized in Table 4-5, the dissolved copper concentrations did not exceed 1.7 µg/L, which is well below 6.8 µg/L, the lower end of the chronic copper criteria.

As shown in Table 4-6, none of the routine surface water samples from creeks exceeded the State criteria for dissolved zinc. Of all the routine surface water samples collected from creeks, seven samples contained dissolved zinc above the detection limit of 0.5 µg/L. As summarized in Table 4-7, none of these locations showed exceedances of the State criteria for dissolved zinc. The dissolved zinc concentrations did not exceed 2.0 µg/L, which is well below 31.8 µg/L, the lower end of the chronic zinc criteria.

Storm Event Sampling from Creeks. As shown in Table 4-4, none of the stormwater surface water samples from creeks exceeded the State criteria for dissolved copper. Of all the stormwater surface water samples collected from creeks, only one sample (WSP4c, the third sample collected at WSP4 during the storm event) contained dissolved copper above the



detection limit of 0.5 µg/L. As summarized in Table 4-5, this location did not show an exceedance of the State criteria for dissolved copper. The dissolved copper concentration of 1.3 µg/L was well below 5.6 µg/L, the lower end of the chronic copper criteria.

As shown in Table 4-6, none of the stormwater surface water samples from creeks exceeded the State criteria for dissolved zinc. Of all the stormwater surface water samples collected from creeks, as summarized in Table 4-7, 21 samples contained dissolved zinc above the detection limit of 0.5 µg/L. None of these locations showed exceedances of the State criteria for dissolved zinc. The dissolved zinc concentrations did not exceed 2.5 µg/L, which was well below the lower end of the chronic zinc criteria (4-day average concentration of 33.7 µg/L).

Lake Water Sampling. As shown in Tables 4-4 and 4-5, of all the lake water samples collected, only three samples contained dissolved copper above the detection limit of 0.5 µg/L and only one grab sample had a concentration above the chronic criteria. This sample was collected from LW-3 near the middle of the lake at a depth of about 10 feet. The dissolved copper concentration in this grab sample was slightly above the chronic criteria, which are based on a 4-day average concentration. This was a discrete sample, and does not represent a 4-day average concentration. Ecology's WQP 1-11 error analysis found that individual daily observations have a much greater chance of exceeding the chronic criteria than 4-day averages (Ecology 2016b).

Of all the lake water samples collected, 11 contained dissolved zinc above the detection limit of 0.5 µg/L. As summarized in Table 4-7, no samples exceeded the State criteria for dissolved zinc. The dissolved zinc concentrations did not exceed 2.0 µg/L, which is well below 49.2 µg/L, the lower end of the chronic zinc criteria.

4.1.3.3 Total Recoverable Metals in Creek and Lake Water Samples

The following sections provide a summary of the total recoverable metals in creek and lake water samples.

Routine Surface Water Samples from Creeks

As shown in Table 4-8, the average total copper concentrations of the routine surface water samples from creeks are below 1.22 µg/L. The highest concentrations were from locations WSP2, WSP3, and WSP4, with concentrations of 11.2, 11.9, and 15.9 µg/L, respectively. As summarized in Table 4-9, eight samples contained total copper above the detection limit of 0.5 µg/L.

As shown in Table 4-10, the average total zinc concentrations of the routine surface water samples from creeks are below 0.87 µg/L. The highest concentration was from location WSP4,

with 3.8 µg/L. As summarized in Table 4-11, 31 samples contained total zinc above the detection limit of 0.5 µg/L.

Stormwater Samples from Creeks

As shown in Table 4-8, the average total copper concentrations of the stormwater samples from creeks are below 0.48 µg/L. The highest concentration was from location WSP4 with 4.2 µg/L. As summarized in Table 4-9, four samples contained total copper above the detection limit of 0.5 µg/L.

As shown in Table 4-10, the average total zinc concentrations of the stormwater samples from creeks are below 2.83 µg/L. The highest concentrations were from locations WSP1 and WSP4 with 11.4 and 11.8 µg/L, respectively. As summarized in Table 4-11, 50 samples contained total zinc concentrations above the detection limit of 0.5 µg/L.

Lake Water Samples

As shown in Table 4-8, the average total copper concentration of the lake water samples was below 1.38 µg/L. The highest concentration was from location LW-1 with 8.1 µg/L. As shown in Table 4-9, three samples contained total copper above the detection limit of 0.5 µg/L.

As shown in Table 4-10, the average total zinc concentrations of the lake water samples are below 3.53 µg/L. The highest concentration is from location LW-1 with 9.4 µg/L. As summarized in Table 4-11, 17 samples contained total zinc above the detection limit of 0.5 µg/L.

Table 4-8. Total Copper (µg/L) in Creek and Lake Water Samples in Spanaway Lake Watershed						
Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Routine water sampling from creeks	Marsh	<0.50 U	0.85	0.25	8.7	16
	SW-1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18
	SW-2	<0.50 U	0.30	0.25	1.1	18
	WSP1	<0.50 U	0.28	0.25	0.60	13
	WSP2	<0.50 U	0.86	0.25	11.2	18
	WSP3	<0.50 U	0.94	0.25	11.9	17
	WSP4	<0.50 U	1.21	0.25	15.9	18
Storm event water sampling from creeks	Marsh	<0.50 U	0.29	0.25	1.0	18 (6 storms)
	SW-1	<0.50 U	0.30	0.25	1.1	18 (6 storms)
	SW-2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)
	WSP1	<0.50 U	0.31	0.25	0.6	6 (2 storms)
	WSP2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)
	WSP3	<0.50 U	<0.50 U	<0.50 U	<0.50 U	18 (6 storms)
	WSP4	<0.50 U	0.47	0.25	4.2	18 (6 storms)
Lake water samples	LW-1	<0.50 U	1.37	0.25	8.1	7
	LW-1E	<0.50 U	0.25	0.25	0.25	12
	LW-1H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	12
	LW-2	<0.50 U	1.26	0.25	7.3	7
	LW-2E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10
	LW-2H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2
	LW-3	<0.50 U	1.33	0.25	7.8	7
	LW-3E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10
	LW-3H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2

Notes:

U = compound was analyzed and not detected.

Statistics calculated using half the detection limit (0.5 µg/L).

Table 4-9. Summary of Surface Water and Lake Water Results with Detectable Total Copper Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Copper (µg/L)
Routine water sampling from creeks	Marsh	11/13/2014	38.0	8.7
	Marsh	3/15/2016	27.5	1.4
	SW-2	11/13/2014	53.6	1.1
	WSP1	3/15/2016	27.8	0.6
	WSP2	11/13/2014	56.0	11.2
	WSP3	11/13/2014	54.8	11.9
	WSP4	11/13/2014	54.8	15.9
	WSP4	3/15/2016	39.2	1.8
Storm event water sampling from creeks	Marshc	12/21/2014	27.0	1.0
	SW-1a	2/5/2015	45.6	1.1
	WSP1c	8/31/2015	41.2	0.6
	WSP4c	10/31/2015	43.8	4.2
Lake water samples	LW-1	11/20/2014	47.0	8.1
	LW-2	11/20/2014	45.7	7.3
	LW-3	11/20/2014	47.1	7.8

Notes:

During each storm event, three grab samples were collected at 12-hour intervals from each creek. The first stormwater samples were labeled with an "a," the second sample with a "b," and the third sample with a "c."

Table 4-10. Total Zinc (µg/L) Ambient Surface Water and Creek Water Monitoring Statistics in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Routine water sampling from creeks	Marsh	<0.50 U	0.37	0.25	1.3	16
	SW-1	<0.50 U	0.51	0.25	1.5	18
	SW-2	<0.50 U	0.37	0.25	2.4	18
	WSP1	<0.50 U	0.86	0.25	4.6	13
	WSP2	<0.50 U	0.39	0.25	1.3	18
	WSP3	<0.50 U	0.53	0.25	1.8	17
	WSP4	<0.50 U	0.70	0.25	3.8	18
Storm event water sampling from creeks	Marsh	<0.50 U	1.39	0.25	10.4	18 (6 storms)
	SW-1	<0.50 U	0.99	0.65	2.6	18 (6 storms)
	SW-2	<0.50 U	0.38	0.25	1.3	18 (6 storms)
	WSP1	<0.50 U	2.82	0.70	11.4	6 (2 storms)
	WSP2	<0.50 U	1.22	0.65	5.0	18 (6 storms)
	WSP3	<0.50 U	0.77	0.25	3.1	18 (6 storms)
	WSP4	<0.50 U	1.60	0.25	11.8	18 (6 storms)
Lake water samples	LW-1	<0.50 U	3.52	2.8	9.4	7
	LW-1E	<0.50 U	0.31	0.25	1.0	12
	LW-1H	<0.50 U	0.30	0.25	0.8	12
	LW-2	<0.50 U	1.44	1.7	2.4	7
	LW-2E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10
	LW-2H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2
	LW-3	<0.50 U	1.48	1.0	4.3	7
	LW-3E	<0.50 U	<0.50 U	<0.50 U	<0.50 U	10
	LW-3H	<0.50 U	<0.50 U	<0.50 U	<0.50 U	2

Notes:

*U = compound was analyzed and not detected.**Statistics calculated using half the detection limit (0.5 µg/L).*

Table 4-11. Summary of Surface Water and Lake Water Results with Detectable Total Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Zinc (µg/L)
Routine surface water sampling from creeks	Marsh	4/14/2015	22.4	1.1
	Marsh	12/7/2015	24.5	1.3
	SW-1	11/13/2014	55.8	0.6
	SW-1	2/19/2015	45.6	0.7
	SW-1	4/14/2015	32.9	0.8
	SW-1	12/7/2015	45.1	1.5
	SW-1	1/13/2016	42.1	1.2
	SW-1	2/8/2016	39.3	1.3
	SW-2	2/19/2015	34.6	2.4
	WSP1	2/19/2015	31.2	4.6
	WSP1	6/9/2015	29.3	0.8
	WSP1	8/11/2015	38.1	0.6
	WSP1	11/19/2015	37.9	1.7
	WSP1	12/7/2015	36.2	1.5
	WSP2	2/19/2015	43.4	1.3
	WSP2	4/14/2015	33.3	0.8
	WSP2	2/8/2016	41.3	1.1
	WSP3	2/19/2015	41.0	0.9
	WSP3	4/14/2015	36.2	1.0
	WSP3	5/5/2015	25.8	0.7
	WSP3	8/11/2015	43.9	1.8
	WSP3	11/19/2015	46.2	0.6
	WSP3	12/7/2015	46.7	0.7
	WSP3	2/8/2016	45.8	0.8
	WSP4	11/13/2014	54.8	0.7
	WSP4	2/19/2015	44.5	0.9
	WSP4	4/14/2015	31.5	1.1
	WSP4	5/5/2015	36.4	3.8
	WSP4	12/7/2015	51.4	1.8
	WSP4	2/9/2016	41.8	0.6
	WSP4	1/13/2016	41.2	0.9
Storm event water sampling from creeks	Marsha	12/20/2014	29.2	5.8
	Marsha	1/17/2015	34.5	0.5
	Marsha	2/5/2015	28.0	1.3

Table 4-11. Summary of Surface Water and Lake Water Results with Detectable Total Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Zinc (µg/L)
	Marsha	6/2/2015	25.3	1.0
	Marsha	8/29/2015	30.5	0.6
	Marshb	12/20/2014	26.3	1.9
	Marshc	12/21/2014	27.0	1.0
	Marshc	8/31/2015	29.5	10.4
	SW-1a	12/20/2014	51.5	2.6
	SW-1a	1/17/2015	45.1	2.6
	SW-1a	2/5/2015	45.6	2.0
	SW-1b	12/20/2014	48.9	2.1
	SW-1b	2/7/2015	31.0	1.0
	SW-1b	8/29/2015	43.2	1.9
	SW-1b	10/31/2015	48.9	0.6
	SW-1c	12/21/2014	50.0	1.3
	SW-1c	2/10/2015	40.0	0.7
	SW-1c	10/31/2015	47.2	1.0
	SW-2a	12/20/2014	45.9	1.3
	SW-2b	12/20/2014	42.6	0.8
	SW-2b	8/29/2015	41.4	0.6
	SW-2c	12/21/2014	40.6	0.7
	WSP1a	8/29/2015	39.0	11.4
	WSP1b	8/29/2015	39.1	0.8
	WSP1c	8/31/2015	41.2	0.6
	WSP1c	10/31/2015	45.5	3.6
	WSP2a	12/20/2014	50.3	3.7
	WSP2a	1/17/2015	41.7	0.6
	WSP2a	2/5/2015	45.3	1.4
	WSP2a	8/29/2015	40.6	5.0
	WSP2b	12/20/2014	46.5	1.8
	WSP2b	8/29/2015	41.5	0.7
	WSP2b	10/31/2015	41.8	1.4
	WSP2c	12/21/2014	48.7	2.4
	WSP2c	2/10/2015	41.0	1.6
	WSP2c	10/31/2015	39.5	1.4

Table 4-11. Summary of Surface Water and Lake Water Results with Detectable Total Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Zinc (µg/L)
	WSP3a	12/20/2014	50.9	1.2
	WSP3a	2/5/2015	45.4	1.9
	WSP3a	8/29/2015	38.9	3.1
	WSP3b	12/20/2014	47.2	1.4
	WSP3b	1/18/2015	46.2	0.9
	WSP3b	8/29/2015	40.8	0.6
	WSP3c	2/10/2015	43.0	2.2
	WSP4a	12/20/2014	51.3	4.4
	WSP4a	2/5/2015	44.3	0.9
	WSP4a	8/29/2015	39.5	4.2
	WSP4b	12/20/2014	45.8	2.4
	WSP4b	8/29/2015	40.7	0.7
	WSP4c	12/21/2014	47.9	1.6
	WSP4c	10/31/2015	43.8	11.8
Lake water samples	LW-1	10/28/2014	51.8	9.4
	LW-1	11/20/2014	47.0	4.0
	LW-1	12/17/2014	52.0	2.4
	LW-1	1/15/2015	68.2	3.5
	LW-1	2/26/2015	39.8	2.8
	LW-1	3/26/2015	59.5	2.3
	LW-1E	10/8/2015	25.5	1.0
	LW-1H	7/1/2015	39.0	0.8
	LW-2	10/28/2014	51.4	1.8
	LW-2	11/20/2014	45.7	2.4
	LW-2	12/17/2014	51.5	1.7
	LW-2	2/26/2015	42.0	2.1
	LW-2	3/26/2015	53.6	1.6
	LW-3	11/20/2014	47.1	2.0
	LW-3	12/17/2014	51.8	1.0
	LW-3	2/26/2015	41.1	4.3
	LW-3	3/26/2015	43.3	2.3

Notes:

During each storm event, three grab samples were collected at 12-hour intervals from each creek. The first stormwater samples were labeled with an "a," the second sample with a "b," and the third sample with a "c."

4.1.3.4 Metals and Hardness in Groundwater

This section provides a summary of hardness, dissolved metals, and total recoverable metals in the groundwater samples. The State aquatic life/metal criteria do not apply to groundwater. Ambient groundwater monitoring statistics and summaries of results that were above non-detect for total copper and total zinc are provided for illustrative purposes below, for reference only.

4.1.3.4.1 Hardness in Groundwater Samples

Hardness data were collected at all groundwater sampling locations. Their ranges are shown in Table 4-12.

Table 4-12. Hardness Ranges in Groundwater Samples (mg/L) in Spanaway Lake Watershed				
Monitoring Location	Sample Location	Minimum	Average	Maximum
Groundwater	LMP-GW1	21.1	33.0	57.0
	LMP-GW2	36.7	38.0	39.4
	LMP-GW3	35.6	43.7	55.3
	LMP-GW4	33.8	49.1	60.1
	LMP-GW5	27.0	30.1	37.1
	LMP-GW6	28.2	37.6	48.8
	WSP-GW1	33.6	46.2	50.9
	WSP-GW2	28.4	32.2	38.2
	WSP-GW3	33.9	45.4	57.1
	WSP-GW4	12.4	32.2	48.5
	WSP-GW5	24.4	29.4	34.4
	WSP-GW6	28.4	34.5	42.6

4.1.3.4.2 Dissolved Metals in Groundwater Samples

None of the groundwater samples collected during this study contained dissolved copper above the detection limit. Table 4-13 provides a summary of the groundwater dissolved copper monitoring statistics.

Table 4-14 provides a summary of the dissolved zinc results for groundwater samples. Table 4-15 provides additional details for the groundwater samples that had detectable dissolved zinc concentrations.

Five samples contained dissolved zinc above the detection limit of 0.5 µg/L. Elevated dissolved zinc concentrations of 106 µg/L and 116 µg/L were observed in LMP-GW2. These anomalous results are suspicious and may be due to contamination from washroom cleaning public toilets located nearby. Because of the low dissolved zinc concentrations observed in the receiving waters (lake and creeks), these elevated dissolved zinc concentrations are considered not representative of major influx to the receiving water bodies.

Table 4-13. Groundwater Dissolved Copper (µg/L) Monitoring Statistics in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Groundwater samples	LMP-GW1	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	LMP-GW2	<0.5 U	<0.5 U	<0.5 U	<0.5 U	4
	LMP-GW3	<0.5 U	<0.5 U	<0.5 U	<0.5 U	7
	LMP-GW4	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	LMP-GW5	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	LMP-GW6	<0.5 U	<0.5 U	<0.5 U	<0.5 U	4
	WSP-GW1	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	WSP-GW2	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	WSP-GW3	<0.5 U	<0.5 U	<0.5 U	<0.5 U	5
	WSP-GW4	<0.5 U	<0.5 U	<0.5 U	<0.5 U	6
	WSP-GW5	<0.5 U	<0.5 U	<0.5 U	<0.5 U	4
	WSP-GW6	<0.5 U	<0.5 U	<0.5 U	<0.5 U	6

Notes:

U = compound was analyzed and not detected.

A lower detection limit of 0.2 µg/L instead of 0.5 µg/L was used for some of the analytes in March 2016.

Table 4-14. Groundwater Dissolved Zinc (µg/L) Monitoring Statistics in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Groundwater samples	LMP-GW1	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW2	<0.50 U	56.00	53.00	116.0	4



Table 4-14. Groundwater Dissolved Zinc ($\mu\text{g/L}$) Monitoring Statistics in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
	LMP-GW3	<0.50 U	0.53	0.25	2.20	7
	LMP-GW4	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW5	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW6	<0.50 U	<0.50 U	<0.50 U	<0.50 U	4
	WSP-GW1	<0.50 U	0.50	0.25	1.50	5
	WSP-GW2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	WSP-GW3	<0.50 U	0.38	0.25	0.90	5
	WSP-GW4	<0.50 U	<0.50 U	<0.50 U	<0.50 U	6
	WSP-GW5	<0.50 U	<0.50 U	<0.50 U	<0.50 U	4
	WSP-GW6	<0.50 U	<0.50 U	<0.50 U	<0.50 U	6

Notes:

U = compound was analyzed and not detected.

Statistics calculated using half the detection limit (0.5 $\mu\text{g/L}$).

Dissolved zinc concentrations for sample result WSP-GW1 and its duplicate, WSP-GW1_dup during the 3/25/2015 sample event was 1.5 $\mu\text{g/L}$ and 1.1 $\mu\text{g/L}$, respectively. The statistical results listed in this summary table do not include results from the duplicate sample.

Table 4-15. Summary of Groundwater Results with Detectable Dissolved Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Dissolved Zinc ($\mu\text{g/L}$)
Groundwater samples	LMP-GW2	12/9/2015	38.8	106 .0
	LMP-GW2	3/14/2016	39.4	116 .0
	LMP-GW3	3/18/2015	42.6	2.2
	WSP-GW1	3/25/2015	58.0	1.5
	WSP-GW3	3/18/2015	36.3	0.9

4.1.3.5 Total Recoverable Metals in Groundwater Samples

Ambient groundwater monitoring statistics and summaries of results that were above non-detect for total copper and total zinc are provided for illustrative purposes below, for reference only.

As shown in Table 4-16, the average total copper concentrations from the groundwater samples are below 0.53 µg/L. The highest concentration, 2.2 µg/L, was from location LMP-GW2. As summarized in Table 4-17, 3 samples contained total copper above the detection limit of 0.5 µg/L.

As shown in Table 4-18, the average total zinc concentrations from the groundwater samples are below 1.06 µg/L. The highest concentration was from location LMP-GW2, 141 µg/L. As summarized in Table 4-19, 11 samples contained total zinc above the detection limit of 0.5 µg/L.

Table 4-16. Total Copper (µg/L) Groundwater Monitoring Statistics in Spanaway Lake Watershed						
Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Groundwater samples	LMP-GW1	<0.5 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	4
	LMP-GW3	<0.50 U	0.53	0.25	2.2	7
	LMP-GW4	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW5	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	LMP-GW6	<0.50 U	<0.50 U	<0.50 U	<0.50 U	4
	WSP-GW1	<0.50 U	0.44	0.25	1.4	6
	WSP-GW2	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	WSP-GW3	<0.50 U	<0.50 U	<0.50 U	<0.50 U	5
	WSP-GW4	<0.50 U	0.53	0.25	1.9	6
	WSP-GW5	<0.50 U	<0.50 U	<0.50 U	<0.50 U	4
	WSP-GW6	<0.50 U	<0.50 U	<0.50 U	<0.50 U	6

Notes:

U = compound was analyzed and not detected.

Statistics calculated using half the detection limit (0.5 µg/L). Some analytes in March 2016 were analyzed with a lower detection limit (0.2 µg/L). Half of the applicable detection limits were used for calculating statistics.

Table 4-17. Summary of Groundwater Results with Detectable Total Copper Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Copper (µg/L)
Groundwater	LMP-GW3	3/18/2015	42.6	2.2
	WSP-GW1	3/17/2016	40.8	1.4
	WSP-GW4	3/23/2015	12.4	1.9

Table 4-18. Total Zinc (µg/L) Ambient Groundwater Monitoring Statistics in Spanaway Lake Watershed

Media Type	Sample Location	Minimum	Average	Median	Maximum	Number of Samples
Groundwater	LMP-GW1	<0.50 U	0.25	0.25	0.25	5
	LMP-GW2	<0.50 U	64	57	141	4
	LMP-GW3	<0.50 U	1.0	0.25	4.1	7
	LMP-GW4	<0.50 U	0.42	0.25	1.1	5
	LMP-GW5	<0.50 U	0.72	0.25	2.6	5
	LMP-GW6	<0.50 U	0.49	0.25	1.2	4
	WSP-GW1	<0.50 U	0.70	0.25	1.7	6
	WSP-GW2	<0.50 U	0.38	0.25	0.9	5
	WSP-GW3	<0.50 U	0.46	0.25	1.3	5
	WSP-GW4	<0.50 U	0.25	0.25	0.25	6
	WSP-GW5	<0.50 U	0.25	0.25	0.25	4
	WSP-GW6	<0.50 U	0.25	0.25	0.25	6

Notes:

Statistics calculated using half the detection limit (0.5 µg/L).

Table 4-19. Summary of Groundwater Results with Detectable Total Zinc Concentrations in Spanaway Lake Watershed

Media Type	Sample Location	Sample Date	Total Hardness (mg/L)	Total Copper (µg/L)
Groundwater	LMP-GW2	12/9/2015	38.8	113
	LMP-GW2	3/14/2016	39.4	141
	LMP-GW3	3/18/2015	42.6	4.1
	LMP-GW3	7/23/2015	38.0	2.1
	LMP-GW4	3/18/2015	59.1	1.1
	LMP-GW5	3/24/2016	28.8	2.6
	LMP-GW6	3/25/2015	48.8	1.2
	WSP-GW1	3/25/2015	58.0	1.7
	WSP-GW1	3/17/2016	40.8	1.5
	WSP-GW2	3/23/2015	31.1	0.9
	WSP-GW3	3/18/2015	36.3	1.3

4.1.3.6 Copper and Zinc Sources in the Spanaway Lake WSP Area

As noted above, only one of the creek or lake samples collected for the WSP exceeded the acute or chronic criteria for dissolved copper. One sample collected near the middle of Spanaway Lake (sampling location LW-3) contained 7.5 µg/L of dissolved copper, which is slightly above the chronic criteria (4-day average concentration of 6.0 µg/L). As stated above, single grab samples have a much greater chance of exceeding chronic criteria than 4-day averages do (Ecology 2016b).

MS4 discharges do not appear to be a likely source for the elevated copper concentration in the LW-3 sample because nearly all stormwater runoff from impervious areas in the watershed is infiltrated, and none of the groundwater samples upgradient of the lake contained dissolved copper above the detection limit (0.5 µg/L). Samples collected from Coffee Creek upstream of the lake had considerably lower dissolved copper concentrations than the LW-3 sample.

Domestic septic system effluent typically contains low concentrations of copper and zinc. Copper and zinc in the subsurface are subject to specific adsorption on ferric, aluminum, and manganese hydroxides. None of the monitoring wells around the lake contained detectable dissolved copper concentrations. Thus, septic systems do not appear to be a likely source.

It is possible that the elevated dissolved copper concentration in the mid-lake sample could be related to historical use of copper sulfate for algae control. Copper sulfate was reportedly used as an algicide in Spanaway Lake (Longfellow and Holt 2004).



Dissolved zinc concentrations in all the creek and lake samples were far below the acute and chronic criteria. Two groundwater samples collected from the monitoring well near the Spanaway Park boat ramp (LMP-GW2) contained elevated zinc concentrations. It is possible that runoff from the boat ramp is affecting this shallow monitoring well. Potential zinc sources associated with boat ramps include sacrificial anodes on hulls and motors, motor oil, galvanized metal trailers, and tires. Another possible source is runoff generated during cleaning of a public restroom near the well. This bathroom and the rest of the park is connected to the sanitary sewer system rather than onsite septic systems. There are no MS4 outfalls near LMP-GW2.

4.1.4 Fecal Coliform Bacteria

Fecal coliform bacteria are commonly used as an indicator of possible fecal contamination because they originate in human and animal feces. Although they are generally not harmful themselves, they indicate the potential presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Therefore, their presence in streams suggests that pathogenic microorganisms might also be present and that swimming in or eating shellfish from these waters might be a health risk.

The State water quality standards for fecal coliform vary depending on the designated uses of the water body. Spanaway Lake (sample locations LW-1, LW-2, and LW-3) and Coffee Creek upstream of the lake (sample locations WSP1 and SW-2) are designated for extraordinary contact. For water bodies with this designated use, the geometric mean fecal coliform concentration should not exceed 50 cfu/100 mL and no more than 10 percent of samples can have concentrations exceeding 100 cfu/100 mL. The water bodies downstream of the lake (sample locations SW-1, WSP2, WSP3, and WSP4) are designated for primary contact. For these water bodies, the geometric mean fecal coliform concentration must not exceed 100 cfu/100 mL and less than 10 percent of samples should have concentrations exceeding 200 cfu/100 mL.

Figure 4-10 shows the fecal coliform concentrations in the lake, creek, and groundwater samples.

Lake Water Sampling

Fecal coliform concentrations in the lake water samples ranged from non-detect to 80 cfu/100 mL. All the lake water samples met both parts of the State's fecal coliform criteria, as shown in Table 4-20 below.

Table 4-20. Fecal Coliform Bacteria (cfu/100 mL) Results: Routine Surface Water Sampling from Creeks & Lake (10/2014–3/2016) in Spanaway Lake Watershed

WSP Site ID	Water Body	Wet Season			Dry Season			Full Year		
		Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}	Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}	Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}
Marsh	JBLM marsh	11	3	36	5	51	40	16	7	38
WSP1	Coffee Creek below marsh	8	0.31	0	5	3	0	13	1	0
SW-2	Coffee Creek at Spanaway Loop Rd.	13	4	0	5	71	40	18	8	11
LW-3	Spanaway Lake: south	9	0.01	0	10	0.01	0	19	0.01	0
LW-2	Spanaway Lake: northwest	9	0	0	10	0.01	0	19	0	0
LW-1	Spanaway Lake: north	11	0.02	0	20	0.01	0	31	0.01	0
SW-1	Spanaway Creek at Military Rd.	13	12	0	5	74	20	18	20	6
WSP2	138th/Spanaway	13	6	8	5	166	40	18	15	17
WSP4	Morey Creek	13	12	0	5	373	80	18	32	22
WSP3	Tule Lake outlet	12	56	0	5	124	40	17	71	12

Notes:

ND = non-detect. (Geomean calculations used a value of 0.001 for concentrations below detection limits.)

Values in bold exceed criteria.

Wet season is from October 1 through April 31. Dry season is from May 1 through September 30.

- For water bodies with extraordinary contact designated use (Marsh, SW-2, and WSP1), the geometric mean fecal coliform concentration should not exceed 50 cfu/100 mL and no more than 10% of samples can have concentrations exceeding 100 cfu/100 mL.
- The water bodies downstream of the lake (SW-1, WSP2, WSP3, and WSP4) are designated for primary contact; the geometric mean fecal coliform concentration must not exceed 100 cfu/100 mL and less than 10% of samples should have concentrations exceeding 200 cfu/100 mL.

Routine Water Sampling from Creeks

Routine surface water fecal coliform results were evaluated under three periods: during the wet season (October 1 through April 31), dry season (May 1 to September 30), and full year. Table 4-20 provides a summary of these results.

As summarized in Table 4-20, the fecal coliform concentrations in the marsh did not meet the Part 1 criterion, which states that the geometric mean fecal coliform concentration should not exceed 50 cfu/100 mL for the dry season. The marsh also did not meet the Part 2 criterion, which states that no more than 10 percent of samples can have concentrations exceeding 100 cfu/100 mL during the wet season, dry season, and full year.

Fecal coliform concentrations at WSP1 met all criteria for each evaluation period. Fecal coliform results for SW-2 (Coffee Creek) did not meet Part 1 criteria for the dry season and did not meet the Part 2 criteria for the dry season and full year evaluation periods. SW-2 is in Coffee Creek, upstream of the lake. Coffee 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.

Fecal coliform concentrations from the downstream locations included SW-1, WSP2, WSP3, and WSP4. During the wet season and full year evaluation period, each of these locations met Part 1 of the criteria. During the dry season, WSP2, WSP3, and WSP4 exceeded the Part 1 criteria. During the dry season, each location exceeded Part 2 of the criteria. For the full year evaluation period, WSP2, WSP3, and WSP4 exceeded the Part 2 criteria.

Stormwater Sampling from Creeks

Stormwater surface water fecal coliform results were evaluated under three periods: during the wet season (October 1 through April 31), dry season (May 1 to September 30), and full year. Table 4-21 provides a summary of these results.

As summarized in Table 4-21, the fecal coliform concentrations in the marsh did not meet the Part 1 criterion, which states that the geometric mean fecal coliform concentration should not exceed 50 cfu/100 mL for the dry season. The marsh also did not meet the Part 2 criterion, which states that no more than 10 percent of samples can have concentrations exceeding 100 cfu/100 mL during the wet season, dry season, and full year. Waterfowl and other wildlife are the likely source of the fecal coliform measured in the samples from the marsh.

Fecal coliform concentrations at WSP1 and SW-2 met the Part 1 criteria for each evaluation period. However, WSP1 exceeded the Part 2 criteria during the wet season and full year period and SW-2 exceeded the Part 2 criteria during each evaluation period. As stated above, SW-2 is in Coffee Creek, upstream of the lake. Coffee Creek originates below a large wetland complex on JBLM and passes through more wetland areas between JBLM and Spanaway Loop Road. 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 is the most likely source of fecal coliform bacteria to Coffee Creek at SW-2.

Fecal coliform concentrations from the downstream locations included SW-1, WSP2, WSP3, and WSP4. During the wet season, each location met the Part 1 criteria; however, Part 2 was exceeded. During the dry season, each location exceeded both Part 1 and Part 2 criteria. For the full year evaluation period, SW-1 and WSP3 met the Part 1 criteria and exceeded the Part 2 criteria, whereas WSP2 and WSP4 exceeded both Part 1 and Part 2 criteria.



Table 4-21. Fecal Coliform Bacteria (cfu/100 mL) Monitoring Results: Stormwater Samples from Creeks (12/2014–10/2015) in Spanaway Lake Watershed

WSP Site ID	Water Body	Wet Season			Dry Season			Full Year		
		Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}	Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}	Count	Geomean	Percent of Samples > 100 or 200 ^{a,b}
Marsh	JBLM marsh	12	2	33	6	205	50	18	8	39
WSP1	Coffee Creek below marsh	3	1	33	3	23	0	6	4	17
SW-2	Coffee Creek at Spanaway Loop Rd.	12	5	17	6	69	50	18	12	28
SW-1	Spanaway Creek at Military Rd.	12	22	25	6	484	100	18	62	50
WSP2	138th/Spanaway	12	66	25	6	289	67	18	108	39
WSP4	Morey Creek	12	26	25	6	241	50	18	55	33
WSP3	Tule Lake outlet	12	89	25	6	213	50	18	119	28

Notes:

ND = non-detect. (Geomean calculations used a value of 0.001 for concentrations below detection limits.)

Values in bold exceed criteria.

Wet season is from October 1 through April 31. Dry season is from May 1 through September 30.

- For water bodies with extraordinary contact designated use (Marsh, SW-2, and WSP1), the geometric mean fecal coliform concentration should not exceed 50 cfu/100 mL and no more than 10% of samples can have concentrations exceeding 100 cfu/100 mL.
- The water bodies downstream of the lake (SW-1, WSP2, WSP3, and WSP4) are designated for primary contact; the geometric mean fecal coliform concentration must not exceed 100 cfu/100 mL and less than 10% of samples should have concentrations exceeding 200 cfu/100 mL.

Groundwater Sampling

Fecal coliform concentrations in the groundwater samples ranged from non-detect to 120 cfu/100 mL (Table 4-22). As shown in Figure 4-10 below, the groundwater samples generally had lower fecal coliform concentrations than samples collected from the creeks. Samples collected from the monitoring wells near the lake (LMP-GW1, LMP-GW3, LMP-GW4, and LMP-GW6) had low fecal coliform concentrations except for one sample collected from the monitoring well located in the County park (LMP-GW2). MODFLOW particle tracking shows that most of the groundwater discharge to Spanaway Lake comes from the south, where monitoring wells LMP-GW1, LMP-GW4, and LMP-GW3 are located. As shown in Table 4-22, LMP-GW1 and LMP-GW4 had no fecal coliform detections, while one result of 10 cfu/100 mL was found in one sample from LMP-GW3. The MODFLOW results indicate that LMP-GW5 is downgradient of the lake. The highest fecal coliform concentration was observed in a sample collected from WSP-GW6, which is in a portion of JBLM with no known human-related sources.

Table 4-22. Fecal Coliform Bacteria Monitoring Results: Groundwater in Spanaway Lake Watershed

Site ID	Number of Samples	Fecal Coliform (cfu/100 mL)	
		Minimum	Maximum
LMP-GW1	4	ND	ND
LMP-GW2	4	ND	100
LMP-GW3	10	ND	10
LMP-GW4	5	ND	ND
LMP-GW5	5	ND	115
LMP-GW6	4	ND	ND
WSP-GW1	8	ND	ND
WSP-GW2	8	ND	10
WSP-GW3	8	ND	10
WSP-GW4	9	ND	13
WSP-GW5	7	ND	ND
WSP-GW6	9	ND	120

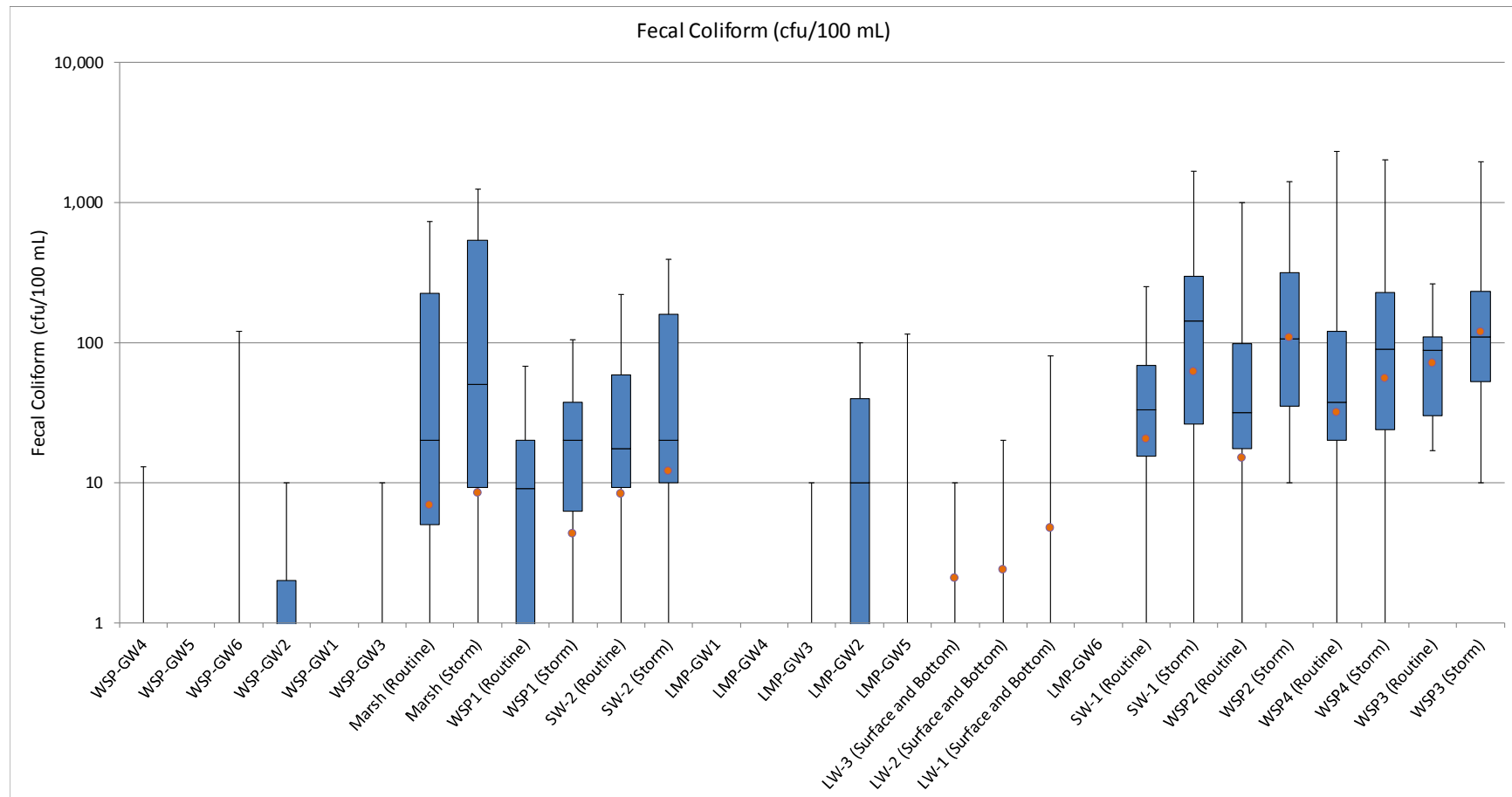


Figure 4-10. Fecal coliform concentrations in lake, creeks, and groundwater in Spanaway Lake watershed

4.1.4.1 Fecal Coliform Sources in the Spanaway Lake WSP Area

Elevated fecal coliform concentrations were observed at most monitoring locations during the WSP monitoring period. Potential sources include septic systems, stormwater runoff, and wildlife. The following sections describe each potential source.

Coffee Creek (SW-2)

Coffee Creek concentrations were considerably higher than the lake water samples collected from LW-1, LW-2, and LW-3. The Coffee Creek sub-basin upstream of SW-2 has very little development (~1 percent urban). Most of the sub-basin is in a portion of JBLM covered with forest, prairie, and a large marsh. Samples collected from the JBLM marsh, which is about ½ mile upstream of SW-2, contained higher fecal coliform concentrations than SW-2. The marsh supports a large wildlife population with more than 20 species of waterfowl and 110 other bird species (ebird.org 2017). Thus, the land use and monitoring data suggest that wildlife is the predominant source of fecal coliform bacteria in Coffee Creek upstream of Spanaway Loop Road. Coffee Creek may receive additional fecal coliform via stormwater runoff from the residential areas located along the creek downstream of Spanaway Loop Road.

Septic Systems

The WSP area includes more than 4,000 onsite sewage disposal systems (OSDSs) or septic systems. For the Spanaway LMP project, BC developed a model to estimate fecal coliform loads from septic systems in the watershed based on typical fecal coliform concentration in drainfield effluent, location/distance to lake, estimated depth to groundwater, and technical literature on subsurface transport and die-off rates. The model results indicated that septic systems more than 350 feet from the lake are unlikely to contribute fecal bacteria to the lake because of filtering, adsorption, and die-off.

Approximately 60 septic systems are located in groundwater capture zones within 350 feet of the gaining reaches of Spanaway Lake, Spanaway Creek, or Morey Creek. Of these systems, approximately 48 have estimated depths to groundwater of less than 10 feet. These systems are likely to have fecal coliform removal efficiencies on the order of 1- 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 new pressurized systems in the Spanaway, Tillicum, and Bethel areas (TPCHD 1994). 1-log removal would result in a concentration of 75,000 cfu/100 mL, while 4-log removal would result in 75 cfu/100 mL. This suggests 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 (BC 2016).

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. Pets and livestock are also potential sources. Livestock have been observed near Spanaway Creek downstream of Morey Creek. Creek flooding could mobilize fecal material from domestic animals and wildlife.

Because of the very permeable soils and lack of surface conveyance systems, there is relatively little direct stormwater runoff to the receiving water bodies in the Spanaway Lake WSP. The HSPF model simulations indicate that groundwater provides 99 percent of the total discharge of the Spanaway Lake WSP lakes and creeks. The only significant stormwater discharge is from the Military Road drainage system, which enters Spanaway Creek downstream of Spanaway Lake. The watershed model indicates that stormwater from the Military Road outfall composes less than 2 percent of the annual flow in Spanaway Creek.

Stormwater Infiltration Facilities

Infiltrated stormwater from impervious areas is another potential fecal coliform source. The WSP area contains more than 1,400 stormwater infiltration structures including drywells, trenches, and ponds. The septic system evaluation cited above found that septic systems more than 350 feet from the lake are unlikely to contribute appreciable fecal coliform to the lake. Fecal coliform concentrations in stormwater are typically several orders of magnitude lower than fecal coliform concentrations in septic tank effluent. Therefore, stormwater infiltration facilities more than 350 feet from receiving water bodies are not expected to be significant sources of fecal coliform. Two County infiltration ponds and approximately 20 drywells are located in groundwater capture zones within 350 feet upgradient of receiving water bodies in the WSP area.

Wildlife

Waterfowl and other wildlife can be a significant source of fecal bacteria to lakes and creeks. Alderisio and DeLuca (1999) reported that Canada goose droppings had an average of 15,300 fecal coliforms 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* bacteria 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 dropping generated about one fourth as much fecal material as the average goose dropping. A 2002–03 microbial source tracking study in the Clarks Creek watershed found that about two thirds of the 680 fecal samples analyzed were from birds and rodents (Milne et al. 2004). A study conducted in the Tualatin watershed found similar results (Clean Water Services 2006).

More than 20 waterfowl species have been observed on Spanaway Lake (eBird 2017). Ecology and TPCHD have observed as many as 75 geese and 400 other waterfowl in the northern portion of Spanaway Lake. More than 130 bird species including 20 species of waterfowl have been observed at JBLM marsh. The land use data, limited direct stormwater runoff, and dry weather fecal coliform concentrations suggest that waterfowl and other riparian animals may be an important source in the Spanaway Lake WSP.

4.1.5 Benthic Macroinvertebrates

An evaluation of benthic habitat conditions in the Spanaway Lake watershed was conducted based on Puget Sound Lowlands B-IBI scores.

B-IBI scores are calculated using the benthic macroinvertebrate community found in undisturbed conditions as a benchmark. The Puget Sound Lowlands B-IBI is based primarily on targeted riffle samples from moderate to high-gradient streams with coarse sediments (Karr and Chu 1999, Fore et al. 1996, Morley and Karr 2002).

The MS4 Permit requires that the WSP predict future B-IBI scores in the Spanaway Lake watershed based on hydrologic modeling and regression equations developed for other creeks in the Puget Sound lowlands (DeGasperi et al. 2009). If the modeling results indicate that future B-IBI scores are likely to be less than 38 (the threshold for “good” benthic conditions under the 10–50 B-IBI scoring system), or less than 90 percent of the model-simulated historical B-IBI scores, then the WSP must include stormwater management strategies for achieving the B-IBI target scores.

4.1.5.1 Background

This section provides background information on benthic macroinvertebrates as indicators of human impacts on streams.

4.1.5.1.1 Human Impacts on Urban Streams

Numerous studies have shown that urban development can adversely affect watershed health (Booth et al. 2016; Dorfmeier 2014; Fore et al. 2013; King County 2012; DeGasperi et al. 2009; May et al. 1997; Morley and Karr 2002; Booth et al. 2005; Waite et al. 2008). For example, Fore et al. evaluated B-IBI and watershed data from more than 700 sites in the Puget Sound lowlands and found that B-IBI was highly correlated with watershed urbanization (Fore et al. 2013).

Urbanization involves replacing native vegetation and topsoil with impervious surfaces, which reduces infiltration and evapotranspiration, and construction of artificial drainage networks designed to quickly convey runoff to receiving water bodies. These landscape alterations

reduce base flows and increase peak flows. Moreover, they can increase the frequency and duration of geomorphically significant flows, causing stream channel erosion, down-cutting, and instability problems. Benthic macroinvertebrates in Puget Sound lowland streams evolved under pre-development flow regimes and are best adapted to those flow patterns.

Stormwater runoff from urban and agricultural areas can carry toxic substances (e.g., metals and pesticides), nutrients, sediments, oxygen-demanding substances, pathogens (e.g., bacteria, viruses, and parasites), and other pollutants to receiving water bodies. In addition, stream temperatures can increase because of removal of riparian vegetation, reduced base flows, and artificial impoundments.

The general “causal sequence” by which human activities can impair stream health is shown in Figure 4-11.

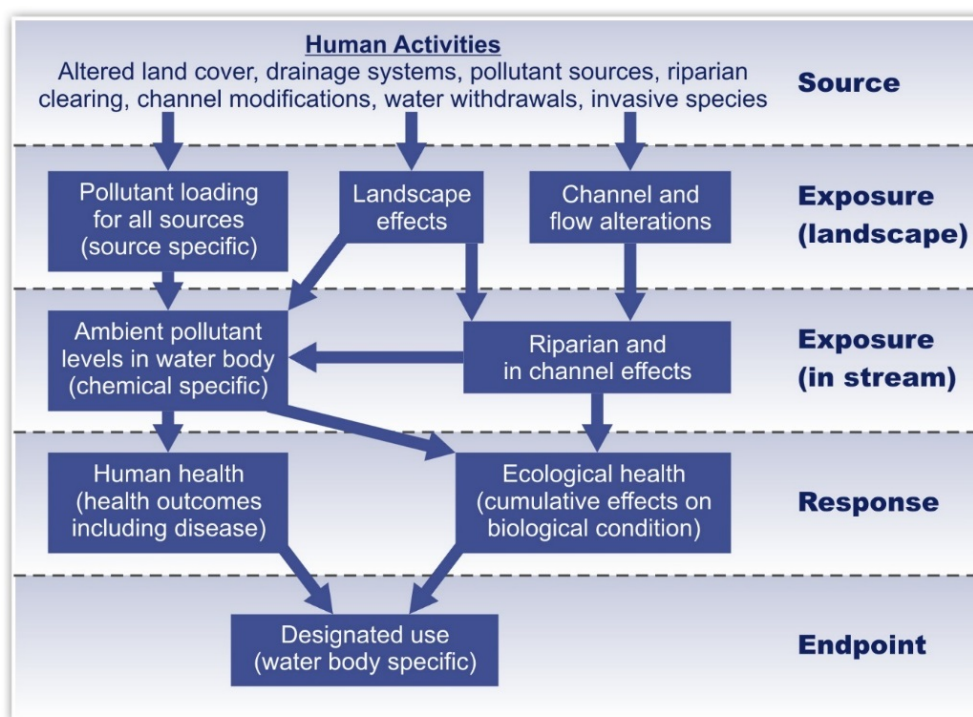


Figure 4-11. Causal sequence by which human activities affect receiving waters

Source: U.S. EPA 2005, modified from Karr and Yoder 2004.

As shown in Figure 4-11, a wide range of human activities can affect stream health. Municipal stormwater management can affect some, but not all, of these activities. The potential for improving stream health through municipal stormwater management actions can vary depending on the specific stressors affecting the stream.

4.1.5.1.2 Indicators of Aquatic Health

The potential impacts resulting from human activities can be assessed at each level in the causal sequence (Figure 4-11). However, indicators at the “response” level, such as benthic macroinvertebrate or fish assemblages, are the closest to the designated uses of the water bodies (Karr and Yoder 2004; U.S. EPA 2005). Response indicators reflect the combined influence of all in-stream exposures, landscape exposures, and sources throughout the watershed.

Direct measurements of resident biota in surface waters are the most appropriate means of evaluating the capacity of an ecosystem to support aquatic life (Barbour et al. 2007; Karr and Yoder 2004; U.S. EPA 2000). These methods measure the response of the resident biota to the combined effects of water pollution (e.g., toxics, nutrients, sediment, and temperature), altered hydrology, channel instability, and other stressors affecting the water body. Many jurisdictions (including the County) routinely conduct benthic macroinvertebrate sampling to help evaluate biological conditions in receiving water bodies.

Puget Sound B-IBI

Assessment of benthic macroinvertebrate communities in wadable streams as a measure of the degree of human disturbance on biota has been used regionally since the early 1990s (Morley and Karr 2002). There are several reasons for this method’s popularity. Benthic macroinvertebrate populations are diverse, abundant, relatively easy and inexpensive to collect and analyze, and capable of repopulation after collection or disturbance. Benthic macroinvertebrates respond to and integrate physical and chemical aspects of their environment through time. Species common in lotic waters of the Puget Sound lowlands have unique life-cycle requirements that are diagnostic of temperature regimes, nutrient enrichment, and other stressors to aquatic ecosystems.

The Puget Sound Lowlands B-IBI is the primary assessment tool that has been used in the Pacific Northwest to evaluate stream biological conditions since the early 1990s (Morley and Karr 2002). This multimetric index is the sum of the values assigned to 10 metrics: total taxa richness; mayfly, stonefly, and caddisfly taxa richness; long-lived taxa richness; intolerant taxa richness; percent tolerant individuals; percent predator individuals; clinger taxa richness; and percent dominance of the three most dominant taxa (Wilhelm 2014). A more complete description of the 10 metrics, and their expected response to watershed disturbance, can be found in Attachment B, B-IBI and Biological Condition Gradient (BCG) Metrics.

The categories of biological condition assigned to B-IBI scores are described in Table 4-23. Several regional studies across hundreds of B-IBI sites in the Puget Sound area have been completed since the establishment of an online database and analysis tool, the Puget Sound



Stream Benthos (PSSB), created in 2008 by a consortium of Western Washington cities and counties.

Invertebrates that live in the sand, gravel, and cobble substrate of streams in the Pacific Northwest are a critical food source for young salmon. Stream invertebrates constitute 70 to 80 percent of juvenile salmonid food consumption after emergence from eggs and prior to returning to the ocean as smolt (Koehler et al. 2006).

In the 1990s, the B-IBI was developed as 10 individual metrics that originally were scored with a 1, 3, or 5 rating representing poor, fair, and good biological conditions in stream sites, respectively. The summed amount from the 10 metrics resulted in a score from 10 (worst) to 50 (best).

In 2012, the County and other Puget Sound jurisdictions agreed to update the Puget Sound Lowlands B-IBI as part of an EPA grant. The updated B-IBI scoring served several functions including the following:

- Incorporation of updated taxa lists using new taxonomic information
- Use of new empirically derived data available from a much more extensive Puget Sound lowlands data set
- Development of a cumulative B-IBI score without gaps
- Increased comparability of data sets analyzed at different levels of taxonomic resolution (Dorfmeier 2014)

The new B-IBI scoring system was on a scale of 0 to 10 for each metric, which were then added together to create a score from 0 (worst) to 100 (best). A crosswalk comparing the old and new B-IBI scoring systems and category definitions is shown in Table 4-23.

Municipal stormwater discharges are not the only cause for a low B-IBI score. Other human factors such as channel modifications, invasive species, and loss of habitat complexity can affect B-IBI scores. B-IBI scores are also affected by naturally occurring conditions such as channel slope, geology, soils, lakes, and wetlands. Most Puget Sound lowlands reference streams (representing the best available habitat for benthic macroinvertebrates) are cobble-riffle streams in higher-gradient areas of the Puget Sound region. B-IBI scores for low-gradient streams may be lower because of natural or historical conditions rather than modern human disturbance (Wisseman 2017).

Table 4-23. B-IBI Condition Categories and Scoring Comparison for Puget Sound

Biological Condition	Description	10–50 B-IBI	0–100 B-IBI
Excellent	Comparable to least disturbed reference condition. Overall high taxa diversity, particularly of mayflies; stoneflies; caddisflies; and long-lived, clinger, and intolerant taxa. Relative abundance of predators high.	46–50	80–100
Excellent/good		44–46	
Good	Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of mayflies, stoneflies, and caddisflies; proportion of tolerant taxa increases.	38–44	60–80
Good/fair		36–38	
Fair	Total taxa richness reduced: particularly intolerant, long-lived, stonefly, and clinger taxa; relative abundance of predators declines; proportion of tolerant taxa continues to increase.	28–36	40–60
Fair/poor		26–28	
Poor	Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; percent dominance of three most abundant taxa often very high.	18–26	20–40
Poor/very poor		16–18	
Very poor	Overall taxa diversity very low and dominated by a few highly tolerant taxa. Mayfly; stonefly; caddisfly; and clinger, long-lived, and intolerant taxa largely absent. Relative abundance of predators very low.	10–16	0–20

Biological Condition Gradient

Another method of assessing biological response to the increased presence of stressors on aquatic ecosystems is the BCG (U.S. EPA 2016). Like the Puget Sound Lowlands B-IBI, it uses stream macroinvertebrate samples to track the degree of change in an ecosystem from “as naturally occurs” to severely altered. The BCG also provides a numerical score that can be analyzed for positive or negative trends from year to year, and may be used to evaluate potential for improvement in impacted systems. Unlike the B-IBI, the preliminary Puget Sound Lowlands BCG considers the impact of stream gradient, and distinguishes between streams with greater than 1 percent slope and streams with less than 1 percent slope. The BCG also provides more diagnostic information on stressors than the B-IBI, because it incorporates information on more levels of sensitive and tolerant taxa, presence of organism anomalies, and degree of dominance by non-native taxa.

The Puget Sound Lowlands calibrated version of the BCG is still being developed (Wisseman 2017). Once finalized, it could be used as an alternative reportable metric for public outreach, including for the County's water quality report cards.

4.1.5.1.3 Stream Biological Potential

Bioassessments, such as the B-IBI, identify the degree of impairment compared to pristine or least disturbed "reference" watersheds. They do not necessarily establish reasonable thresholds or criteria for watersheds that have been substantially altered by human activities. Urban development generally entails an array of landscape changes and in-stream stressors that can adversely affect watershed health (see Figure 4-12, below). It is rarely feasible to eliminate these stressors from existing urban areas, especially areas that developed prior to current land use codes and stormwater management regulations (Booth et al. 2007).

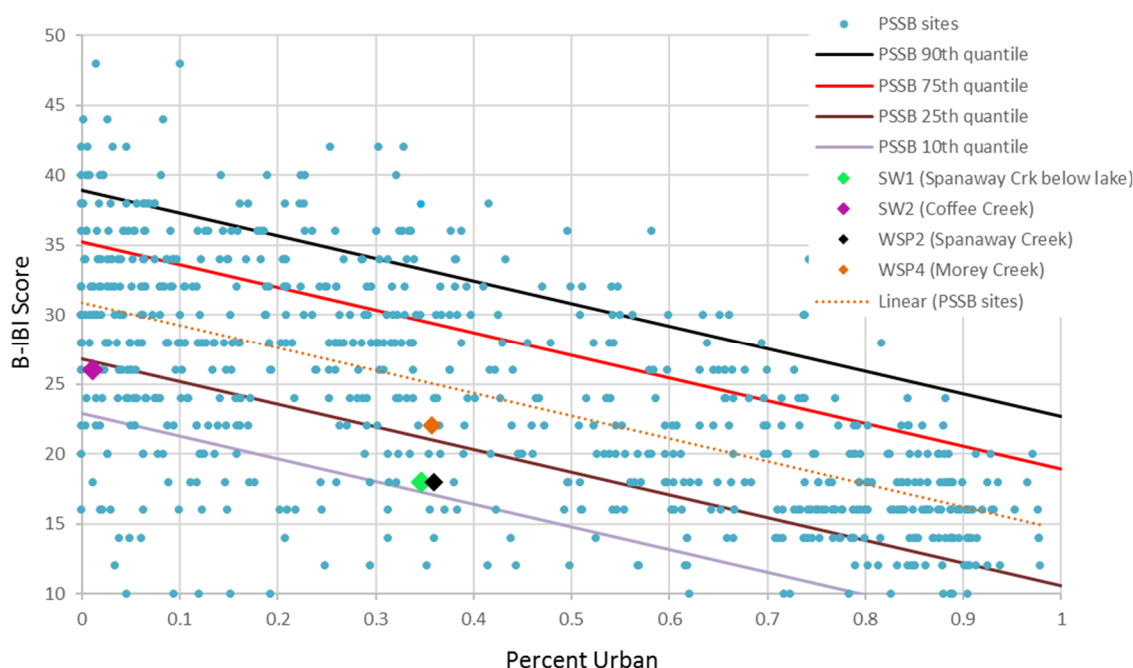


Figure 4-12. B-IBI score vs. percent urban in drainage area for Puget Sound Lowlands sites

To develop more appropriate expectations for urban stream biological condition, the Water Environment Research Foundation (WERF) (Barbour et al. 2007) developed a bioassessment tool to help estimate the biological potential for a water body based on its biological index value and urban development level. WERF's method was intended to allow managers to

compare existing biological conditions in an urban water body to the *potential* conditions that could be achieved given the nature and extent of the limiting factors caused by urban development. Barbour et al. plotted many biological index data points from three different regions of the United States against urban gradient index values for each sample location (Barbour et al. 2007). Using quantile-regression techniques, they established regression lines that indicate the probability of a specific percentage of the points falling below that line. Barbour et al. used the 90th quantile line to approximate the biological potential of a given site (Barbour et al. 2007). This approach was used when comparing the Spanaway Lake B-IBI results to other sites in the Puget Sound lowlands along an urbanization gradient in Section 4.1.5.3.

Biological potential can vary depending on natural conditions. The geology and natural land cover of the Spanaway Lake WSP are quite different from most of the Puget Sound lowlands. Enormous outburst floods from ancient glacial Lake Puyallup covered most of the watershed with relatively flat, very permeable gravel deposits dotted with kettle lakes (like Spanaway lake). Because of the very permeable soils and flat topography, the Spanaway Lake WSP stream network is quite small in proportion to the watershed area. Much of the Spanaway Lake WSP area was covered with prairie instead of forest (Troost 2014).

Low-gradient streams tend to have warmer water temperatures and lower DO because of longer water residence times. Lakes and wetlands in low-slope basins can result in additional warming. Depositional habitat where fine-grained sediment dominates is more common as channel slope decreases, though this kind of habitat was found at only one of the sites sampled for benthic macroinvertebrates (WSP4, Morey Creek). These factors can significantly affect the structure of the benthic invertebrate community (Wisseman 2017). Lower-gradient streams are capable of high productivity and high biodiversity in undisturbed situations where high habitat complexity exists (for example, upstream and downstream of beaver ponds). These sites are also frequently the sites most impacted by human disturbance, as they are the easiest sites to develop. Development usually entails draining water more rapidly from the landscape, which greatly reduces habitat complexity and favors tolerant organisms with short life cycles (Wisseman 2017).

Certain types of invertebrates are better adapted to low-gradient streams, which frequently have depositional areas dominated by fine sediment. These include organisms that burrow, sprawl, and swim within and across these deposits, and have a higher percentage of taxa that feed by collecting fine organic particles (collector-gatherers). Short-lived organisms that have multiple generations in a single year tend to be common. Taxa that are tolerant of low DO in the summer months are frequently found.

Listed below are other common attributes of low-gradient streams, particularly depositional streams dominated by fine sediment (Wisseman 2017):

- Total taxa richness is lower (B-IBI metric): Benthic communities in uniform fine sediment deposits are typically less diverse than those in more structurally complex cobble riffles. *Chironomid* midges, segmented worms, small clams, mites, and other warm water taxa can dominate.
- Taxa richness of *Ephemeroptera-Trichoptera-Plecoptera* (EPT) is lower (multiple B-IBI metrics): Species in these three insect orders typically dominate benthic communities in lotic waters with coarse substrates. Few species in these orders are adapted to living in/on fine sediment. Those that do occur are more tolerant of low DO and warmer water.
- Dominance is often higher (B-IBI metric): Communities often display super-dominance by a few taxa that are well adapted to this habitat.
- Intolerant taxa richness (B-IBI metric): Taxa identified as particularly intolerant of human disturbance in the Puget Sound lowland studies are typically cool-cold water species associated with coarse substrates of erosional habitats (Fore et al. 2013). Intolerant taxa associated with fine sediments have not been included.
- Tolerant taxa dominance (B-IBI metric): Taxa identified as particularly tolerant of human disturbance in the Puget Sound lowland studies are often ones associated naturally with fine sediment in depositional areas, as they are more resistant to lower DO and higher stream water temperatures (Fore et al. 2013).
- Clinger taxa richness is low (B-IBI metric): Most clingers require coarse gravel or cobble substrate.
- Long-lived taxa richness and abundance are lower (B-IBI metric): With simplified channels and lower habitat complexity, there is less refugia for longer-lived taxa during periods of higher and lower flows.
- Percent predator species is lower (B-IBI metric): Communities tend either to be predator-poor or to have a few larger predators that dominate the trophic group. Channelization and loss of habitat complexity may also reduce the available pool of predators.
- Higher percentage of tolerant Crustacea: Low-gradient streams tend to be in the valleys and basins where calcium ions are present in higher concentrations—this is important for mollusks and crustaceans to form shells.
- Higher percentage of non-insects: Calcium- and macrophyte-rich streams with lots of fine particulate matter favor non-insects, including crustaceans, worms, and mollusks.
- High diversity and percentage of *Chironomidae* taxa: Chironomids are a diverse taxa group, well represented in both lentic and lotic habitats. Midge communities in low-gradient streams have a wide range of species present, representing both erosional-lotic and depositional-lentic associated species.

As noted above, the Puget Sound Lowlands B-IBI is based primarily on targeted riffle samples from moderate to high-gradient streams with coarse sediments (Karr and Chu 1999, Fore et al. 1996, Morley and Karr 2002). Ideally, benthic data from low-gradient streams in developed

areas should be compared to low-gradient streams in undisturbed areas; however, appropriate reference sites for low-gradient Puget Sound lowland streams have yet to be identified.

4.1.5.2 Monitoring Results

Table 4-24 summarizes the monitoring results for benthic macroinvertebrate samples collected for the Spanaway Lake WSP. For comparison, Ecology's proposed Regional Stormwater Monitoring Program (RSMP) biological indicator threshold for B-IBI scores on the 0–100 scale is 60.8 (DeGasperi 2016). All the sites fell below this threshold. The highest B-IBI score (40) was observed in Coffee Creek just upstream of Spanaway Lake. The lowest score (11) was observed in Spanaway Creek just downstream of the lake outlet. Morey Creek and Spanaway Creek just downstream of the split with Morey Creek share an almost identical drainage area, yet their scores were significantly different (14.5 for lower Spanaway Creek versus 35.3 for Morey Creek). This suggests that the difference in B-IBI scores at WSP2 and WSP4 may be attributable to local conditions.

Table 4-24. B-IBI Results for Spanaway Lake WSP Monitoring Sites													
Site Code	Site Name	Year	Scores: 0–100 Scale, 2012 Taxa List										
			Overall Score	Taxa Richness	Ephemeroptera Richness	Plecoptera Richness	Trichoptera Richness	Clinger Richness	Long-lived Richness	Intolerant Richness	Percent Dominant	Predator Percent	Tolerant Percent
SW-1	Spanaway Lake outlet	2015	11	0.3	0.0	0.0	2.5	0.6	5.0	0.0	1.3	1.3	0.0
SW-2	Coffee Creek	2015	40	4.1	4.3	5.7	3.8	4.1	2.5	0.0	5.3	3.3	7.4
WSP2	Spanaway Creek	2015	14	2.4	0.0	0.0	2.5	0.0	3.8	0.0	1.7	4.2	0.0
WSP4	Morey Creek	2015	35	9.7	1.4	0.0	2.5	2.4	2.5	0.0	4.4	10	2.4

Excellent	Good	Fair	Poor	Very poor
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The data provided in Table 4-24 are based on one year of sampling. B-IBI scores can vary considerably from year to year, so B-IBI scores from a single year should be interpreted with caution.

4.1.5.3 Comparison to Regional B-IBI Scores

To compare the Spanaway Lake WSP area B-IBI scores with the scores of other sites in the Puget Sound lowlands, BC used methods and data described in Fore et al.'s 2013 paper, *Using Natural History Attributes of Stream Invertebrates to Measure Stream Health*. Fore et al. concluded that higher urbanization in the drainage area upstream of a benthic monitoring site is correlated with lower B-IBI scores (Fore et al. 2013).

BC determined the percent urbanization in the Spanaway Lake WSP tributary areas to compare to the Fore et al. regional sites, using the same method. To calculate the percent urbanization, the tributary area upstream of the Spanaway Lake benthic invertebrate monitoring sites was first delineated in GIS using USGS 10-foot contours. Then, the 2006 National Land Cover Database (NLCD) raster was imported and compared with the tributary areas. Three NLCD grid codes (22, 23, and 24) were selected (developed low intensity, developed medium intensity, and developed high intensity) and the area of these urbanized grid codes in each tributary was calculated. This area was then divided by the total area of the tributary area to determine the percentage of the basin considered to be "urbanized."

This process allowed the Spanaway Lake WSP B-IBI scores and associated urbanization levels to be compared to the B-IBI scores and urbanization levels of other Puget Sound lowlands monitoring sites. Figure 4-12 shows how the Spanaway Lake WSP sites compare to the 784 sites included in the Fore et al. (2013) study. The 10–50 B-IBI scoring system was used for compatibility with Ecology's criteria for the WSP.

Table 4-25 summarizes the tributary area, percentage urban, and channel slope upstream of each benthic macroinvertebrate sampling site. Historical maps indicate that prairie covered much of the Spanaway Lake watershed, with forested areas around the lake (see Figure 2-2). The old maps show numerous wetlands upstream of Spanaway Lake.

Site	Description	Percentage A and B Soils	Tributary Area (acres)	Percentage Urban	Slope
SW-2	Coffee Creek	86	2,882	1.2	0.0035
SW-1	Spanaway Creek downstream of Spanaway Lake	91	13,756	34.7	0.0006
WSP2	Spanaway Creek (lower)	91	14,504	35.9	0.0056
WSP4	Morey Creek	91	14,492	35.8	0.0006

As indicated in Figure 4-12, the B-IBI scores for the Spanaway Lake WSP sites were relatively low compared to the Puget Sound Lowlands sites evaluated in the Fore et al. (2013) study. The B-IBI scores for SW-1 (Spanaway Creek below the lake) and WSP2 (Spanaway Creek below the split with Morey Creek) were both 18 under the 10–50 scoring system, putting them in the lower 15 percent of sites with similar levels of watershed urbanization. Site SW-2 (Coffee Creek) scored in the lower 25 percent of Puget Sound Lowlands sites with similar levels of urbanization. WSP4 (Morey Creek) was slightly above the 25th quantile for sites with similar urbanization levels.

WSP4 and WSP2 are located a short distance downstream of the point where Morey Creek splits off from Spanaway Creek; consequently, the upstream watershed area and percent urbanized are virtually identical for both sites. Nevertheless, the B-IBI score at WSP2 was considerably lower than the score at WSP4, indicating that factors other than the percent of urbanized area in the watershed exerted a strong influence.

The B-IBI score at SW-2 (Coffee Creek) site was in the “fair” range even though only about 1.2 percent of its watershed area is urbanized. However, this site is downstream of a major road, and is within a landscaped apartment complex, with lawn extending down to the edge of the creek. The relatively low B-IBI scores at this site and others could be due to local channel and riparian alterations (e.g., landscaped riparian area, sparse riparian tree canopy) as well as natural conditions (groundwater-dominated flow regime, low gradient).

4.1.5.4 Biological Condition Gradient Evaluation

The County sample sites were plotted on the BCG, an additional or alternative index to the B-IBI described in Section 4.1.5.1.2. As shown in Figure 4-13, the Spanaway Lake WSP sites range from biological condition 3 to 5-. Sites in this range show some disturbance to biotic integrity with fully intact ecological function (sites SW-2 and WSP4) to more serious disruption of the taxonomic balance at WSP2 and SW-1. A more complete evaluation of the site data and additional explanation of the BCG metrics is available in Attachment C.

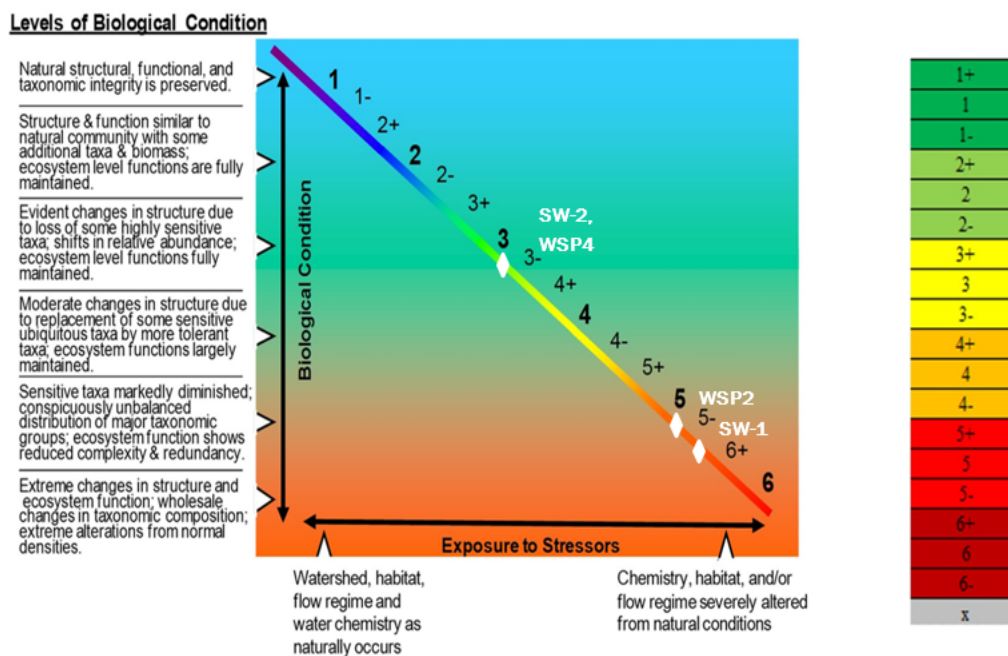


Figure 4-13. Biological Condition Gradient

4.1.5.4.1 Hydrologic Indicators

Urbanization can dramatically alter the hydrologic regime. Replacing native vegetation and topsoil with impervious surfaces reduces infiltration and evapotranspiration, thereby increasing runoff. Artificial drainage networks quickly convey this runoff to receiving water bodies. These landscape alterations reduce base flows and increase peak flows. Moreover, they can increase the frequency and duration of geomorphically significant flows, causing stream channel erosion, down-cutting, and bank instability problems.

Changes in the hydrologic regime due to urban development can cause a range of adverse impacts on the stream community, both directly and indirectly. Evaluation of creek restoration efforts in the Puget Sound area have focused on flow alteration over water quality changes due to urbanization as the key factor in the loss of biological function as measured by B-IBI. A clear relationship between high levels of commonly collected water quality parameters such as copper, zinc, and fecal coliform and unhealthy benthic macroinvertebrate communities has not been established (Dorfmeier 2014).

DeGasperi et al. (2009) evaluated a variety of hydrologic metrics to assess their relationships with B-IBI scores in 16 Puget Sound lowlands creeks (DeGasperi et al. 2009). High pulse count (HPC) and high pulse range (HPR) had the strongest correlation with B-IBI scores. HPC is defined

as the number of days during each water year that daily average flows are equal to or greater than twice the long-term daily average flow rate. HPR is defined as the number of days between the start of the first high flow pulse and the end of the last high flow pulse during a water year. Both metrics have been shown to increase with increasing urbanization.

Other metrics evaluated by DeGasperi et al. (2009) include low pulse count (LPC), low pulse duration (LPD), and high pulse duration (HPD). LPC is defined as the number of times in each calendar year that discrete low flow pulses occurred. It is expected to increase as a response to urbanization. LPD is the annual average duration of low flow pulses during a calendar year. It is expected to decrease with increased urbanization. HPD is the annual average duration of high flow pulses during a water year, which is expected to decrease with urbanization (DeGasperi et al. 2009).

For the Spanaway Lake WSP, the County established flow monitoring stations on Coffee Creek upstream of the lake (SW-2), Spanaway Creek downstream of the lake (SW-1), Spanaway Creek below the split (WSP2), and Morey Creek (WSP4). Flows were measured between October 2014 and May 2016. This monitoring period encompassed two atypical winter seasons—one much drier than normal (2014–15) and one much wetter than normal (2015–16).

BC used the County flow data to develop an HSPF model of the watershed. The preliminary HSPF model was used to simulate flows at SW-1, SW-2, WSP2, and WSP4 for 1950–2016, assuming existing land use/land cover conditions. BC used the preliminary model results to calculate the hydrologic metrics described by DeGasperi et al. (2009) and Horner (2012). Table 4-26 lists the hydrologic metrics calculated based on the preliminary HSPF simulations for 1950–2016 and the metric definitions from DeGasperi et al. (2009).

Table 4-26. Spanaway Creek Existing Condition Hydrologic Metrics (1950–2016 Simulation) and Comparative Data

Hydrologic Metric	SW-1	SW-2	WSP2	WSP4	Mean (Range) from 16 Creeks in DeGasperi et al. 2009
LPC	3.8	2.4	4.3	2.7	10 (2–28)
LPD	25.2	48.4	25.2	19.5	26 (7–93)
HPC	1.8	1.4	2.1	2.1	10 (2–22)
HPD	19.6	29.6	15.8	16.0	7 (2–31)
HPR	106.3	103.6	112.9	113.9	168 (34–306)

Source: DeGasperi et al. 2009.

As indicated in Table 4-26, the Spanaway Lake WSP streams have fewer low-flow periods and LPDs (a positive indicator) are mostly above average compared to the streams included in DeGasperi et al. (2009). Stream “flashiness” is less pronounced as indicated by the low HPC and HPR numbers. The relatively stable hydrologic regime in the Spanaway streams is not surprising given the groundwater-dominated flow regime, detention in lakes and wetlands, and almost complete reliance on infiltration for stormwater management.

As recommended by Ecology (2016c), BC used the regression equations developed by DeGasperi et al. (2009) and Horner (2012) and the HSPF model-simulated flows to estimate B-IBI scores at the four Spanaway Lake WSP sites. Table 4-27 lists the predicted B-IBI scores based on the model-simulated hydrologic metrics and the regression equations for LPC, LPD, HPC, HPD, and HPR.

Table 4-27. Predicted B-IBI Scores Based on Spanaway Creek Existing-Conditions Hydrologic Metrics (1950–2016 Simulation)					
Hydrologic Metric	SW-1	SW-2	WSP2	WSP4	Source of Regression Equation
LPC	32	36	31	35	DeGasperi et al. 2009
LPD	27	34	27	25	DeGasperi et al. 2009
HPC	40	41	39	39	Horner 2012
HPD	39	44	37	37	DeGasperi et al. 2009
HPR	32	32	31	31	Horner 2012
Observed 2015 B-IBI scores	18	26	18	22	

Note: The 10–50 B-IBI scale was used for consistency with the hydrologic metric regression equations.

The regression equations produced a wide range of predicted B-IBI scores for a given site. Overall, the regression equations predicted B-IBI scores considerably higher than the observed scores. This pattern suggests that altered hydrology is not the main limiting factor for B-IBI scores in the Spanaway Lake watershed. Other factors, such as elevated water temperature from solar heating of Spanaway Lake and habitat simplification, may be more important in the Spanaway Lake WSP. The biological potential of the Spanaway Lake WSP is difficult to estimate because undisturbed reference sites with similar watershed conditions (e.g., very permeable soils, low gradient, prairie land cover, groundwater-dominated, large natural lakes) have yet to be identified.

4.1.5.4.2 Stream Substrate

A primary distinguishing attribute used for classifying benthic macroinvertebrates is whether they are associated with erosional habitats with predominantly coarse sediment, or depositional habitats with predominantly fine sediments (Merritt et al. 2008). Lower B-IBI scores tend to correlate with increased fine sediment loading because it is commonly associated with urban development (Hawley 2015). Sediment size and percent embeddedness (the degree to which fine sediments surround coarser sediments in the substrate of stream) is critical to benthic biota because it is frequently the pore spaces between larger pieces of substrate where they feed, hunt, and hide. Depending on their trophic group, they may also cling to or anchor themselves on coarse sediment pieces. Most of the WSP planning area is covered by coarse-textured outwash soils, but lower-gradient streams tend to have depositional areas where fine sediment may accumulate on the substrate.

Pebble count and sediment samples were collected from targeted riffles in the same location and usually on the same day as the benthic macroinvertebrate samples. An estimate of substrate embeddedness was taken at each site during the May 25, 2017, field visit. For the pebble count, a 100-count random sample of stream sediment size was collected using a standard Wolman protocol (Wolman 1954), useful for determining substrate size percentages and whether the substrate is representative of an erosional or depositional hydrologic regime. The surface substrate tallied during the pebble count is the most accessible habitat for benthic macroinvertebrates.

Sediment grab samples from beneath the surface substrate were also collected and analyzed for particle size distribution. These samples, taken from these deeper sediments, are not typically available to benthic macroinvertebrates as habitat. Instead, the sediment samples were collected to provide data on long-term channel stability, and to provide additional information to support interpretation of other benthic and hydrologic metrics (BC 2015).

Mean percent substrate embeddedness is one of the greatest attributable risks to B-IBI scores (Dorfmeier 2014), and consequently embeddedness data were collected for each site. A qualitative estimate of embeddedness was collected using the categories on the County 2016 B-IBI: Site Description Form. Sites SW-1 and SW-2 had low embeddedness (11 to 25 percent). Site WSP4 on Morey Creek had moderate embeddedness (around 50 percent), and the WSP2 site on Spanaway Creek had the highest embeddedness, in the 51 to 90 percent range.

Table 4-28 contains the pebble count and sediment substrate measurements for each site.

Table 4-28. Pebble Count and Sediment Sample Size Distributions for Spanaway Creek

Size Class (%)	Size (mm)	SW-1		SW-2		WSP2		WSP4	
		Pebble Count	Sediment Sample	Pebble Count	Sediment Sample	Pebble Count	Sediment Sample	Pebble Count	Sediment Sample
Sand and fines	<2	10%	6%	9%	16%	21%	11%	81%	9%
Gravel fine-medium	2–16	35%	30%	36%	22%	38%	21%	10%	21%
Gravel coarse	16–63	36%	38%	35%	21%	27%	39%	9%	44%
Cobble	64–256	19%	26%	18%	41%	14%	29%	0%	26%
Boulder	>256	0%	0%	2%	0%	0%	0%	0%	0%
Sand and fines	<2	10%	6%	9%	16%	21%	11%	81%	9%

A recent study found that substrate composition (percent fines, small gravel and cobble, sand-fines, and embeddedness) presented the greatest attributable risk to B-IBI scores for Puget Sound lowlands sites (Dorfmeier 2014). Percentage of sand and fine sediment was highly correlated with negative impacts on B-IBI scores (Dorfmeier 2014). Only one of the Spanaway Lake WSP sites (Morey Creek, WSP4) had substrate dominated by sand, yet the B-IBI score (35.3) for this site was considerably higher than that of the sites on Spanaway Creek: SW-1 (11) and WSP2 (14.5). SW-1, SW-2, and WSP2 all contained a mix of erosional and depositional fauna.

4.1.5.4.3 Water Quality

To support development of the Spanaway Lake WSP, the creek locations shown on Figure 3-1 were monitored for copper, zinc, fecal coliform, hardness, DO, pH, total suspended solids (TSS), turbidity, and water temperature. Creek samples were collected at monthly intervals and during six storm runoff events. Spanaway Lake, Coffee Creek (SW-2), and Spanaway Creek near the lake outlet (SW-1) were also sampled and analyzed for total phosphorus (TP) to support development of an LMP. A recent study found that Puget Sound Lowlands B-IBI scores are sensitive to several surface water quality parameters including DO, pH, TP, and turbidity (Dorfmeier 2014). While the study did not examine water temperature because of a lack of

continuous temperature data for the sites studied, temperature was identified as a variable that could have synergistic relationships with other stressors and should be examined further (Dorfmeier 2014).

All creek samples met the pH criteria (6.5 to 8.5). None of the creek samples exceeded water quality criteria for copper or zinc. Turbidity and TP often exceeded the benchmarks used in the Dorfmeier (2014) study.

Elevated water temperature appears to be an important stressor in the Spanaway Lake WSP. Daily maximum water temperatures in Spanaway Creek just downstream of Spanaway Lake (SW-1) exceeded 23°C for 104 days between July 2014 and June 2016. The 7-DADMax exceeded 27°C in July 2015. High water temperatures tend to depress B-IBI scores because most intolerant taxa in the Puget Sound lowlands are also cool-cold water taxa (Wisseman 2017). Ecology's proposed bioassessment guidelines note that sites where water temperatures regularly exceed 23°C are poor locations for bioassessment (Ecology 2017). As discussed in Section 4.1.2 above, the elevated water temperatures downstream of Spanaway Lake appear to be due primarily to natural warming in the lake. Decreased riparian shade is probably a contributing factor to the elevated temperatures downstream of SW-2, WSP2, and WSP3.

DO was generally above the water quality criterion of 8 milligrams per liter (mg/L) at the creek locations downstream of Spanaway Lake, except for one anomalously low value (3 mg/L) recorded at SW-1 during the initial round of monitoring. Coffee Creek (SW-2) also had an anomalously low value on that date, indicating that the two DO readings on this date may be suspect. Elevated water temperatures can exacerbate DO problems.

Ecology performed biweekly sampling in Spanaway Creek near SW-1 between March 2013 and February 2014. The agency found that DO ranged from 8.6 mg/L to 12.2 mg/L. Ecology performed continuous DO monitoring near SW-1 from August 26 through 29, 2013, and found DO concentrations ranging from 7.9 to 11.0 mg/L. During this period in August 2013, water temperatures were near summer maximums (Fields 2016).

4.1.5.5 Interpretation of Stressors

With larger and more long-term data sets available, it is increasingly possible to use stream benthos data to diagnose stressors (Wisseman 2017). However, while analytical robustness and interpretation can provide increasing information, an important caveat for the interpretation of the Spanaway Lake WSP area data set is that in compliance with permit requirements and the Ecology-approved scope of work and project QAPP, interpretation of the results is based on one year's data. Benthic macroinvertebrate sample data naturally vary from year to year. More years of data would reduce the influence of this typical year-to-year variability and increase overall confidence in the conclusions.

In addition to the analysis of possible stressors, some observations regarding the benthic macroinvertebrate community at the Spanaway Lake WSP sites appear significant. Specifically, the trophic/feeding group structures appear to be unbalanced, and non-insect and crustacean abundance and richness are unusually high.

- **Unbalanced trophic/feeding group structures:** Feeding group integrity is important because invertebrate communities that lack a balanced trophic/feeding group structure is one indicator of low biotic integrity. Human disturbance is one of the leading causes of unbalanced feeding group structure. From most to least well-balanced trophic/feeding groups, the sites rank as follows: SW-2, WSP4, SW-1, and WSP2. Scrapers, predators, and long-lived taxa are poorly represented at SW-2, but shredders are present in significant numbers. At WSP4, predator richness and numbers are moderately high, but the benthic community is dominated by fine particle-collector gatherers, and scrapers are very rare (this is expected in fine sediment-dominated stream reaches). At SW-1, fine particle-collecting related taxa dominate the benthic community even though this is an erosional habitat dominated by cobble riffles, possibly due to invertebrates drifting down from the lake and pond upstream. Another possibility is that particle-collectors may be more dominant in lower gradient streams (Wisseman 2017).
- **Non-insect and tolerant crustacean abundance and richness is high** at all sites, and very high at WSP2, where non-insects are super-dominant in the community (81 percent). Large populations of non-insect and tolerant crustaceans tend to be common in low-gradient habitat (Wisseman 2017). The presence of more tolerant species results in lower B-IBI scores.

Table 4-29 contains a summary of stressors based on Robert Wisseman's analysis of the Spanaway Lake WSP area benthic macroinvertebrate 2015 samples for the project. The categories of **high**, **moderate**, **low**, and **not indicated** indicate how much impact the stressor is considered to have on stream biotic integrity at the site, and are based on best professional judgment. Attachment C provides a detailed analysis of the benthic community at each WSP site.

Table 4-29. Benthic Invertebrate Community Assessment: Potential Stressors/Limiting Factors for Spanaway Creek				
Potential Stressor	SW-1 (Spanaway Creek near Spanaway Lake Outlet)	SW-2 (Coffee Creek)	WSP2 (Spanaway Creek: Lower)	WSP4 (Morey Creek)
Altered hydrology	Not indicated	Not indicated	Not indicated	Not indicated
Physical channel disturbance	Not indicated	Not indicated	Not indicated	Not indicated

Table 4-29. Benthic Invertebrate Community Assessment: Potential Stressors/Limiting Factors for Spanaway Creek

Potential Stressor	SW-1 (Spanaway Creek near Spanaway Lake Outlet)	SW-2 (Coffee Creek)	WSP2 (Spanaway Creek: Lower)	WSP4 (Morey Creek)
Sand/fine substrate	Not indicated	Not indicated	Moderate	High
Low DO	Moderate	Not indicated	Moderate	Moderate
High water temperature	High	Not indicated	High	High
Acute toxicity	Not indicated	Not indicated	Not indicated	Not indicated
Nutrient enrichment	Not indicated	Not indicated	Low	Not indicated
Habitat simplification	Moderate	Moderate	High	Low
Substrate embeddedness	Low	Low	High	Moderate

The following bullets summarize the potential stressors identified in Table 4-29:

- **Altered hydrology:** Extreme “spikes” or intermittent/stagnant flow were not indicated by the taxa at any of the sites. The groundwater-fed flow is steady and not prone to the flashiness or low summer baseflow found in many other urbanizing Puget Sound watersheds. Hydrology does not appear to be a limitation at any of the Spanaway Lake WSP sites. This observation is supported by the results of the hydrologic model simulations for 1950–2015.
- **Physical channel disturbance:** Excessive scouring, bedload transport, or intermittent flows in summer are not indicated by the fauna or by physical evidence at any of the sample sites. A large amount of stream scour or flashy flows would be unusual for a low-gradient stream with this level of groundwater influence. Thus, physical channel disturbance does not appear to be a limitation at any of the Spanaway Lake WSP sites.
- **Sand/fine substrate:** Fauna ranges from a mix of erosional and depositional related taxa at SW-2 to a dominance of fine sediment-related taxa at SW-1, WSP2, and WSP4. The sample site substrate at WSP4 is mostly fine sediment, while WSP2 substrates are composed of mostly coarse sediment. At WSP2, the significant number of fine sediment-related taxa captured in the 2015 samples may indicate that these invertebrates have drifted downstream from depositional areas upstream. Depositional conditions dominated by fine sediment are typical of low-gradient stream reaches.



- **Low dissolved oxygen:** Despite the elevated water temperatures downstream of Spanaway Lake, DO was generally above the water quality standards even directly below the lake (upstream of SW-1). However, the taxa indicate that a combination of slightly lower DO and elevated water temperature may be a stressor at SW-1, WSP2, and WSP4.
- **High water temperatures:** The invertebrates present are tolerant of warmer water, with no or very few cold-water species. This is likely due to the large amount of marsh, pond, and lake area upstream of these locations. The SW-1 site just downstream of Spanaway Lake shows biological evidence of high temperatures and possibly low DO.
- **Acute toxicity** is not indicated at any of the Spanaway Lake WSP sites by the benthic fauna.
- **Nutrient enrichment** is indicated at slight to moderate levels at the Spanaway Lake WSP2 only. Sites downstream of larger lakes typically support large numbers of filtering benthic invertebrates; however, this is not the case at SW-1.
- **Habitat simplification and microhabitat complexity is variable:** This stressor is low in some areas, but higher in others. As indicated by the benthic community composition, habitat complexity is low at SW-2, SW-1, and WSP2, but higher at WSP4.
- **Substrate embeddedness** was high at WSP2, moderate at WSP4, and low at the other sites. Because the degree of embeddedness directly affects the habitat quality of benthic macroinvertebrates, and high embeddedness frequently correlates to low B-IBI scores, this variable may help to explain some of the score differential between WSP2 and WSP4.

4.1.5.6 Summary

Excessive flow, intermittent flow, “flashy” flow, or stagnant flow are not indicated as stressors to the benthic macroinvertebrate fauna at any of the sites. The most important stressors for stream biota in the Spanaway Lake watershed appear to be elevated water temperature and low habitat complexity. Elevated water temperatures appear to limit benthic organisms in Spanaway and Morey creeks downstream of Spanaway Lake. The elevated creek temperatures are due primarily to warming that occurs within Spanaway Lake during the summer months because of the lake’s long HRT and large open water area. Some creek reaches downstream of the lake, such as the Spanaway Creek reach containing site WSP2, have limited riparian canopy. The lack of riparian shade exacerbates the temperature impacts of the lake. Actions to increase riparian shade in these reaches would help to mitigate the impact of the lake on downstream water temperatures.

Low habitat complexity appears to be another important limiting factor for benthic organisms in the Spanaway Lake WSP area. Some reaches (such as Spanaway Creek just downstream of Morey Creek) have been straightened and armored, and contain little large woody debris.

Unlike many other watersheds in the Puget Sound area, altered hydrology does not appear to be a stressor for benthic organisms in the Spanaway Lake WSP area. The Spanaway Lake WSP area is covered by very permeable soils. Nearly all runoff from impervious areas is infiltrated, so there is very little direct stormwater runoff to the lake or creeks. Groundwater is the main source of flow for the Spanaway Lake WSP surface water bodies.

None of the creek samples collected during the Spanaway Lake WSP monitoring period exceeded water quality criteria for copper or zinc. These monitoring results are consistent with the findings of the benthic data evaluation, which indicated that acute toxicity is not an issue in the Spanaway Lake WSP creeks.

While excessive fine sediment has been identified as a key stressor for many Puget Sound lowland streams (Dorfmeier 2014), fine sediment was observed only at WSP4 (Morey Creek), and dominance of fine substrate is normal and expected in this low-gradient, depositional reach. Higher embeddedness at WSP2 on Spanaway Creek may be significant; other sites had only low or moderate embeddedness.

4.1.5.7 Benthic Macroinvertebrate Summary

Ecology's proposed RSMP biological indicator threshold for B-IBI scores on the 0–100 scale is 60.8 (DeGasperi 2016). All of the sites fell below this threshold. The highest B-IBI score (40.5) was observed in Coffee Creek just upstream of Spanaway Lake. The lowest score (11) was observed in Spanaway Creek just downstream of the lake outlet. Morey Creek and Spanaway Creek just downstream of the split with Morey Creek share an almost identical drainage area, yet their scores were significantly different (14.5 for lower Spanaway Creek versus 35.3 for Morey Creek). This suggests that the difference in B-IBI scores at WSP2 and WSP4 may be attributable to local conditions.

The B-IBI scores for SW-1 (Spanaway Creek below the lake) and WSP2 (Spanaway Creek below the split with Morey Creek) were both 18 under the 10–50 scoring system, putting them in the lower 15 percent of sites with similar levels of watershed urbanization. Site SW-2 (Coffee Creek) scored in the lower 25 percent of Puget Sound Lowlands sites with similar levels of urbanization. WSP4 (Morey Creek) was slightly above the 25th quantile for sites with similar urbanization levels.

WSP4 and WSP2 are located a short distance downstream of the point where Morey Creek splits off from Spanaway Creek; consequently, the upstream watershed area and percent urbanized are virtually identical for both sites. Nevertheless, the B-IBI score at WSP2 was

considerably lower than the score at WSP4, indicating that factors other than the percent of urbanized area in the watershed exerted a strong influence.

The B-IBI score at SW-2 (Coffee Creek) site was in the “fair” range even though only about 1.2 percent of its watershed area is urbanized. However, this site is downstream of a major road, and is within a landscaped apartment complex, with lawn extending down to the edge of the creek. The relatively low B-IBI scores at this site and others could be due to local channel and riparian alterations (e.g., landscaped riparian area, sparse riparian tree canopy) as well as natural conditions (groundwater-dominated flow regime, low gradient).

Note that the monitoring program was conducted for only one year. B-IBI scores can vary considerably from year to year, so B-IBI scores from a single year should be interpreted with caution.

4.2 Ecology Clover Creek Watershed Assessment

Ecology published the *Clover Creek Watershed Fecal Coliform, Dissolved Oxygen, and Temperature Source Assessment Report* in October 2016 (Ecology 2016a). Ecology conducted the study because water quality data showed that some water bodies in the Clover Creek watershed did not meet State criteria (WAC 173-201A) for fecal coliform, DO, and temperature. The project was originally intended to support development of a TMDL. However, Ecology subsequently decided to support the County’s STI approach rather than a TMDL for the watershed.

Ecology’s monitoring program included fecal coliform, temperature, benthic macroinvertebrates, and periphyton. The Ecology study also assessed streamflow gains and losses. The Clover Creek Assessment did not include copper or zinc analyses, however.

The Clover Creek Assessment included monitoring of Spanaway and Morey creeks between March 2013 and February 2014. Four of Ecology’s sites were located near WSP monitoring locations, as shown on Figure 4-14. As noted in Table 4-30, Ecology monitored fecal coliform at fixed-network and stormwater sample locations, continuous temperature from thermistors, diurnal DO concentrations, discharge measurements, riparian shade estimates, and macroinvertebrate and periphyton (Bio) samples.

Table 4-30. WSP Site IDs, Clover Creek Site IDs and Monitored Parameters

Clover Creek Assessment Report Site ID	Corresponding WSP Site	Clover Creek Assessment Report Site Description	Fecal Coliform Fixed Site	Fecal Coliform Storm Site	Temperature	DO	Discharge	Shade	Bio
SPA1.8	~SW-1	Spanaway Creek at Spanaway Park	✓	✓	✓	✓	✓	✓	✓
SPA1.4	~WSP2	Spanaway Creek at 138th St S	✓	✓	✓	-	✓	✓	-
SPA0.5	~WSP3	Spanaway Creek at Spanaway Loop Rd. S	✓	✓	✓	-	-	-	-
MORO.9	~WSP4	Morey Creek at Spanaway Loop Rd. S	✓	✓	✓	-	✓	✓	-
MORO.1	None	Morey Pond outlet to bypass at JBLM	✓	✓	✓	-	✓	✓	-

NA = this site does not correspond to a WSP location.

- = no samples collected.

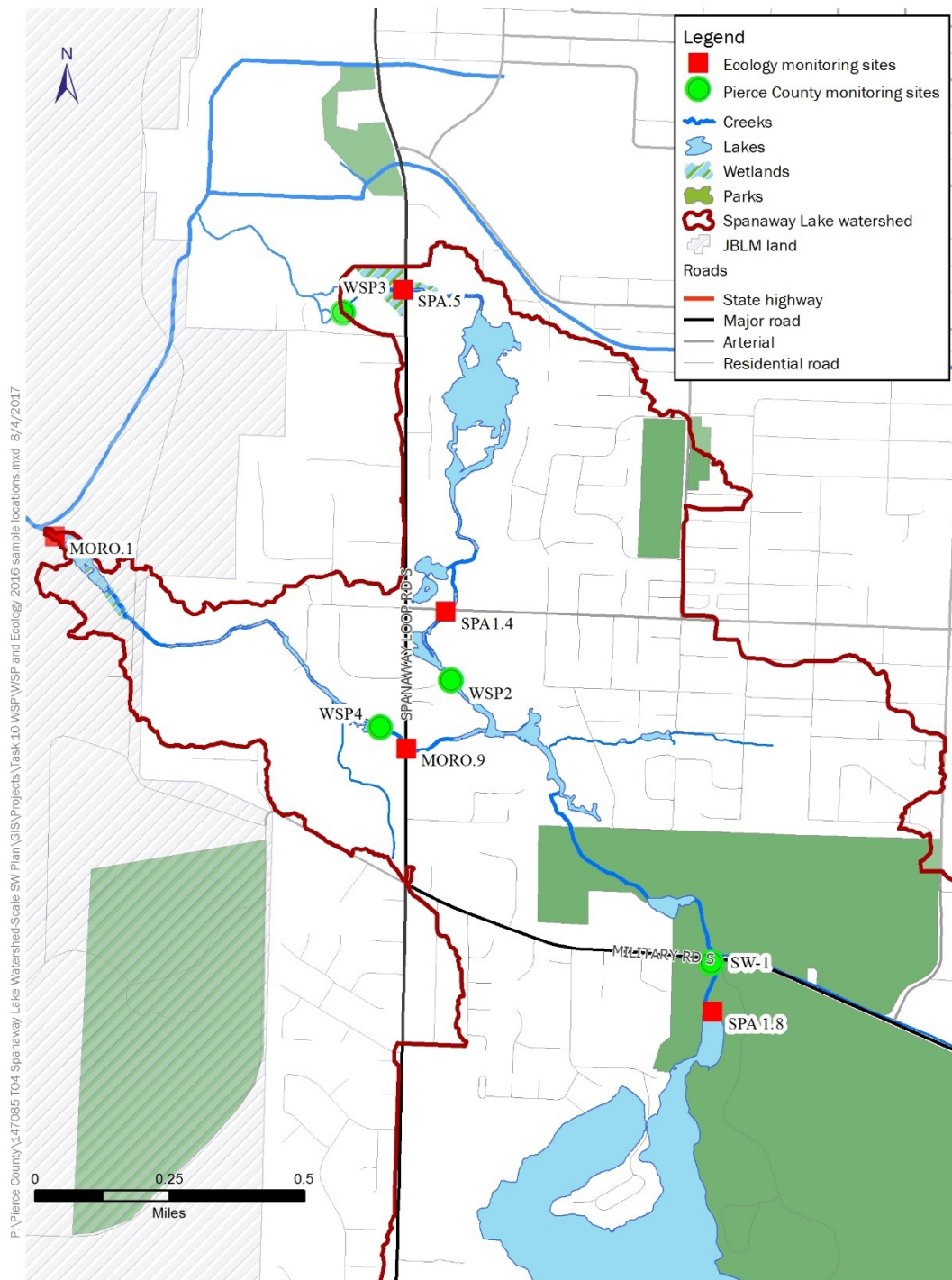


Figure 4-14. Spanaway Lake WSP and Ecology Clover Creek Assessment water quality monitoring locations

The amount of precipitation received within the Spanaway Lake watershed during the two monitoring periods was very different, which could be a reason for differing results in some of the parameters, such as fecal coliform bacteria. The monitoring period for Ecology's Clover Creek monitoring program occurred from March 2013 to February 2014, a total of 14 months. During this monitoring period, a total of 48.3 inches of precipitation was recorded at the Spanaway Golf Course weather station. The Spanaway Lake WSP monitoring program occurred from October 2014 to March 2016, a total of 18 months, with a total of 71.1 inches of precipitation recorded at the Spanaway Golf Course weather station. As can be seen on Figure 4-15, the total monthly precipitation values are significantly different from both monitoring programs. The wet season months (October–April) during Ecology's study totaled 27.3 inches. The Spanaway Lake WSP had wet seasons in 2015 and 2016, with totals of 28.4 and 38.8 inches, respectively. The dry season months (May–September) during Ecology's study totaled 14.7 inches, whereas the Spanaway Lake WSP's dry season months totaled 3.9 inches—an exceptionally dry season.

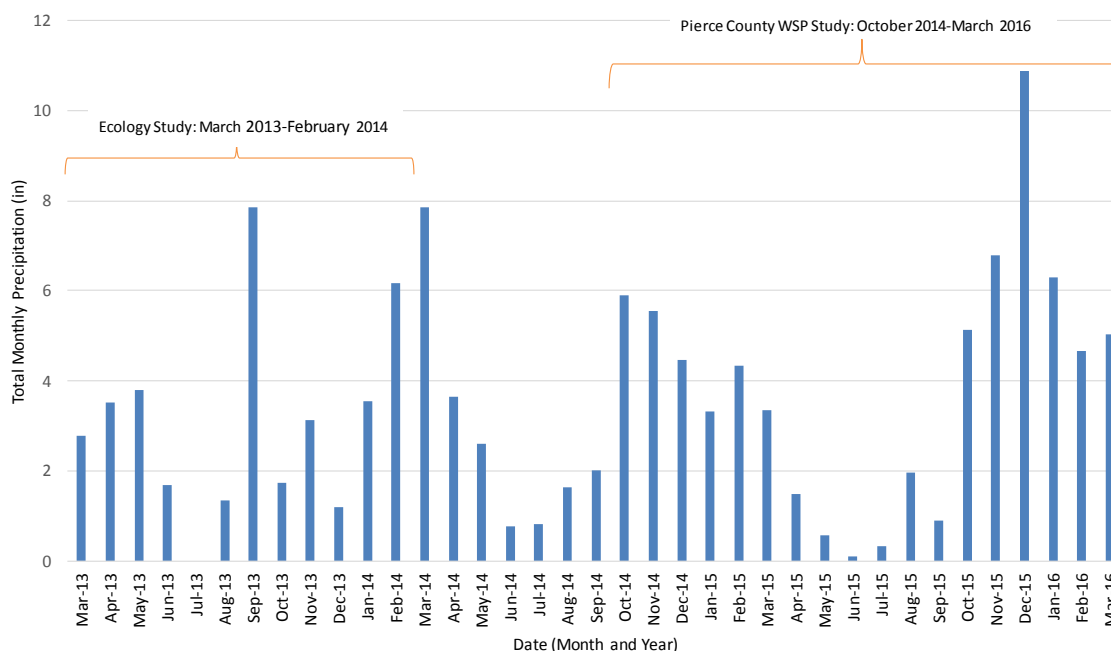


Figure 4-15. Total monthly precipitation during Ecology's and Pierce County's monitoring programs

4.2.1 Streamflow (Synoptic Gains/Losses)

Ecology measured instantaneous stream discharge biweekly at the study sites from March 2013 to February 2014, as summarized in Table 4-31.

Based on this study's findings, Spanaway Creek gained flow between the lake, SPA1.8 (~SW-1) and site below the split, SPA1.4 (~WSP2). The mean flow gain during this monitoring period ranged from 0.10 cubic foot per second (cfs) to 2.46 cfs. Flow was not measured at SPA0.5 (~WSP3) because the site was a wetland without discernible channel and flow direction (Ecology 2016a).

Spanaway Creek gained the most during average (almost 1.5 cfs) and maximum (approximately 1.0 cfs) flow conditions. A small amount was gained during minimum flow (approximately 0.3 cfs). Spanaway Creek flowed during the entire monitoring period (March 2013 and February 2014) and appeared less flashy than other parts of the Clover Creek watershed (Ecology 2016a).

From the 24 stream discharge measurements collected, the average flow for sites SPA1.8 (~SW-1) and SPA1.4 (~WSP2) were 18 cfs and 19 cfs, respectively. The minimum flows were 6.2 and 6.5 and maximum flows were 33 and 34 cfs, respectively.

Morey Creek appeared to lose flow going downstream, between the split, MOR0.9 (~WSP4) and confluence with Clover Creek, MOR0.1. The mean flow loss during this monitoring period ranged from 4.77 to 0.00 cfs (Ecology 2016a). On average, downstream of the split, 25 percent of the flow goes to Morey Creek and 75 percent of the flow goes to Spanaway Creek.

From the 24 stream discharge measurements collected at MOR0.1, the average flow was 1.6 cfs with a minimum and maximum flow of 0.5 cfs and 7.7 cfs, respectively.

The streamflow was higher at MOR0.9, near where it branched off from Spanaway Creek. Morey Creek lost at minimum (approximately 0.5 cfs), average (approximately 1.3 cfs), and maximum (approximately 3.5 cfs) flows. Morey Creek contributed an average of over 1.5 cfs (minimum approximately 0.5, maximum over 7.5 cfs) to Clover Creek.

Table 4-31. Instantaneous Stream Discharge Measurements in the Clover Creek Watershed

Ecology Site ID	SPA1.8 (~SW-1)	SPA1.4 (~WSP2)	MORO.9 (~WSP4)	MORO.1
Number of samples collected	24	24	23	24
Average daily flow (cfs)	18	19	2.9	1.6
Minimum daily flow (cfs)	6.2	6.5	1.0	0.5
Maximum daily flow (cfs)	33	34	11	7.7

A true comparison of the streamflow discharge rates cannot be conducted, as measurements were taken during different times and years. Additionally, the WSP measurements were collected continuously, allowing the data set to capture all flow conditions, for a much longer monitoring duration period than Ecology's instantaneous measurements, which numbered less than 25.

However, a comparison of the summary results (Tables 4-1 and 4-31) shows that the average daily flow rate of 27 cfs collected at SW-1 is higher than the average daily flow rate of 18 cfs collected at SPA1.8. The minimum (2.6 cfs) and maximum (72 cfs) flow rates at SW-1 differ greatly from the minimum (6.2 cfs) and maximum (33 cfs) flow rates at SPA1.8.

The average daily flow rate of 26 cfs collected at WSP2 is higher than the average daily flow rate of 19 cfs collected at SPA1.4. The minimum (1.7 cfs) and maximum (58 cfs) flow rates at WSP2 differ greatly from the minimum (6.5 cfs) and maximum (34 cfs) flow rates at SPA1.4.

The average daily flow rate of 8.7 cfs collected at WSP4 is higher than the average daily flow rate of 2.9 cfs collected at MORO.9. The minimum (0.0 cfs) and maximum (39 cfs) flow rates at WSP4 differ greatly from the minimum (1.0 cfs) and maximum (11 cfs) flow rates at MORO.9.

4.2.2 Water Temperature

Ecology deployed temperature data loggers (thermistors) at each Spanaway Creek and Morey Creek monitoring location where there was streamflow from May to September 2013. Ecology staff downloaded loggers approximately every 4 weeks.

Each location exceeded the 7-DADMax of 17.5°C. The 7-DADMax temperature exceeded 17.5°C for more than 90 days at each location. A summary showing the 7-day average of daily maximum temperatures (°C) for each location is provided in Table 4-32.



Temperature measurements taken during site visits exceeded 17.5°C from June to September at SPA0.5 and SPA1.4. At SPA1.8, temperature exceeded the criterion from May to September.

Table 4-32. 7-Day Average of Daily Maximum Temperatures for Spanaway and Morey Creeks

Ecology Site ID	Date	7-DADMax (°C)
SPA1.8 (~SW-1)	7/1/2013 and 7/3/2013	25.3
SPA1.4 (~WSP2)	7/1/2013	22.6
SPA0.5 (~WSP3)	7/1/2013	25.4
MORO.9 (~WSP4)	7/1/2013	22.5
MORO.1	7/1/2013	24.8

The water temperature monitoring results from the WSP and Ecology study were comparable, with exceedances of the 7-DADMax water quality criterion of 17.5°C at each location. Although the temperature monitoring results were higher in the Spanaway Lake WSP study, the trends were the same in both studies.

4.2.3 Fecal Coliform Bacteria

Ecology collected creek samples within the vicinity of the WSP locations (SW-1, WSP2, WSP3, and WSP4) from March 2013 to February 2014, as summarized in Table 4-33, which shows that all of the fecal coliform concentrations collected during the wet season (October through April) and the full year met the water quality criteria for *Primary Contact Recreation* at Spanaway and Morey creeks. During the dry season (May through September), SPA0.5 (~WSP3) did not meet the Part 2 criterion, which states that no more than 10 percent of samples can have concentrations exceeding 200 cfu/100 mL.

Ecology collected samples in the stream during one storm event, on June 13, 2013. Sample sites SPA1.8, SPA0.5, MORO.9, and MORO.1 exceeded the criterion for a single sample (200 cfu/100 mL), as shown in Table 4-33.

Table 4-33. Fecal Coliform Bacteria (cfu/100 mL) Results from the Ecology Clover Creek Assessment (3/2013–2/2014)

Ecology Site ID (~WSP Site ID)	Wet Season			Dry Season			Full Year			6/13/2013 Storm Event Sample
	Count	Geomean	Percent of Samples > 200	Count	Geomean	Percent of Samples > 200	Count	Geomean	Percent of Samples > 200	
SPA1.8 (~SW-1)	13	10	0	10	38	10	23	18	4	220
SPA1.4 (~WSP2)	13	17	0	10	74	0	23	33	0	190
SPA0.5 (~WSP3)	13	38	0	10	71	20	23	50	9	250
MORO.9 (~WSP4)	11	11	0	10	49	10	21	22	5	220
MORO.1 ^a (NA)	13	9	0	10	10	10	23	17	4	310

Notes:

Distribution is not normally distributed based on Shapiro-Wilk Normality Test; difference between the seasons determined to be statistically significant.

Wet season is from October 1 through April 31. Dry season is from May 1 through September 30.

The water bodies downstream of the lake (SPA1.8 (~SW-1), SPA1.4 (~WSP2), SPA0.5 (~WSP3), MORO.9 (~WSP4), and MORO.1) are designated for primary contact; the geometric mean fecal coliform concentration must not exceed 100 cfu/100 mL, and less than 10% of samples should have concentrations exceeding 200 cfu/100 mL.

The Clover Creek assessment and the WSP fecal coliform results for the wet season were similar. The geomeans for SW-1 and SPA1.8 are 12 cfu/100 mL and 10 cfu/100 mL, respectively. The geomeans for WSP2 and SPA1.4 are 6 cfu/100 mL and 17 cfu/100 mL, respectively. The geomeans for WSP3 and SPA0.5 are 56 cfu/100 mL and 38 cfu/100 mL, respectively. The geomeans for WSP4 and MOR0.9 are 12 cfu/100 mL and 11 cfu/100 mL, respectively. All samples met Parts 1 and 2 of the water quality criteria during the wet season.

The WSP samples had higher geomeans than Ecology's samples collected during the dry season. The geomeans for SW-1 and SPA1.8 are 74 cfu/100 mL and 38 cfu/100 mL, respectively. Similarly, the geomeans for WSP2 and SPA1.4 are 166 cfu/100 mL and 74 cfu/100 mL, respectively. The geomeans for WSP3 and SPA0.5 are 124 cfu/100 mL and 71 cfu/100 mL, respectively. The geomeans for WSP4 and MOR0.9 are 373 cfu/100 mL and 49 cfu/100 mL, respectively. During the dry season, the WSP monitoring locations did not meet several of the Parts 1 and 2 criteria, whereas only one sample (SPA0.5) did not meet the Part 1 criteria. These differences could be related to differences in weather and stream conditions. The weather was unusually warm and dry when much of the Spanaway Lake WSP monitoring was conducted, as discussed in Section 4.2.5.1. Fecal coliform bacteria tend to be higher when there is less water because of dilution and more wildlife.

A general comparison for the full year results shows that the WSP sample locations did not meet the Part 2 criteria for locations WSP2, WSP3, and WSP4, whereas all of Ecology's sample locations did. Again, this could be attributable to the unusually warm and dry weather that occurred during the Spanaway Lake WSP monitoring period.

A true comparison of the storm sample results cannot be conducted, as Ecology collected samples only from one event, whereas the Spanaway Lake WSP monitoring program collected up to three samples per storm event, where six storm events were sampled in total. A general comparison shows that during storm events, at almost all of the sites, fecal coliform concentrations exceed the Primary Contact Recreation standard (200 cfu/100 mL).

4.2.4 Aquatic (B-IBI and Periphyton)

Ecology conducted a riparian assessment to determine percent of effective shade and canopy cover, diurnal surveys for DO in August and December 2013, and a collection of benthic macroinvertebrates and periphyton to conduct a bioassessment of the Clover Creek watershed, as summarized below.

4.2.4.1 Riparian Corridor

Ecology measured percent average canopy cover and effective shade using hemispherical photography. Hemispherical digital photographs were taken from July 22 to August 1, 2013.

Photographs were taken looking upward from beneath the plant canopy, using a 180-degree fish-eye lens and digital camera. Images were generally taken in the middle of a stream channel (Ecology 2016a).

Canopy cover is the percentage of the sky that is blocked by vegetation or topography. Effective shade is the fraction of total possible solar radiation above the vegetation and topography that is blocked from reaching the surface of the stream and summed over a full day (Ecology 2016a).

Monitoring locations that had the highest effective shade were SPA1.8 (~SW-1) and MOR0.9 (~WSP4), both at slightly over 80 percent. The percent average effective shade was relatively low at SPA1.4 (~WSP2) at 21.6 percent. Monitoring results from Morey Creek showed that the percent average effective shade was higher at the upstream site (MOR0.9 at 82.1 percent) than at the downstream site (MOR0.1, 53.2 percent).

4.2.4.2 Diurnal Surveys for Dissolved Oxygen

Ecology conducted a diurnal survey for DO from August 26–29, 2013, at SPA1.8 (~SW-1). The DO criterion for Spanaway Creek is 8.0 mg/L. SPA1.8 fell below the daily minimum DO water quality criterion on August 27 and had a very pronounced diurnal fluctuation (Ecology 2016a).

Ecology deployed a multi-probe logging temperature, conductivity, pH, and DO at half-hour intervals from December 16–19, 2013, at SPA1.8. Results showed that the monitoring location met the water quality criteria.

Ecology collected DO measurements biweekly at the Spanaway and Morey creek monitoring sites from March 2013 to February 2014 (these DO measurements did not occur at the same time of day and do not account for diurnal fluctuations in DO). All of the DO measurements taken at the Spanaway Creek locations were above the 8.0 mg/L criterion (Ecology 2016a).

The minimum and 10th percentile of DO concentration collected at the Morey Creek site visits were below the criterion of 8.0 mg/L. DO at MOR0.1 was below 8.0 mg/L from July to September. DO at MOR0.9 (~WSP4) was below 8.0 mg/L from June to December (Ecology 2016a).

4.2.4.3 Bioassessment Methods

Ecology collected benthic macroinvertebrate and periphyton samples during the first 2 weeks of October 2013 at SPA1.8 (~SW-1). According to the B-IBI, 0–100 scoring method, the biological condition at SPA1.8 was “very poor”. Taxa richness was reduced at SPA1.8 compared to the reference sites, as was richness of all EPT taxa. Clinger, long-lived, predator, dominant, and nitrogen autotroph taxa richness was also reduced. The proportion of dominant and

tolerant species was higher at SPA1.8. No intolerant taxa were collected at SPA1.8 (Ecology 2016a).

Comparing the periphyton metrics for SPA1.8 to the reference sites, SPA1.8 had higher Shannon diversity and taxa richness values, had a higher percentage of two taxa groups that are indicators of elevated nutrient levels, a higher percentage of facultative nitrogen heterotroph taxa, higher percentages of eutraphentic taxa, higher percentages of low DO, higher percentages of motile and siltation taxa compared to the reference sites, and higher percentages of metals tolerant and acidophilous taxa. The periphyton data indicate possible nutrient enrichment and low DO conditions.

The overall B-IBI scores from both studies are comparable, showing very poor quality near SW-1.

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SECTION 5: REFERENCES

Reports

- Adams, Karen. 2012. *Standard Operating Procedures and Minimum Requirements for the Collection of Freshwater Benthic Macroinvertebrate data in Wadeable Streams and Rivers*. Washington State Department of Ecology Environmental Assessment Program.
- Alderisio, K., and N. DeLuca. 1999. "Seasonal Enumeration of Fecal Coliform Bacteria from the Feces of Ring-Billed Gulls (*Larus delawarensis*) and Canada Geese (*Branta Canadensis*).” *Applied and Environmental Microbiology* 65:12, 5628-5630.
- Barbour, Michael T., Michael J. Paul and David W. Bressler. 2007. *Bioassessment: A Tool for Managing Aquatic Life Uses for Urban Streams*. Sponsored by the Water Environment Research Foundation (WERF).
- Booth, Derek. 2005. *Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America*.
- Booth, D., J. Karr, S. Schauman, C. Konrad, S. Morley, M. Larson, and S. Burges. 2007. *Reviving urban streams: land use, hydrology, biology, and human behavior*. *Journal of the American Water Resources Association (JAWRA)* 40(5): 1351–1364.
- Booth, D., A. Roy, B. Smith, and K. Capps. 2016. *Global perspectives on urban stream syndrome*. *Freshwater Science* 35(1):412–420.
- BC. 2015. FINAL Spanaway Lake Watershed Scale Plan-Quality Assurance Project Plan (QAPP). Prepared for Pierce County, Washington. April.
- BC. 2016. *Draft Spanaway Lake Management Plan*. For Pierce County Public Works and Utilities, Surface Water Management, December.
- BC. 2017. HSPF model of Spanaway Lake Watershed Scale Plan area.
- Caromile, Stephen J. and Chad S. Jackson. 2002. *Warmwater Fish Survey of Spanaway Lake, Pierce County, Spring 2000*. Washington Department of Fish and Wildlife, Warmwater Enhancement Program. June.
- Clean Water Services. 2006. Watershed Health Index for the Tualatin Watershed. November, 2006.

- DeGasperi, C. L., Berge, H. B., Whiting, K. R., Burkey, J. J., Cassin, J. L. and Fuerstenberg, R. R. 2009. *Linking Hydrologic Alteration to Biological Impairment in Urbanizing Streams of the Puget Lowland, Washington, USA*. JAWRA Journal of the American Water Resources Association, 45: 512–533.
- DeGasperi, Curtis. 2016. *RSMP Puget Lowland Ecoregion Streams – Screening Thresholds*. November.
- Dorfmeier, Elene, et.al. 2014. *Updating the Benthic Index of Biotic Integrity (B-IBI): Outcomes and Key Findings*. King County.
- Ebird.org. 2017. Hotspot Map for Spanaway Marsh.
<https://ebird.org/ebird/hotspot/L526943?yr=all&m=&rank=hc>.
- Ecology. 1995. Initial Watershed Assessment, Water Resources Inventory Area 12: Chambers-Clover Creek Watershed, Open File Report 95-09.
- Ecology. 2012. Water Quality Policy 1-11, Revised July 2012.
- Ecology. 2016a. Clover Creek Watershed Fecal Coliform Bacteria, Dissolved Oxygen, and Temperature. Source Assessment Report. Publication No. 16-03-039. October.
- Ecology. 2016b. Water Quality Standards for the Surface Waters of the State of Washington, Chapter 173-201A WAC. Adopted August 1, 2016. Revised March 2017. (Publication 06-10-091). 142 p.
- Ecology, 2016c. Guidance and Discussion of Key Assumptions for the Watershed-Scales Stormwater Planning Requirement in the Western Washington Municipal Stormwater Permits. Memorandum from Dan Garipey and Ed O'Brien dated March 29, 2016.
- Ecology. 2017. *Water Quality Assessment/Policy 1-11 Updates, Bioassessment Alternatives Proposed by Ecology*, January.
- Fields, Jaqueline Renée. 2016. Clover Creek Watershed Fecal Coliform Bacteria, Dissolved Oxygen, and Temperature: Source Assessment Report. Washington State Department of Ecology, Olympia, Washington, October.
- Fore L.S., Karr J.R. and Wisseman R.W. 1996. *Assessing invertebrate responses to human activities: evaluating alternative approaches*. Journal of the North American Benthological Society, 212–231.
- Fore, Leska, et al. 2013. *Using Natural History Attributes of Stream Invertebrates to Measure Stream Health*.

- Gannett, Henry, Geographer in Charge, USGS. 1897. Land classification by J.W. Rankine and G.H. Plummer, surveyed in 1897.
- Hawley, R.J. and G.J. Vietz. 2015. *Addressing the urban stream disturbance regime*. Urban Streams, University of Chicago Press.
- Horner, Richard. 2012. *Development of a Stormwater Retrofit Plan for Water Resources Inventory Area (WRIA) 9 and Estimation of Costs for Retrofitting all Developed Lands of Puget Sound: Development of Flow and Water Quality Targets*. King County, Washington.
- Hussong, D. J. Damare, R. Limpert, J. Sladen, R. Weiner, and R. Colwell. 1979. "Microbial Impacts of Canada Geese (*Branta Canadensis*) and Whistling Swans (*Cygnus columbianus columbianus*) on Aquatic Ecosystems." *Applied and Environmental Microbiology* 37:4, 14–20.
- Karr, J. R. and C. O. Yoder. 2004. *Biological assessment and criteria improve TMDL planning and decision making*. *Journal of Environmental Engineering* 130:594–604.
- King County. 2012. *Stormwater Retrofit Analysis for Juanita Creek Basin in the Lake Washington Watershed. Ecology Grant: G0800618*. Prepared by Jeff Burkey, Mark Wilgus P.E., and Hans Berge. King County Department of Natural Resources and Parks. Water and Land Resources Division. Seattle, Washington.
- Koehler, Michele, et al. 2006. *Diet and Bioenergetics of Lake-Rearing Juvenile Chinook Salmon in Lake Washington*. *American Fisheries Society* 135:1580–1591.
- Longfellow, B. and Z. Holt. 2004. *Sediment Core Sampling in Spanaway Lake: A Timeline for Heavy Metal Presence in a Shallow Urbanized Lake*. University of Washington, Tacoma.
- May, Chris, et al. 1997. *Effects of Urbanization on Small Streams in the Puget Sound Lowland Ecoregion*. University of Washington, Seattle, Washington.
- Milne, M., D. Repp, and M. Samadpour. 2004. Microbial Source Tracking for Fecal Coliform TMDL, Puyallup, Washington.
- Moriarty, E., N. Karki, M. Mackenzie, L. Sinton, and B. Gilpin. 2011. "Faecal Indicators and Pathogens in Selected New Zealand Waterfowl." *New Zealand Journal of Marine and Freshwater Research* 45:4, 679–688.
- Morley, S. A., and J. R. Karr. 2002, *Assessing and Restoring the Health of Urban Streams in the Puget Sound Basin*, *Conservation Biology*, 16:1498–1509.

- nhc, 2002. *Hydrology for 2002 Floodplain Mapping Study of Pierce County, Washington Streams, Clover Creek, Spanaway Creek, and North Fork Clover Creek*, July 17.
- nhc, 2005a. *Flood Insurance Mapping Study for Morey Creek from Clover Creek to Spanaway Creek Pierce County, WA and Incorporated Areas Community Number – 530138*. Prepared for: The Federal Emergency Management Agency. December 2005 (NAVD 1998 version).
- nhc, 2005b. *Flood Insurance Mapping Study for Spanaway Creek RM 0.22 (Spanaway Loop Rd.) to RM 2.14 (Spanaway Lake) Pierce County, WA and Incorporated Areas Community Number – 530138*. Prepared for: The Federal Emergency Management Agency, December 2002 (updated to NAVD of 1998, July 2005).
- Pierce County Public Works & Utilities Water Programs Division (Pierce County). 2005. *Clover Creek Basin Plan, Volume 1: Basin Plan and SEIS and Volume 2: Appendices. Appendix C, Clover Creek Stream Assessment*.
- Pierce County GIS database, provided to BC in 2014.
- Puget Sound Regional Council (PSRC). 2017.
- Runge, Judy, Marc Marcantonio, and Monty Mahan. 2003. *Salmonid Habitat Limiting Factors Analysis: Chambers-Clover Creek Watershed, WRIA 12, Pierce Conservation District*. June.
- Scherer, N., H. Gibbons, K. Stoops, and M. Muller. 1995. "Phosphorus Loading of an Urban Lake by Bird Droppings." *Lake and Reservoir Management* 11:4, 317–327.
- Tobiason, Fred L. 2003. *Historic Flows, Flow Problems, and Fish Presence in Clover Creek 1924–1942: Interviews with Early Residents*. Professor Emeritus, Chemistry, Pacific Lutheran University, Tacoma, Washington. July 18.
- Tacoma-Pierce County Health Department (TPCHD). 1994. *Clover/Chambers Creek Basin Septic/Biomat Monitoring Project. Final Report*. Prepare for Washington State Department of Ecology Grant G9200319.
- Troost, K.G. 2014. *Jokulhlaups from Glacial Lake Puyallup, Ice Age Floods Institute Field Trip Guide*. Sept. 20. 38 p.

- U.S. Department of Transportation Federal Highway Administration, Washington State Department of Transportation, and Pierce County. 2003. Cross-Base Highway (State Route 704) I-5 to SR 7 Final Environmental Impact Statement Appendix K – Vegetation, Wildlife, and Fisheries Discipline Report, Lakewood and Pierce County, Washington.
- U.S. EPA. 2000. *Stressor Identification Guidance Document*. EPA-822-B-00-025. Washington, D.C.
- U.S. EPA. 2005. *Use of Biological Information to Better Define Designated Aquatic Life Uses in State and Tribal Water Quality Standards: Tiered Aquatic Life Uses*. EPA-822-R-05-001, U.S. Environmental Protection Agency, Washington, DC.
- U.S. EPA. 2016. *A Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems*. EPA-842-R-16-001. Washington, D.C.
- USGS. 2007. Toxicity of Metals in Water and Sediment to Aquatic Biota. By John M. Besser and Kenneth J. Leib. Chapter 19 of Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado. Edited by Stanley E. Church, Paul von Guerard, and Susan E. Finger. Professional Paper 1651. U.S. Department of Interior and U.S. Geological Survey.
- Waite, Ian et al. 2008. *Effects of Urbanization on Stream Ecosystems in the Willamette River Basin and Surrounding Areas, Oregon and Washington*. National Water-Quality Assessment Program. USGS.
- Wilhelm, Jo et al. 2014. *Recalibration of the Puget Sound Lowland Benthic Index of Biotic Integrity*. King County.
- Winecka, Lance. 2016. *SPSSEG Sand Wand Demonstration Project on Spanaway Creek*. Project Sponsor: Pierce County Surface Water Management, September 13, 2016.
- Wolman, M.G. 1954. *A Method of Sampling Coarse River-Bed Material*. Transactions of the American Geophysical Union 35(6):951–956.

Books

- Karr, J. R. and E. W. Chu. 1999. *Restoring life in running waters: better biological monitoring*. Island Press, Washington D.C.
- Merritt, et al. 2008. *An Introduction to the Aquatic Insects of North America*. Fourth Edition., Dubuque, Iowa.

Personal Communications

Vincent, Carla, personal communication, April–May 2017.

Wisseman, Bob, personal communications, March–May 2017.

Internet Document

Natural Resources Conservation Service (NRCS). 2001. Soil Survey Geographic (SSURGO) database via the U.S. Department of Agriculture (USDA) Data Gateway.

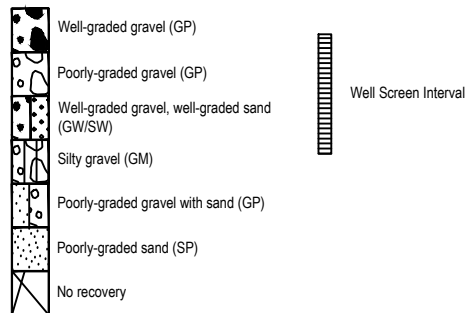
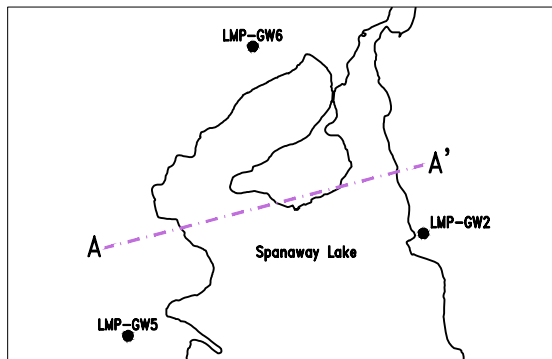
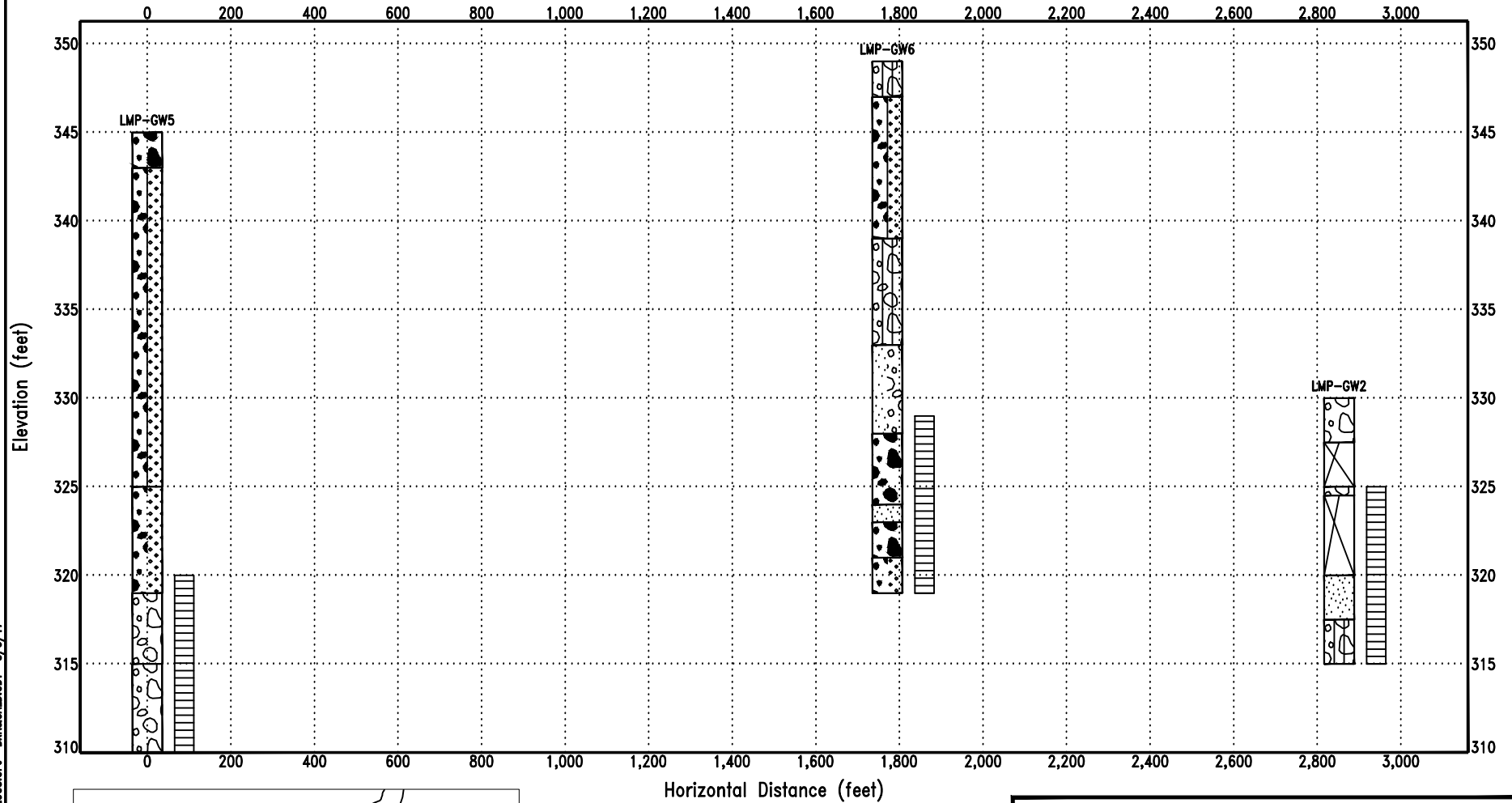




Attachment A: Geologic Cross Sections, Borehole Logs and Well Construction Details



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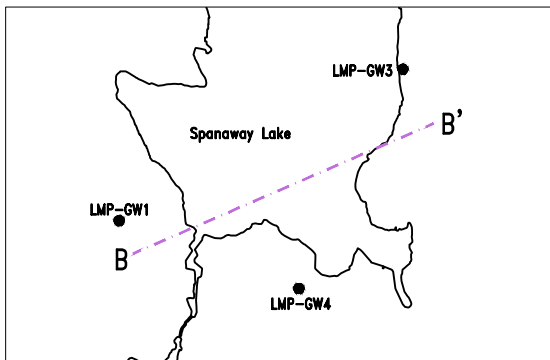
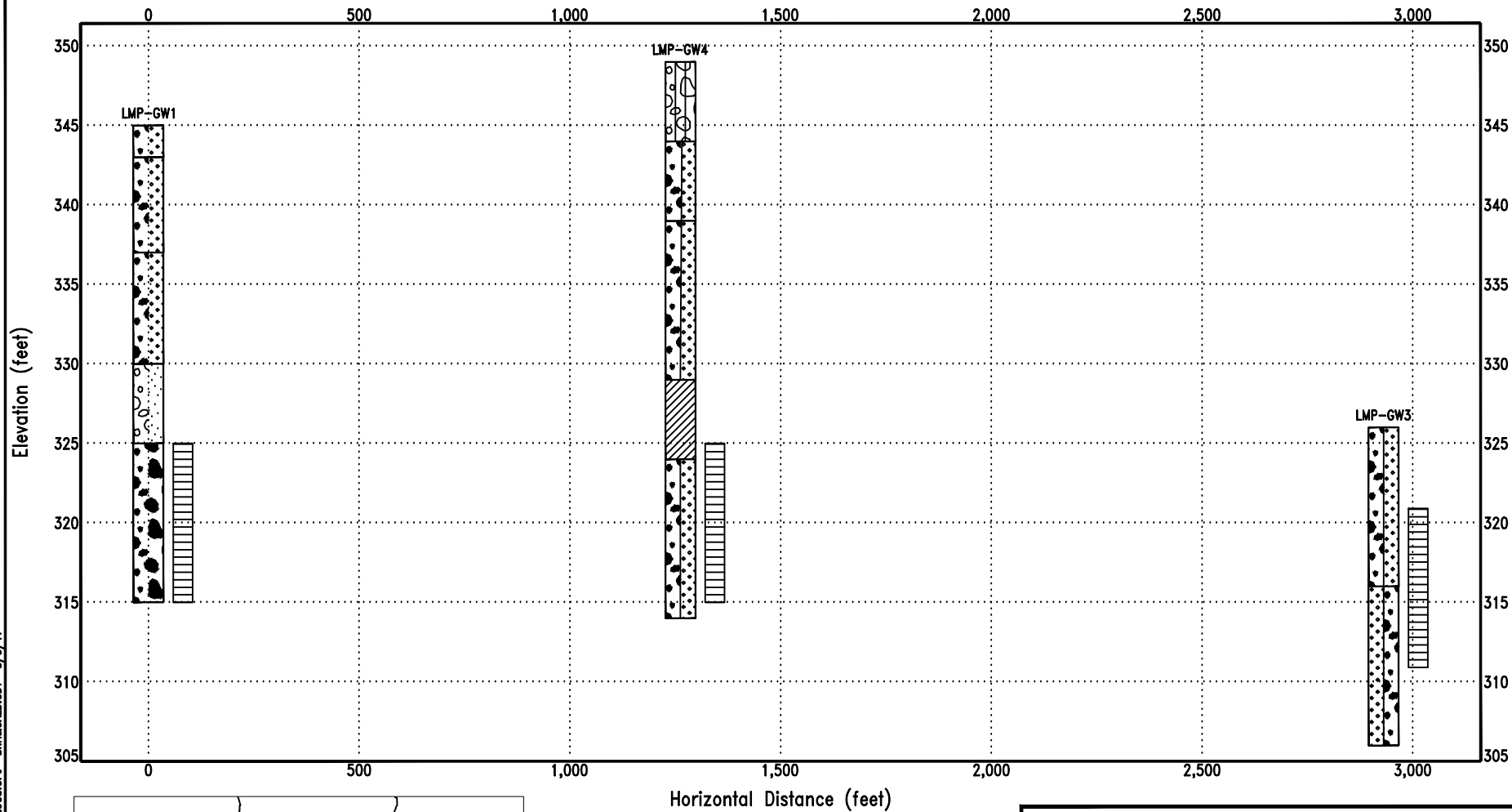


Cross Section A-A'

Brown and Caldwell

PREPARED FOR:
Spanaway Lake
Management Plan

DATE:	8/1/2017
SCALE:	AS SHOWN
DRAWN BY:	DM
CHECKED BY:	SP
PROJECT #:	147085



- Well-graded gravel (GP)
 - Poorly-graded gravel (GP)
 - Well-graded gravel, well-graded sand (GW/SW)
 - Silty gravel (GM)
 - Poorly-graded gravel with sand (GP)
 - Poorly-graded sand (SP)
- Well Screen Interval

Cross Section B-B'

	PREPARED FOR:	DATE: 8/1/2017
	Spanaway Lake Management Plan	SCALE: AS SHOWN
		DRAWN BY: DM
		CHECKED BY: SP
		PROJECT #: 147085

Project Name: Spanaway Lake Management Plan

Project Number: 145775Sheet 1 of 1

Project Location: Lake Spanaway		Logged By: Jim Bethune		Checked By:	
Drilling Contractor: Holt		Date Started: 2/4/15		Date Finished: 2/4/15	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 30.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 346.00		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: Ecology Well ID Tag No.: BIK237 Notice of Intent No. RE10796		Slot Size: .010		Filter Material: 10/20	
		Development Method: Purge			

Depth (feet)		Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28					Dark brown organics. 70% Gravel to 3". 30% well graded sand. (Damp) 70% well graded Gravel to 3". 30% well graded sand (F->C). Light Brown. (Moist) 80% well graded gravel. 20% well graded sand (F->C). Trace silt. Light brown. (moist) 90% Gravel. Poorly graded ~1", 10% M-C sand. ~6" layers 4 @ bottom of sequence. Dark brown, grey,dark brown, red brown. (Wet @ 19') Coarser with depth. 2 layer groups, pea sized to 3". (Wet)					
			G.W.							Cement Bentonite Sand Screen Backfill

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775Sheet 1 of 1

Project Location: Lake Spanaway		Logged By: Jeremiah Thomas		Checked By:	
Drilling Contractor: ESN NW		Date Started: 12/16/14		Date Finished: 12/16/14	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 15.0	Depth to Static Water: (feet) 8.0		
Drilling Method: Geoprobe/HSA	Borehole Diameter: 4"	TOC Elevation: 333.20		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: Ecology Well ID Tag No.: BIM034 Notice of Intent No. RE10756		Slot Size: .010	Filter Material: 10/20		
		Development Method: Purge			

[illegible]

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775

Sheet 1 of 1

Project Location: Lake Spanaway		Logged By: Jim Bethune		Checked By:	
Drilling Contractor: Holt		Date Started: 2/3/15		Date Finished: 2/3/15	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 20.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 330.00		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: Ecology Well ID Tag No.: BIK234 Notice of Intent No. RE10797		Slot Size: .010	Filter Material: 10/20		
		Development Method: Purge			

Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
0 2 4 6 8 10 12 14 16 18 20				85% subrounded gravel, well graded to 3". 15% well graded sand. Trace silt (Wet - 9')					 Concrete Bentonite Sand Screen Backfill
				Well graded F->C sand. Gravel to 3". 15% gravel, cobbles to 5". Trace silt (wet)					

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Jim Bethune	Checked By:
Drilling Contractor: Holt		Date Started: 2/2/15	Date Finished: 2/2/15
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 35.0	Depth to Static Water: (feet)
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 341.90	Ground Elevation:
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC	
Comments: Ecology Well ID Tag No.: BIK232 Notice of Intent No. RE10798		Slot Size: .010	Filter Material: 10/20
		Development Method: Purge	

[illegible]

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775

Sheet 2 of 2

	Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
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Project Name: **Spanaway Lake Management Plan**

Project Number: 145775

Sheet 1 of 2


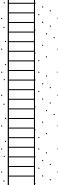
Project Location: Lake Spanaway		Logged By: Jim Bethune	Checked By:
Drilling Contractor: Holt		Date Started: 2/2/15	Date Finished: 2/2/15
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 35.0	Depth to Static Water: (feet)
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 348.10	Ground Elevation:
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC	
Comments: Ecology Well ID Tag No.: BIK233 Notice of Intent No. RE10799		Slot Size: .010	Filter Material: 10/20
		Development Method: Purge	

[illegible]

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775

Sheet 2 of 2

Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID	Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
32 34		GP		Graded beds of clean sand & gravel. Increasing size with depth						 Screen

Project Name: **Spanaway Lake Management Plan**

Project Number: 145775Sheet 1 of 1

Project Location: Lake Spanaway		Logged By: Jim Bethune	Checked By:
Drilling Contractor: Holt		Date Started: 2/3/15	Date Finished: 2/3/15
Drilling Equipment:	Driller: Brian Owens	Total Boring Depth: (feet) 30.0	Depth to Static Water: (feet)
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 343.90	Ground Elevation:
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC	
Comments: Ecology Well ID Tag No.: BIK235 Notice of Intent No. RE10800		Slot Size: .010	Filter Material: 10/20
		Development Method: Purge	

Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
0		GM		Dark brown organics. 70% Gravel to 3", cobbles to 5". 30% Silt and fine sand. (Damp)					
2				20% F-C sand, much fine sand. 80% gravel, well graded to 3" and cobbles to 5". (Dry to Moist)					
4									
6									
8									
10		GM		20% fine sand to silt. 80% gravel to 3", Cobbles to 5". (Damp) light brown					
12									
14									
16				60% M->C sand. 40% gravel to 1.5". Poorly graded light brown. (wet)					
18									
20									
22		GW		Clean and increasing in size. Pea to 3". Dark brown. (Wet)					
24									
26		SP		Clean, poorly graded. Subangular					
28		GW		to 3". No sand. Tan. (wet)					
30				30% sand, gravel to 2". Blue gray. (wet)					
32									
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42									
44									
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Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Jim Bethune	Checked By:
Drilling Contractor: Holt		Date Started: 12/22/14	Date Finished: 12/22/14
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 40.0	Depth to Static Water: (feet)
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 374.43	Ground Elevation:
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC	
Comments: BIK210		Slot Size: .010	Filter Material: 10/20
		Development Method: Purge	

[illegible]

Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 2 of 2[illegible]

Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Jim Bethune		Checked By:	
Drilling Contractor: Holt		Date Started: 12/22/14		Date Finished: 12/22/14	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 40.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 391.23		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: BIK211		Slot Size: .010	Filter Material: 10/20		
		Development Method: Purge			

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Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

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Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 1

Project Location: Lake Spanaway		Logged By: Jim Bethune		Checked By:	
Drilling Contractor: Holt		Date Started: 2/4/15		Date Finished: 2/4/15	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 30.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 355.76		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: BIK236		Slot Size: .010		Filter Material: 10/20	
		Development Method: Purge			






















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Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Jim Bethune		Checked By:	
Drilling Contractor: Holt		Date Started: 12/23/14		Date Finished: 12/23/14	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 40.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 434.04		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: BIK212		Slot Size: .010		Filter Material: 10/20	
		Development Method: Purge			

Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
0				Organic rich, dark, gravely					
2				30% fine, poorly graded sand. Gravel to 3". (Moist to dry)					
4				30% sand, well graded. 70% well graded gravel to 3"+. Grey. (Wet)					
6				40% compact fine sand. Gravels well graded. Trace fines. grey. (Wet)					
8				Trace coarse sand and fines. Well Graded. Brow. (Wet)					
10		GW		trace fines sticking to gravel. Brown. No sand. (Wet)					
12				30% fine, poorly graded sand. Gravel to 3". (Moist to dry)					
14				30% sand, well graded. 70% well graded gravel to 3"+. Grey. (Wet)					
16				40% compact fine sand. Gravels well graded. Trace fines. grey. (Wet)					
18				Trace coarse sand and fines. Well Graded. Brow. (Wet)					
20				Organic rich, dark, gravely					
22				30% fine, poorly graded sand. Gravel to 3". (Moist to dry)					
24				30% sand, well graded. 70% well graded gravel to 3"+. Grey. (Wet)					
26				40% compact fine sand. Gravels well graded. Trace fines. grey. (Wet)					
28				Trace coarse sand and fines. Well Graded. Brow. (Wet)					
30				Organic rich, dark, gravely					
32				30% fine, poorly graded sand. Gravel to 3". (Moist to dry)					
34				30% sand, well graded. 70% well graded gravel to 3"+. Grey. (Wet)					
36				40% compact fine sand. Gravels well graded. Trace fines. grey. (Wet)					
38				Trace coarse sand and fines. Well Graded. Brow. (Wet)					
40				Organic rich, dark, gravely					
42				30% fine, poorly graded sand. Gravel to 3". (Moist to dry)					
44				30% sand, well graded. 70% well graded gravel to 3"+. Grey. (Wet)					
46				40% compact fine sand. Gravels well graded. Trace fines. grey. (Wet)					
48				Trace coarse sand and fines. Well Graded. Brow. (Wet)					
50				Organic rich, dark, gravely					

Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Carolyn		Checked By:	
Drilling Contractor: Holt		Date Started: 12/10/14		Date Finished: 12/11/14	
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 70.0		Depth to Static Water: (feet)	
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 425.84		Ground Elevation:	
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC			
Comments: BIK208		Slot Size: .010	Filter Material: 10/20		
		Development Method: Purge			

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Project Name: **Spanaway Lake Watershed-Scale SW Plan**

Project Number: 147085

Sheet 1 of 2

Project Location: Lake Spanaway		Logged By: Jim Bethune	Checked By:
Drilling Contractor: Holt		Date Started: 12/11/14	Date Finished: 12/14/14
Drilling Equipment:	Driller:	Total Boring Depth: (feet) 60.0	Depth to Static Water: (feet)
Drilling Method: Sonic	Borehole Diameter: 4"	TOC Elevation: 393.36	Ground Elevation:
Sampling Method:		Diameter and Type of Well Casing: 2" Schedule 40 PVC	
Comments: BIK209		Slot Size: .010	Filter Material: 10/20
		Development Method: Purge	

Depth (feet)	Depth to Water	USC Soil Type	Lithology	Description	PID Readings	Sampled Interval	Recovery (feet)	Sample ID	Remarks
0				Dark, earthy odor					
2				to 5" with sand. 70% well graded gravel. 30% well graded sand. Trace silt. Light gray					
4									
6									Bentonite
8									
10									
12		GW GC		90% gravel. 10% clay, sticky. Trace medium sand. Gravel to 3", well graded.					
14									
16									Grout
18		GW GC		sticky light brown clay on gravel. 15% clay					
20									
22									
24									
26									
28									

Project Name: **Spanaway Lake Watershed-Scale SW Plan**

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Attachment B: B-IBI and BCG Metrics

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Attachment B

B-IBI and BCG Metrics

(Adapted from the Puget Sound Stream Benthos website)

B-IBI Metrics

The following sections and tables (Tables B-1 and B-2) provide brief descriptions of the B-IBI metrics and their expected response to disturbance.

Total Taxa Richness. Total taxa richness includes all of the different invertebrates collected from a stream site: mayflies, caddisflies, stoneflies, true flies, midges, clams, snails, and worms. Biodiversity in streams declines as flow regimes are altered, habitat is lost, chemicals are introduced, energy cycles are disrupted, and alien taxa invade.

Ephemeroptera (Mayfly) Taxa Richness. Mayfly diversity declines in response to most types of human influence. Many mayflies graze on algae and are particularly sensitive to chemical pollution that interferes with their food source. In nutrient-poor streams, livestock feces and fertilizers from agriculture can increase the numbers and types of mayflies present. If many different taxa of mayflies are found while the variety of stoneflies and caddisflies is low, nutrient enrichment may be the cause.

Plecoptera (Stonefly) Taxa Richness. Stoneflies are the first to disappear from a stream as human disturbance increases. Many stoneflies are predators that stalk their prey and hide around and between rocks; others are shredders and feed on leaf litter that drops from an overhanging tree canopy. Hiding places between rocks are lost as sediment washes into a stream. Most stoneflies, like salmonids, require cool water temperatures and high oxygen to complete their life cycles.

Trichoptera (Caddisfly) Taxa Richness. Different caddisfly species (or taxa) feed in a variety of ways: some spin nets to trap food, others collect or scrape food on top of exposed rocks. Many caddisflies build gravel or wood cases to protect them from predators; others are predators themselves. Even though they are very diverse in habit, taxa richness of caddisflies declines steadily as humans eliminate the variety and complexity of their stream habitat.

Intolerant Taxa Richness. These are the most sensitive taxa; they represent approximately 5 to 10 percent of the taxa present in the region. They are the first to disappear as human disturbance increases.

Clinger Taxa Richness and Percent. Taxa defined as clingers have physical adaptations that allow them to hold onto smooth substrates in fast water. These animals typically occupy the open area between rocks and cobble along the bottom of the stream, and may use these areas to forage, escape from predators, or lay their eggs. Clingers are particularly sensitive to fine sediments that fill these spaces and eliminate the variety and complexity of these small habitats. Sediment also prevents clingers from moving down deeper into the stream bed, or hyporheic zone, of the channel.

Long-Lived (Semi-Voltine) Taxa Richness. These invertebrates require more than 1 year to complete their life cycles and are exposed to all the human activities that influence the stream during that period. If the stream is dry part of the year, or subject to flooding, these animals may disappear. Loss of long-lived taxa may also indicate an ongoing problem that repeatedly interrupts their life cycles.

Percent Tolerant. Tolerant animals are present at most stream sites, but as disturbance increases, they represent an increasingly large percentage of the assemblage. Invertebrates designated as tolerant represent the 5 to 10 percent most tolerant taxa in a region.

Percent Predator. Predator taxa represent the peak of the food web and depend on a reliable source of other invertebrates that they can eat. The percentage of animals that are obligate predators provides a measure of the trophic complexity supported by a site. Less disturbed sites support a greater diversity of prey items and a variety of habitats in which to find them.

Percent Dominance. As diversity declines, a few taxa come to dominate the assemblage. Opportunistic species that are less particular about where they live replace species that require special foods or types of physical habitat. Dominance is calculated by adding the number of individuals in the three most abundant taxa and dividing by the total number individuals in the sample.

Table B-1. B-IBI Metrics and Their Expected Response to Disturbance	
Metric	Response to Disturbance
Taxa Richness and Composition	
Total number of taxa	Decrease
Number of <i>Ephemeroptera</i> (mayfly) taxa	Decrease
Number of <i>Plecoptera</i> (stonefly) taxa	Decrease
Number of <i>Trichoptera</i> (caddisfly) taxa	Decrease
Number of long-lived taxa	Decrease
Tolerance	
Number of intolerant taxa	Decrease
Percent of individuals in tolerant taxa	Increase
Feeding ecology and other habits	
Percent of individuals that are predators	Decrease
Number of clinger taxa	Decrease
Population attributes	
Percent dominance (top 3 taxa)	Increase

Table adapted from Karr and Chu 1999.

BCG Metrics

Table B-2. Biological Condition Gradient Metrics				
	Poor	Fair	Good	
Negative Indicators	Increase with Increasing Human Disturbance, Domination by Fine Sediment, Lower DO, Warmer Thermal Regime, and Nutrient Enrichment			
Low or excessively high total abundance (m ²)	<500 >20,000	500–999	1,000–20,000	< 500 indicates either ultra-oligotrophic conditions or high physical or chemical disturbance > 20,000 is indicative of nutrient enrichment in mid-order, forested streams
Percent non-insects	=>10	5–9	0–4	Generally increases with the suite of factors resulting from human disturbance to stream ecosystems
Non-insect taxa richness	=>10	5–9	0–4	Generally increases with the suite of factors resulting from human disturbance to stream ecosystems
Percent crustaceans	=>10	5–9	0–4	Common taxa in Puget Sound lowlands tend to increase with greater urbanization, particularly <i>Crangonyx</i> and <i>Caecidotea</i>
Percent <i>Oligochaeta</i>	=>10	5–9	0–4	High density and dominance may indicate nutrient enrichment
Percent Tolerant snails	=>10	5–9	0–4	May dominate in disturbed and enriched Puget Sound lowland streams, but presence of some taxa dependent on glaciation history
Percent <i>Baetis tricaudatus</i>	>19	10–19	0–9	Ubiquitous taxa that tends to dominate when habitats are disturbed physically (e.g., floods) or by toxins
Percent <i>Simuliidae</i>	=>10	5–9	0–4	Ubiquitous taxa that tends to dominate when habitats are disturbed physically (e.g. floods) or by toxins
Percent <i>Chironomidae</i>	>30	10–29	<10	Generally increases with the suite of factors resulting from human disturbance to stream ecosystems
Percent non-native taxa	>=1	0	0	In Puget Sound lowland streams primarily the New Zealand mud snail (<i>Potamopyrgus antipodarum</i>) and the Asiatic clam (<i>Corbicula</i>)
Positive Indicators	For Puget Sound Lowland Streams			
EPT taxa richness	0–14	15–20	>20	Richness of <i>Ephemeroptera</i> (mayflies) + <i>Plecoptera</i> (stoneflies) + <i>Trichoptera</i> (caddisflies). Ubiquitous insect orders in streams with many sensitive taxa.
Percent cold-cool water biota	0	<1	>1	Optimal thermal regime indicators for Puget Sound lowland streams
Cold-cool water biota richness	0	1	>1	Optimal thermal regime indicators for Puget Sound lowland streams

Table B-2. Biological Condition Gradient Metrics				
	Poor	Fair	Good	
<i>Perlidae</i> richness	0	1	>1	Large, long-lived, predaceous stoneflies that are sensitive to embedding and disturbance
<i>Nemouridae</i> richness	0–1	2	>2	Shredder stoneflies. Higher richness generally correlated with higher habitat complexity and intermediate substrate stability
<i>Rhyacophila</i> richness	0–1	2	>2	Free-living predaceous caddisflies. Higher richness generally correlated with higher habitat complexity and intermediate substrate stability.
<i>Ephemerellidae</i> richness	0–1	2	>2	Diverse family of stream mayflies. Higher richness generally correlated with higher habitat complexity and intermediate substrate stability.
<i>Heptageniidae</i> richness	0–1	2	>2	Ubiquitous scraper mayflies in running waters correlated with healthy diatom and algal communities

Source: Robert Wisseman, Aquatic Biology Associates, Inc.

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Attachment C: Site-Specific Analysis

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Attachment C

Site-Specific Analysis

In addition to the standard B-IBI analysis (total score and individual metrics), the 2015 benthic community was analyzed in depth by Robert Wisseman, principal of Aquatic Biology and a macroinvertebrate expert with many years of professional experience. His analysis considered negative indicators (percent non-insects, percent non-insect taxa richness, percent non-native species, and percent tolerant species), positive indicators (stonefly/mayfly/caddisfly taxa richness, percent cold-cool water biota and taxa richness), total abundance per square meter, frequency of depositional and fine sediment-loving taxa, trophic and feeding group balance, stressors indicated, preliminary biological condition gradient score for the site, and overall “best professional judgement.” For all sites, 0–100 B-IBI scoring and the Fore et al. 2012 taxa attributes were used.

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Site name:
SW-1 (Spanaway Creek downstream of Spanaway Lake outlet)



Figure C-1. SW-1 (Spanaway Creek) looking upstream, 5/25/2017

Habitat attributes: SW-1 is located several hundred meters (m) below the lake outlet. The low-to moderate-gradient stream outlet channel traverses a short, densely forested and shaded reach and empties into a small, more open pond created by a low dam, which then empties into a moderate-gradient outflow channel bounded on one bank by forest, and the other bank by suburban yard. Notes from May 25, 2017, field visit: The channel is 2–4 m wide; the width-to-depth ratio is moderate; sinuosity is low as it appears to have been straightened and channelized below the dam; water depth averages 20 cm; stream banks are rocky, stable, and with high coverage by vegetation and roots; shading from trees is moderate at and above the site; habitat is about 75 percent riffle and 25 percent glide; no pools, alcoves, or pocket water is found in this stream reach; no large woody debris is present; channel roughness is low; little substrate disturbance from high winter flows is evident; flow was strong from the wet spring; no turbidity was evident; cobble substrates dominate; cobbles were slick with abundant filamentous algal growth; embeddedness of riffle cobbles was estimated to be 25–50 percent; rocks were loosely consolidated, not armored; crevice space between cobbles was moderate to

high; little fine silt was detected when substrates were disturbed; significant pore space in the hyporheic appears to be present; and overall habitat complexity is low to moderate.

Benthic community: Nearly all the taxa present are classified as BCG 4 and 5, intermediate to highly tolerant. One non-native taxa was present, *Corbicula fluminea*, the Asiatic clam. The dominant organism present is *Crangonyx*, an amphipod that is a particularly good indicator of human disturbance and urbanization in the Puget Sound lowlands. *Caecidotea*, a tolerant isopod crustacean, is subdominant, and a good indicator of human disturbance. *Hydropsyche* are net-spinning caddisflies, often found in abundance at lake outlets. Its cousin, *Cheumatopsyche*, is typically found at lake outlets where there is considerable nutrient enrichment. Its absence suggests that nutrient enrichment is not a significant stressor at the site. Flatworms (*Trepaxonemata*) are also dominant, which cannot currently be related to habitat conditions. The midge community present is a mix of running water and standing water taxa. Midge taxa characteristic of nearly anoxic conditions are not present. Over half the community are crustaceans and mollusks, indicating that calcium is not a limiting factor.

Total abundance of invertebrates is in the normal, moderate range. Stream reaches located at lake outlets often exhibit very high total invertebrate abundances, because of nutrient enrichment in some lakes and the export of planktonic algae and zooplankton in the water column, which in turn supports high densities of filtering benthic invertebrates. However, the site is located several hundred meters below the true outlet and there is an intervening settling pond, so the benthic community may not be similar to the one found 0–100 m below the Spanaway Lake outlet. At this site, significant nutrient enrichment is not indicated because of moderate total densities.

B-IBI score 11, which is very poor. Nine of the 10 B-IBI metrics scored very low. Only long-lived taxa richness was fair, and these taxa were tolerant snails, leeches, and the Asiatic clam (*Corbicula*). For a moderate-gradient, cobble and riffle dominated site, the B-IBI indicates severe impairment.

BCG level 5-, given that this is a moderate-gradient, cobble riffle dominated site. The community is dominated by highly tolerant taxa (BCG attribute 5), and tolerant, non-native taxa are present (BCG attribute 6). No sensitive taxa are present (BCG attribute 1–3).

Depositional habitat and fine sediment related taxa dominate the benthic community. These taxa may be drifting down from the lake and pond upstream and settling in the limited pockets and slackwater available. Only a few taxa are associated with coarse substrates present.

Total taxa richness is 28, very low, indicating a lack of overall habitat complexity and/or water quality limitations.

Trophic and feeding groups: The benthic community is super-dominated by fine particle collectors. Shredders, scrapers, and predators are rare.

Negative indicators: Non-insects and tolerant crustaceans are super-dominant. The tolerant crustaceans *Crangonyx* and *Caeidotea* compose 46 percent of the community. These taxa have been identified in the Puget Sound lowlands as ones that respond the most positively to increasing urbanization.

Positive indicators: An extremely low number of EPT taxa are present. Lack of any cold-cool water biota indicates that this stream warms considerably in the summer and is non-supportive of salmonids. Absence of all other positive indicator taxonomic groups points to very low habitat quality and complexity.

Stressors indicated and major limiting factors

Flow: Because of the groundwater-fed nature of the basin, substantial flows are maintained at this site year-round. Winter flows probably rise and fall slowly, not exhibiting intense peaks that would lead to substantial scouring and resorting of substrates.

Dissolved oxygen: Probably moderate to high in the winter and low to moderate in the summer, but never anoxic. Enough benthic invertebrates are present in the July 2015 sample that require at least moderate levels of DO, that indicate oxygen deprivation is not a limiting factor.

Thermal: Most taxa present are tolerant of considerable summer warming. High stream water temperatures may occur for extended periods over the summer. High and extended warm water temperatures appear to be the major limiting factor to benthic community development at this site, precluding the establishment of many EPT and intolerant taxa populations that would otherwise find the riffle habitat and cobble substrates at this site suitable for colonization.

Nutrient enrichment: Moderate total invertebrate densities and the mix of taxa present indicate that nutrient enrichment is not excessive at this site. For example, the net-spinning caddisfly present is *Hydropsyche* instead of *Cheumatopsyche*, which tends to replace *Hydropsyche* in streams that are heavily nutrient-enriched. The low number of segmented worms (*Oligochaeta*) and midges (*Chironomidae*) also indicates at most moderate enrichment. Midge genera present are not ones associated with high levels of enrichment.

Toxins: Catastrophic limitations from toxins is not indicated, though low-level, chronic impacts may be occurring.

Chemistry: High crustacean and mollusk abundance indicates that calcium is not a limiting factor.

Substrates: Dominated by stable cobble that is only lightly embedded, suggesting that substrate is not a limiting factor to EPT, long-lived, and intolerant taxa evaluated in the B-IBI for the Puget Sound lowlands.

Habitat complexity: Taxa present indicate that habitat complexity is only low to moderate, despite an extensive reach of stable, cobble-dominated riffle/glide habitat. This reach is little embedded with open hyporheic pore space, ideal for a whole suite of EPT taxa. With no stoneflies and only one mayfly taxa present, something besides physical habitat conditions is severely limiting benthic community development at this site. That factor is probably an extended period of elevated stream water temperature each summer.

Possible remediation to improve biotic integrity: High and extended water temperature appears to be the dominant stressor at this site. This is substantially natural, as the extensive open wetlands and a large shallow lake upstream of the site are natural solar collectors.

Site location: This site is downstream of a lake outlet with high and extended summer water temperatures that are substantially natural in nature. There are no realistic remedial actions to ameliorate. Subsequent sampling will only reiterate this conclusion. If available, a site midway between the lake outlet and the distributary fork may be more appropriate.

Site name: SW-2 (Coffee Creek)



Figure C-2. SW-2 (Coffee Creek) looking downstream, 5/25/2017

Habitat attributes: The site is in a short stream segment of several hundred meters between Spanaway Lake and extensive wetlands found on Joint Base Lewis-McChord. The actual benthic sampling site is approximately 25 m above the lake in an apartment development. It is just below a more wooded reach near Spanaway Loop Road. Access to this wooded reach is blocked by a fence. There are a few scattered trees along the sampling reach, and lawn abuts both banks. The source water for the site comes from the extensive and minimally disturbed wetland across the Spanaway Loop Road on Joint Base Lewis-McChord property. This is a groundwater-fed system. Stream temperatures at the site are relatively cool year-round.

The stream at this site is a wetland-spring-groundwater-fed site. Flows and temperature show low amplitude over the year. Notes from May 25, 2017, field visit: the stream channel has a moderate gradient; appears to have been channelized in the apartment development area; base flow width is 3–4 m; depths are 20–30 cm; habitat is about 50 percent riffle and 50 percent glide; cobbles compose 60 percent and sand/gravel 40 percent of the substrates;

embeddedness is about 25 percent; crevice space between cobbles is moderate; there is little entrained silt in surface sediments; and little resorting or scouring of substrates occurs in the winter. Cobble and rubble tops support dense growths of aquatic moss year-round, leaving very little exposed rock surface for scrapers. Moderate amounts of filamentous algae were present, indicating slight nutrient enrichment. Aquatic moss is not a significant source of food for benthic macroinvertebrates.

Total abundance: 4,495 individuals per square meter is in the optimum range, indicating moderate productivity without excessive nutrient enrichment.

Depositional and fine sediment related taxa: The benthic community is dominated by erosional habitat-related taxa.

B-IBI scores: 40.5 is at the low end of the **fair** range for a cobble-bottomed stream, but not inconsistent with wetland-spring-groundwater fed streams where substrates are coated with aquatic mosses.

Biological condition gradient: 3. The benthic community is composed of a mix of **intermediate sensitive** (3) and **intermediate tolerant** (4) taxa. A few **highly tolerant** (5) taxa are present, but in low densities. The provisional score of BCG 3 accounts for the wetland-spring-groundwater fed nature of the system. This type of system tends to display moderate to high invertebrate densities, but low to moderate total taxa richness.

Total taxa richness is 39, moderate for a site with these habitat characteristics.

Negative indicators: Non-insect abundance and richness is high, but not unusually so for a site with these habitat characteristics. The few tolerant taxa present are found in low abundance (*Crangonyx*, *Hyalella*, *Caecidotea*, *Halipus*, *Cricotopus bicinctus* group, and *Juga*).

Positive indicators are all poor or fair, which is to be expected for a moss-dominated site.

Trophic and feeding groups: The benthic community at this site is unbalanced. Shredders are dominant (stoneflies *Malenka* and *Zapada cinctipes*, mayfly *Cinygma*, and caddisfly *Lepidostoma*); collectors sub-dominant; and scrapers and predators are poorly represented.

Stressors indicated and major limiting factors

Flow and stormwater: Excessive substrate disturbance from peak stormwater flows is not indicated. Excessively low or intermittent flows in late summer are not indicated. Flows appear to be adequate year-round.

Dissolved oxygen: Low DO levels during low flow are not indicated. Quite a few taxa are present in numbers that require at least moderate levels of DO year-round.

Thermal: This is a cool-warm water community. No cold-cool water taxa are present. Solar warming in the large area of open marsh and pond above the site is ameliorated by cooler groundwater inflows.

Nutrient enrichment: Excessive nutrient enrichment is not indicated.

Toxins: Acute toxicity is not indicated.

Chemistry: Sufficient calcium is present to support crustaceans and mollusks.

Substrates: Though coarse substrates are dominant, excessive moss coverage limits the development of a diverse erosional habitat benthic community.

Habitat complexity: Channelized; high moss coverage; lack of large woody debris; lack of peak flows to refresh hard surfaces.

Physical disturbance: Excessive scouring or bedload transport during high flows is not indicated.

Possible remediation to improve biotic integrity: Little could be done at this site to augment biotic integrity. The community currently present at this site is substantially natural.

Site location: The current site location is optimal considering how short this stream segment is and where access is practical and possible.

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Site name: WSP2 (Lower Spanaway Creek)



Figure C-3. WSP2 (Lower Spanaway Creek) looking upstream 5/25/2017

Habitat attributes: Spanaway Creek splits into two distributary streams (Spanaway and Morey Creeks) about 0.5 km above this site. The Morey Creek fork traverses a stream segment that appears to have an extensive riparian fringe of brush and trees and extensive beds of macrophytes in-channel. In contrast, the Spanaway Creek fork traverses a stream segment dominated by active pastureland that abuts the stream bank providing little or no riparian vegetation development. The stream is channelized, open, low-moderate gradient, and no macrophyte beds were evident as far upstream as could be seen. The site is in a small housing development at the downstream end of an extensive pasture area. Homeowners have channelized the stream, built a small island in the middle of the channel, and rip-rapped both banks with building stone. Semi-domestic ducks are found in the area. One bank is bordered by lawn, while the other bank and island have some trees that provide partial shade. Bottom substrates in the area are dominated by loosely consolidated sand and gravel with little entrained silt. Homeowners have built some riffle-glide habitat with paving stones.

Total abundance: Is in the low end of the normal range. Nutrient enrichment is not indicated.

B-IBI score 14.5 is very poor, even accounting for the low gradient and high embeddedness of fine sediment. Because this was a targeted riffle sample, it is likely that technicians in July 2015 included some of the larger substrate present in their sampling, increasing the average sediment size. Eight of the 10 B-IBI metrics scored in the very poor range. Total taxa richness is low. No mayflies, stoneflies, or intolerant taxa are present. Just over 50 percent of the benthic community are tolerant taxa. Severe impairment is indicated at this site.

BCG level 5, considering that at least some large substrate had been included in the sampling. The benthic community is dominated by tolerant and highly tolerant taxa (BCG attribute 4–5). Only a few intermediate tolerant taxa are present. Sensitive taxa are absent. No non-native taxa are present.

Depositional and fine sediment related taxa super-dominate the benthic community. Only a few taxa are present in low abundance that are associated with coarse substrates (e.g., *Optioservus* and *Hemerodromia*).

Total taxa richness is 34, low for a fine level taxonomic analysis, indicating low overall habitat complexity.

Negative indicators: Non-insects super-dominate the community (81.4 percent), exceptionally high for even a low-gradient site. Significant human disturbance to habitat and/or water quality is indicated. Crustaceans highly tolerant of human disturbance dominate the community (*Crangonyx*, *Caecidotea*, and *Hyaella*). *Baetis tricaudatus* and *Simuliidae* are absent, which is curious because some hard substrate is present. Midges or worms do not dominate the community, indicating that nutrient enrichment is not a significant stressor.

Positive indicators: Sensitive, positive indicator taxa are virtually nonexistent, probably due primarily to dominance by fine sediment at the site. Most, but not all, of the positive indicator taxa are associated with coarse substrates. No cool-cold water taxa are present.

Trophic and feeding group: Fine particle collector-gatherers super-dominate. Collector-filterers, scrapers, and shredders are rare. The feeding group/trophic balance of the community is severely distorted. Predators are leeches, mites, some midges, and flatworms, all tolerant taxa.

Stressors indicated and major limiting factors

Dissolved oxygen: Periodically chronic low levels of DO are indicated, but not acute and persistent. Probably low in the warm months.

Thermal: No cold-cool water taxa present. All taxa present tolerate relatively high summer water temperatures. Conditions are non-supportive of salmonids. High and extended summer water temperatures appear to be the major stressor at this site as with site SW-1.

Fines and embedding: Very high embedding with fines and dominance of fines in the surface substrates appears to be a major limiting factor. The limited area of larger substrates provided by paving stones placed in the stream is not sufficient to support and maintain populations of most clinger taxa.

Habitat complexity: Very low habitat complexity; i.e., channelized, banks riprapped, dominated by fine sediments, lack of large woody debris, and macrophyte beds.

Nutrient enrichment: Slight to moderate nutrient enrichment is indicated by the extensive filamentous algal growths found on stone tops on May 25, 2017. Low to moderate invertebrate densities found in July 2015 indicate that nutrient enrichment is probably not excessive.

Toxins: Acute toxicity is not indicated. Low-level chronic toxicity may be present.

Physical disturbance: Recent physical disturbance of surface sediments is not indicated.

Chemistry: High abundance of crustaceans and mollusks indicates calcium is not limiting to them. This may indicate higher specific conductance and other ions present.

Benthic community: Super-dominance by non-insects. Highly tolerant amphipods and isopods compose nearly half the community (*Crangonyx*, *Hyalella*, *Caecidotea*). All taxa present are generally tolerant of lower DO, fine sediment, higher summer water temperature, and some fouling by filamentous algae. About one fifth of the community are flatworms (*Trepaxonemata*), which cannot be readily explained. Tolerant midges are the most diverse component (but not most abundant) of the benthic community, and include the highly tolerant genus *Procladius*.

Possible remediation to improve biotic integrity: A lesson and contrast is supplied by the benthic site on the Morey Creek fork located a short distance away. This fork has a more extensive and developed riparian corridor, and an abundance of macrophyte beds that dampen temperature extremes and filter nutrients and silt from the water. Morey Creek WSP4 versus Spanaway Creek WSP2 has total taxa richness of 55 versus 34; B-IBI total score of 35.3 versus 14.5 percent; and BCG level 3–4 versus 5. Because extended and elevated summer water temperature is probably the major limiting factor at this site, establishing that a lush riparian corridor through the upstream pastures could lower stream water temperatures.

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Site name: WSP4 (Morey Creek)

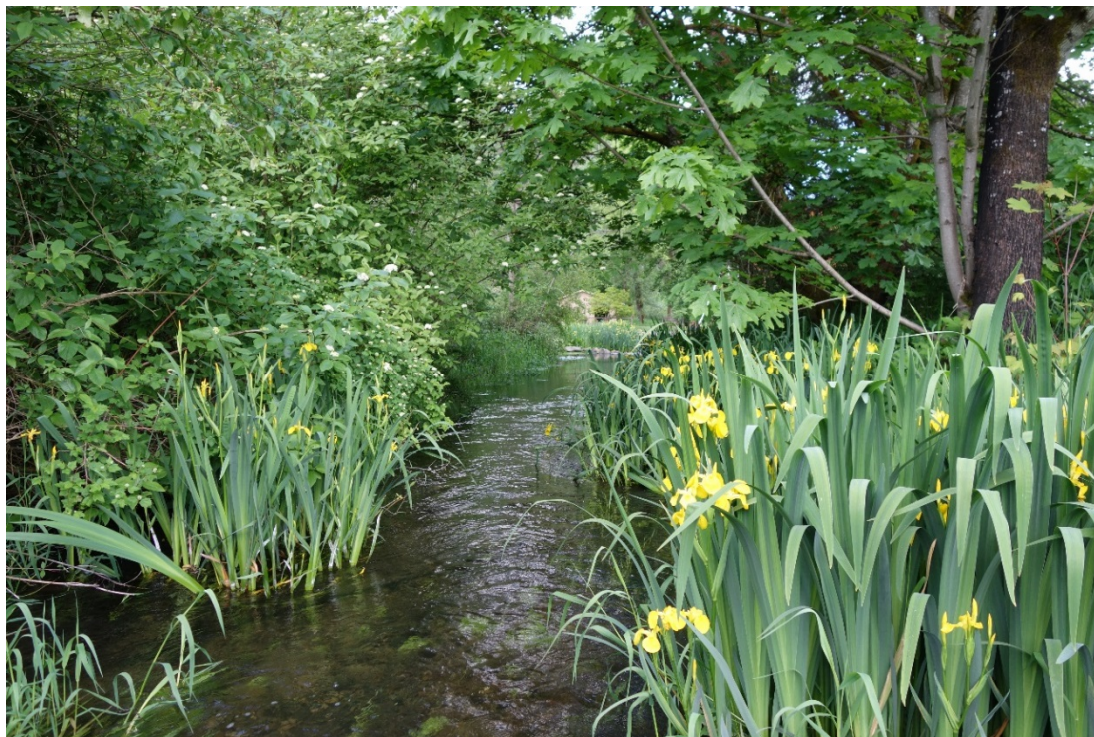


Figure C-4. WSP4 (Morey Creek) looking downstream, 5/25/2017

Habitat attributes: (Notes from May 25, 2017 field visit.) Stream flow was strong and the water clear after the exceptionally wet spring. The site is low gradient. Mid-channel substrates are dominated by sand and fine gravel. Emergent macrophytes line both shores. The site is located just upstream of a residence and about 50 m downstream of a road crossing. To the south, open inactive pasture encroaches the stream bank up to the line of emergent macrophytes, providing little shade. To the north, a riparian fringe of alder and other trees provides shading to about half the channel. Upstream of the road, a distinct riparian fringe of brush and trees is visible that may extend up to the Spanaway/Morey Creek fork. Extensive macrophyte beds (submergent and emergent) found in Morey Creek above the sampling site help to shade the stream, trap fine sediment and undoubtedly absorb nutrients being carried down from the Spanaway Lake area.

Total abundance 812. Relatively low, which may be due in large part to dominance by fine sediment substrates.

B-IBI scores 35.3, which is poor for a cobble-bottomed stream, but for a low-gradient, fine sediment dominated site may be good. Total taxa richness is high, indicating more habitat complexity here than at the other biomonitoring sites located downstream of Spanaway Lake. Predator richness and percent contribution are high, indicating a more trophically balanced community. EPT, clinger, and intolerant taxa are not expected to be numerous or rich in a fine sediment-dominated habitat.

BCG level 3, given that this is a low-gradient, warm water site dominated by fine sediment. The community is dominated by intermediately tolerant (BCG 4) and highly tolerant (BCG 5) taxa. Sensitive taxa are rare or absent. Two highly tolerant taxa dominate the community (*Caecidotea* and *Procladius*), with other highly tolerant taxa being subdominant (*Crangonyx*, *Hyalella*, *Ablabesmyia*). This would prompt a BCG Level 5. However, considering most of the tolerant taxa are normally found in depositional habitats and low-gradient sites, total taxa richness is high, and the suite of taxa present indicate at least moderate habitat complexity, a BCG level of 3 was chosen.

Depositional and fine sediment related taxa are super-dominant at this site. Only a few erosional taxa are present in low numbers that require coarse substrates.

Total taxa richness of 55 is high, indicating moderate to high habitat complexity for a low-gradient stream.

Negative indicators: Non-insect dominance is high and richness is very high. Highly tolerant crustaceans compose a little over one third of the community. Tolerant midge abundance is very high.

Positive indicators: Are all rare or absent. This is expected at a warmer, low-gradient, fine sediment-dominated site. Taxa associated with coarse substrates in cool-cold, moderate- to high-gradient streams are not expected to occur here. EPT richness is low, even for a site with these habitat characteristics, and there is room for improvement there.

Trophic and feeding groups: Predator richness is moderate to high at this site. The high percentage predator is due to the tanypod midge *Procladius* being the second-most dominant organism present. The benthic community is dominated by fine particle collector-gatherers, with a few collector-filterers. Shredders are rare, indicating that detritus may not reside in the system for long before being moved out by stormwater surges. Scrapers are very rare, as would be expected in a fine sediment-dominated habitat.

Benthic community: Highly tolerant crustaceans (*Hyalella*, *Crangonyx*, *Caecidotea*) and midges (particularly *Procladius* and *Ablabesmyia*) dominate the community. The fauna suggests emergent or submergent macrophytes are at this site. Many taxa swim near the sediment surface, many associated with macrophytes, some that sprawl and crawl on the sediment surface, but few taxa that either cling to hard surfaces or burrow in fine sediments. Flow in late

summer is probably very low, nearly static. Why flatworms (*Trepaxonemata*) are rare here and abundant at the adjacent Spanaway Creek sites is a mystery. Many of the taxa present are also found in lentic waters. Only a few obligate stream taxa are present.

Stressors indicated and major limiting factors

Flow and stormwater: Low, nearly stagnant flows in late summer. Peak winter flows probably do not significantly disrupt surface substrates. Also, extensive macrophyte beds found at and above the site significantly dissipate hydraulic power. Summer flows from this groundwater-driven system are probably substantial and sufficient to maintain a healthy benthic community.

Dissolved oxygen: Low, but not near anoxic during summer low flows. Macrophyte beds may aid in oxygenation.

Thermal: Most taxa present are tolerant of considerable summer warming. Non-supportive of salmonids. On May 25, 2017, a fully mature approximately 6-month-old *Dicosmoecus gilvipes* larvae (caddisfly) was found at the site. Taxa requires cool water to develop and sufficient oxygen saturation over summer to maintain the quiescent and immobile prepupal and pupal stage.

Nutrient enrichment: Low total abundance indicates that nutrient enrichment is not significant.

Toxins: Acute toxicity not indicated, though low-level, chronic toxicity may be present.

Chemistry: High crustacean abundance indicates calcium is not a limiting factor.

Substrates: The fauna clearly indicates that fine sediment super-dominates surface substrates at this site. The paucity of burrowers indicates a combination of silt and low DO inhibits colonization of the hyporheic habitat. The few clinger taxa present are probably more associated with macrophytes and branch detritus than with rocks.

Habitat complexity: Appears to be moderate for a low-gradient, fine sediment-dominated site.

Physical disturbance: Peak winter stormwater flows do not appear to significantly disrupt the surface substrates by either scouring or bedload transport.

Possible remediation to improve biotic integrity: The near lack of shredders suggests that riparian inputs of detritus are either low, or the channel lacks sufficient roughness to retain detritus for long during peak fall and winter flows. The riparian corridor in this reach should be evaluated to see if additional tree and shrub plantings may be warranted. Increased shade would also help to cool the stream. Large woody debris and debris jams in the channel would help considerably to increase habitat complexity, retain detritus, and dissipate hydraulic power,

creating flow refugia. Introducing beaver would improve habitat complexity, but may clash with human activity and desires.

Site location: This stream system is very odd in that proceeding downstream, Spanaway Creek splits into two distributary streams (Morey and Spanaway creeks). The site is probably as optimally placed as access through private lands will allow, considering the relatively high B-IBI score and robust benthic community present at the current location (for a low-gradient stream.) This site is a sharp contrast to WSP2, Spanaway Creek downstream of the Spanaway/Morey Creek fork, and may provide a target level of biotic integrity for WSP2 to achieve.