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State of Washington

Burnt Bridge Creek Watershed Fecal Coliform Bacteria, Temperature, Dissolved Oxygen, and pH

Source Assessment Report

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COVER PHOTO: Burnt Bridge Creek near sampling site BBC04.3 from 2008–2009 fieldwork.

Burnt Bridge Creek Watershed Fecal Coliform Bacteria, Temperature, Dissolved Oxygen, and pH

Source Assessment

by

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Executive Summary

Segments of Burnt Bridge Creek (Clark County) and its tributaries do not meet Washington State water quality criteria for temperature, fecal coliform bacteria (FC), dissolved oxygen (DO), and pH. In 2008, the Washington State Department of Ecology (Ecology) selected Burnt Bridge Creek for a water quality improvement project to address these water quality impairments. Burnt Bridge Creek was originally intended for a formal total maximum daily load (TMDL) study, but was changed to a Source Assessment study in 2016 to more effectively address water quality problems in the watershed.

This Source Assessment report presents the technical analysis and results from data collected at sampling sites throughout the study area by Ecology during 2008–2009 (Figure ES-1). A summary of more recent water quality data, collected by the City of Vancouver from 2011-2018, supports the 2008–2009 data used in this report. A TMDL Alternative will be developed using the results from this Source Assessment to prioritize implementation actions to address water quality impairments in the Burnt Bridge Creek watershed.

Summary of Technical Approach

The technical approach for this source assessment report includes the following:

- Data quality assessment for data collected during the 2008–2009 fieldwork period.
- Summary of routine water quality monitoring and sampling conducted by the City of Vancouver since 2010.
- Analysis of FC impairments in the watershed:
    - Summarize FC data collected during 2008–2009 sampling and identify areas that exceed (do not meet) water quality criteria.
    - Compare seasonal FC loading patterns.
    - Perform statistical rollback analysis to determine the relative reductions needed to meet water quality criteria.
- Analysis of temperature impairments in the watershed:
    - Summarize temperature monitoring data from 2008–2009 and identify creek segments that exceed temperature criteria.
    - Complete shade analysis to evaluate current effective and system potential shade along the riparian corridor.
- Summary of DO and pH measurements from 2008–2009 monitoring period.
- Present results in subbasin summary synthesis to connect land use patterns, FC concentrations, and temperatures that can be used to help guide implementation activities that will improve water quality.

Key Findings

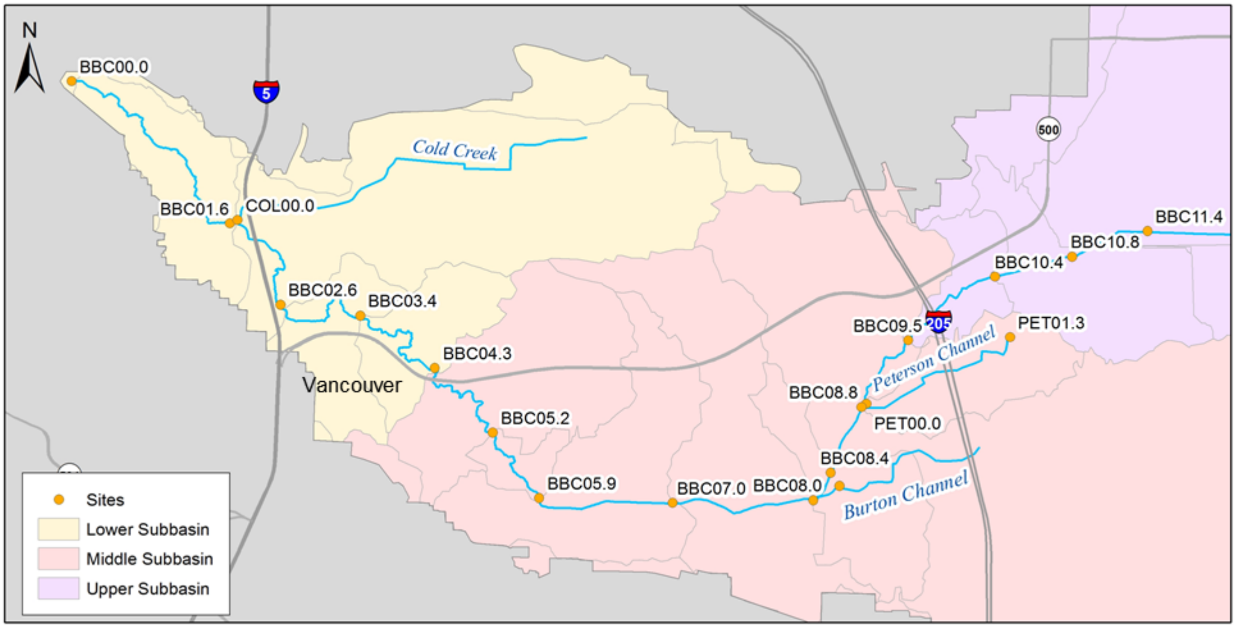

Figure ES-1. Burnt Bridge Creek study area and sampling sites.

Fecal Coliform Bacteria

- All FC sampling sites exceeded FC water quality criteria.
- Geometric mean concentrations were generally higher during the dry season than during the wet season. The highest FC geometric mean concentrations were found at tributary sites during the dry season at Cold Creek, Peterson Channel, and Burton Channel.
- FC loading was higher during the wet season than during the dry season at all sites. The highest FC loads were in the lower subbasin at BBC01.6 and BBC02.6 during the wet season.
- High reductions in FC (>75%) are needed to meet water quality criteria based on the results from the statistical rollback analysis at all of the tributary outlet sites (PET00.0 during both seasons; BUR00.0 during the wet season; COL00.0 during the dry season), two middle subbasin sites (BBC08.4 during the dry season; BBC07.0 during the wet season), and most of the lower subbasin sites (BBC04.3, BBC03.4, BBC02.6, and BBC01.6 during the wet season).
- The FC percent reductions may be used to guide pollution identification and clean-up efforts. As sources of FC are identified and corrected, downstream water quality conditions are expected to improve.

Temperature and Shade

- All sites exceeded temperature criteria, except for the site at the outlet of Cold Creek.
- The overall maximum temperature was observed at BBC00.0. During the temperature-monitoring period, 92% of days at BBC00.0 exceeded criteria.
- Sites with the highest count of dates with temperature above water quality criteria were in the middle subbasin (BBC07.0 with 230 days and BBC05.9 with 222 days).
- In Peterson Channel, discharge from SEH America comprises over half of the flow in the tributary. Maximum temperatures were higher at PET01.3 (near SEH America outfall) than the tributary outlet (PET00.0) by an average of 1.2°C. Temperature differences between the two sites are largest during summer months.
- Along the riparian corridor of Burnt Bridge Creek, approximately 36% of the area is pastureland, 19% is built or paved, and 45% is a mix of varying tree heights and densities.
- The largest shade deficit (difference between current effective shade and system potential shade) is in the upper subbasin (average of 62%). The average shade deficit in the middle watershed is 39% and in the lower watershed is 27%.
- Identifying areas along the riparian corridor with large shade deficits will be useful for guiding restoration activities and vegetation plantings to improve shade along Burnt Bridge Creek and reduce stream temperatures.

Dissolved Oxygen and pH

- Most sites, except BBC04.3 and COL00.0, had at least one day of noncompliance with DO concentrations below water quality criteria during the study period.
- Minimum DO values were generally observed during July, August, or September.
- Most sites had low counts of days not meeting water quality criteria for pH (≤ 3 days), except for BBC00.0 (12 days).
- Sites that met pH criteria during all sampling occurrences include BBC08.8, BBC08.0, BBC05.2, PET00.0, and PET01.3.
- There were a range of pH values throughout Burnt Bridge Creek watershed with overall minimum and maximum pH values in Burton Channel (6.1 and 9.8 s.u., respectively).
- Most results for DO and pH were measured instantaneously during regular sampling events in the morning and afternoon, and therefore do not fully represent the diel range.

Introduction

The Washington State Department of Ecology (Ecology) selected Burnt Bridge Creek for a TMDL in 2008 to address temperature, fecal coliform bacteria (FC), dissolved oxygen (DO), and pH water quality impairments. Ecology conducted fieldwork for this study in 2008–2009. This project was changed to a Source Assessment study in 2016 to more effectively address water quality problems in the watershed.

Following this Source Assessment, a TMDL Alternative will be developed that includes an implementation plan to address water quality impairments in the watershed. Source Assessments and TMDL Alternatives are used to efficiently complete water quality studies that focus on addressing water quality problems through pollution identification, correction, and implementation from primarily nonpoint sources. These water cleanup plans rely on long-term partnerships and collaboration for implementation.

Segments of Burnt Bridge Creek and its tributaries do not meet water quality criteria for bacteria, DO, pH, and temperature and are listed on the Clean Water Act's 303(d) list of impaired waters (Figure 1 and Table 1).

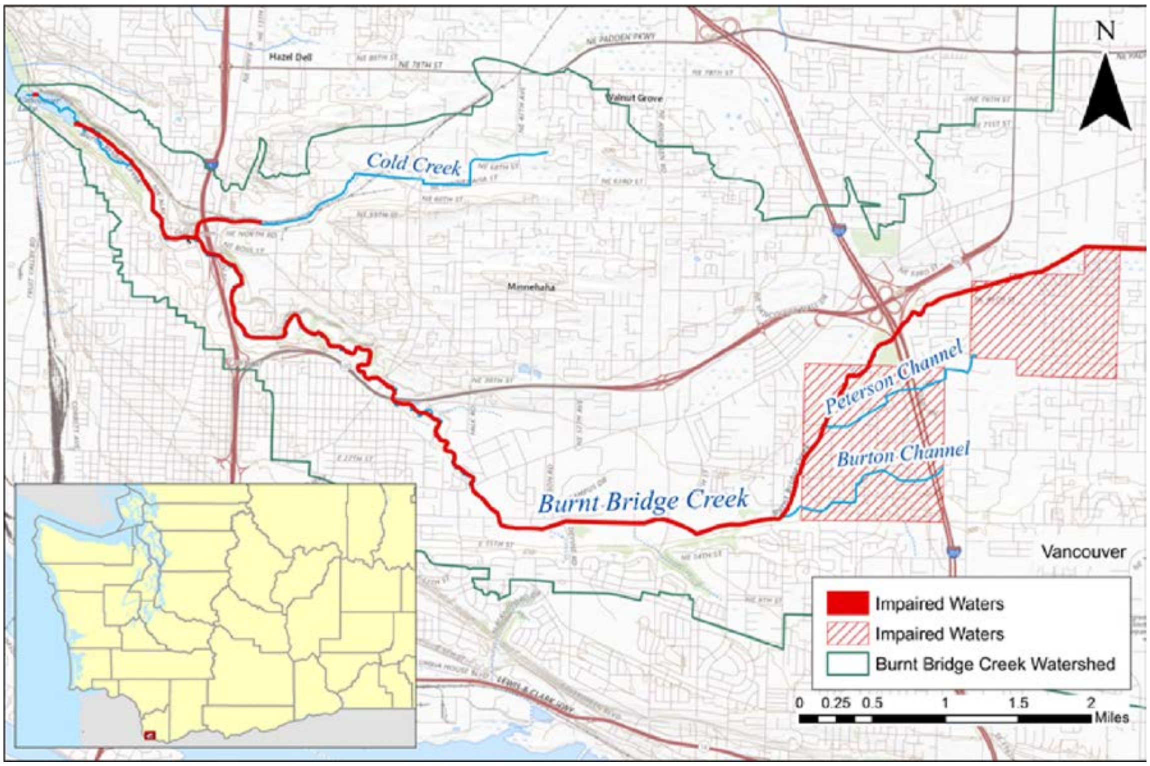

Figure 1. Burnt Bridge Creek watershed and 303(d) listings of impaired waters.

Table 1. 303(d) listings of impaired waters in Burnt Bridge Creek watershed (2014).

Listing ID	Parameter	Waterbody
7827	Bacteria	Burnt Bridge Creek
7829	Bacteria	Burnt Bridge Creek
7833	pH	Burnt Bridge Creek
7836	Dissolved Oxygen	Burnt Bridge Creek
7837	Temperature	Burnt Bridge Creek
7847	Temperature	Burnt Bridge Creek
72118	pH	Burnt Bridge Creek
72484	Bacteria	Burnt Bridge Creek
72890	Temperature	Burnt Bridge Creek
72061	pH	Burton Channel
72872	Temperature	Burton Channel
74296	Bacteria	Burton Channel
78094	Dissolved Oxygen	Burton Channel
72477	Bacteria	Cold Creek
46972	Bacteria	Peterson Channel
47693	Dissolved Oxygen	Peterson Channel
48661	Temperature	Peterson Channel
73857	Temperature	Peterson Channel

Water Quality Standards

Washington State water quality standards are the basis for protecting and regulating the quality of surface waters in Washington State. The standards implement portions of the federal Clean Water Act by specifying the designated and potential uses of water bodies in the state (Table 2). The water quality standards are established to sustain public health and public enjoyment of the waters, and the propagation and protection of fish, shellfish, and wildlife.

Table 2. Burnt Bridge Creek water quality standards.

Note that the bacterial indicator was updated from fecal coliform to E. Coli bacteria in 2019.

Parameter	Use Classification	Criteria
Fecal Coliform Bacteria	Primary Contact Recreation	• Geomean: 100 cfu/100 mL • 10% not to exceed: 200 cfu/100 mL
E. Coli Bacteria (updated in 2019)	Primary Contact Recreation	• Geomean: 100 cfu/100 mL • 10% not to exceed: 320 cfu/100 mL
Temperature	Salmonid Spawning, Rearing, and Migration	17.5°C
Dissolved Oxygen	Salmonid Spawning, Rearing, and Migration	8.0 mg/L
pH	Salmonid Spawning, Rearing, and Migration	6.5–8.5 units

Bacteria

The regulatory freshwater designated uses and criteria for FC bacteria for Burnt Bridge Creek are based on the *Primary Contact Recreation* use [WAC 173-201A-200(2)(b)]. The freshwater quality standards for this study area are:

1. Geometric mean criterion not to exceed 100 cfu/100 mL.
2. Not more than 10% of samples (or any single sample when less than ten samples exist) exceed 200 cfu/100 mL (percent exceedance criterion).

The percent exceedance criterion is calculated as the 90th percentile. The 90th percentile is a measure of statistical distribution that determines the value for which 90% of the data points are lower than 200 cfu/100 mL and 10% are higher. These two water quality criteria ensure that bacteria pollution in a water body will be maintained at levels that will protect human health.

In January 2019, Ecology adopted amendments to chapter 173-201A WAC, Water Quality Standards for Surface Waters of Washington State. This rulemaking updated freshwater quality standards for the protection of water contact recreational uses in state waters. Ecology adopted E. coli as the new bacterial indicator in freshwater, in place of FC, and new numeric criteria to protect water contact recreational uses. The Rule Implementation Plan (Ecology, 2019) includes guidance for the new rulemaking. Data for this study were collected prior to the rulemaking, and this report was completed during the transition period (2020) which allows for the option of using FC as the water quality bacterial indicator.

Samples collected during effectiveness monitoring will be analyzed for E. coli and compared with water quality standards during the water quality assessment to determine attainment of the recreational use. In addition, dual monitoring may be used to compare FC and E. coli samples and develop a relationship between different bacteria concentrations in the watershed.

Temperature

Washington State uses the temperature criteria to ensure a water body’s natural capability for providing full support for designated aquatic life uses. Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a waterbody. The 7-DADMax temperatures represent conditions in the thalweg or mainstream channel; therefore, it is assumed that aquatic species have access to cold-water refugia where they can reside in water that is cooler than the 7-DADMax temperatures. The 7-DADMax temperature criterion also assumes that colder temperatures are available to protect fish at night.

The temperature water quality standards for the Burnt Bridge Creek watershed protect the designated aquatic life uses of “Salmonid, Spawning, Rearing, and Migration, and Salmonid Rearing and Migration.” For these waters, the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.

Washington State uses these criteria to ensure full protection for its designated aquatic life uses. The standards recognize, however, that waters display thermal heterogeneity—some are naturally cooler, and some are naturally warmer. When a water body is naturally warmer than the above-described numeric criteria, the State limits the allowance for additional warming due to human activities. The combined effects of all human activities must not cause more than a 0.3 °C (0.54 °F) increase above the naturally warmer temperature condition.

Dissolved Oxygen

For DO water quality standards, minimum concentrations of DO are used as criteria to protect different categories of aquatic communities, some of which are specified for individual rivers, lakes, and streams. Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are the lowest 1-day minimum oxygen concentrations that occur in a waterbody.

For the Burnt Bridge Creek watershed, the following designated aquatic life use(s) and criteria are to be protected: “Salmonid Spawning, Rearing, and Migration” where the lowest 1-day minimum oxygen level must not fall below 8.0 mg/L more than once every ten years on average.

The described above criterion is used to ensure that where a waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a waterbody is naturally lower in oxygen than the criteria, the state provides an additional allowance for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/L decrease below that naturally lower (inferior) oxygen condition.

While the numeric criteria generally apply throughout a waterbody, they are not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that one take measurements from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously oxygen-rich areas. For example, in a slow moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that are erroneous for comparing to the criteria.

pH

Washington State established pH criteria in the water quality standards primarily to protect aquatic life. While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, at the extremes of pH lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient CO2 from bicarbonate in the water to be directly lethal to fish.

In the State's water quality standards, two different pH criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. To protect the designated aquatic life uses of "Salmonid Spawning, Rearing, and Migration" pH must be within the range of 6.5 to 8.5 s.u., with an anthropogenic allowance of 0.5 s.u.

Watershed Description

Burnt Bridge Creek is located in Clark County in southwestern Washington and is part of the Salmon-Washougal Water Resource Inventory Area (WRIA 28). The creek flows through a highly urbanized landscape from east to west through the City of Vancouver draining approximately 27.6 square miles. Figure 1 shows the extent of the watershed, where Burnt Bridge Creek flows 12.7 river miles from its headwaters near NE 162nd Avenue westward to its confluence with Vancouver Lake west of Interstate 5 (I-5). Vancouver Lake drains to the Columbia River through Lake River.

Hydrology and Hydrogeology

The Burnt Bridge Creek valley was initially formed during the massive Missoula floods that shaped much of the landscape in the Columbia River basin (PBS, 2003). The oversized valley became mostly marshes and wetlands, which existed through much of its history until the 1800s when farmers drained the marshes for agriculture use and channelized the course of the creek. The original defined channel of the creek began near present day 18th Avenue and flowed for approximately five miles before its confluence with Vancouver Lake. The upper watershed wetlands that form the headwaters of Burnt Bridge Creek were drained and channelized for agriculture and significant portions remain as open cultivated fields. Due to its origination from wetlands, Burnt Bridge Creek has a low gradient with approximately 80% of the stream gradient less than 0.1% with reaches flowing through peat deposits and wetland soils.

Three small tributaries and channels feed into Burnt Bridge Creek, from east to west, Peterson Channel, Burton Channel, and Cold Creek. Peterson Channel conveys industrial discharge from a manufacturing company, groundwater, and urban stormwater, Burton Channel discharges groundwater and runoff, and Cold Creek contributes groundwater, urban runoff, and industrial stormwater to Burnt Bridge Creek.

Burnt Bridge Creek is highly influenced by the exchange of surface and groundwater. The substrate underlying Burnt Bridge Creek is comprised of highly permeable alluvium from the Terrace Landscape Unit (Herrera and PGG, 2019; Sinclair and Kardouni, 2012). The porosity of the underlying sediments in Burnt Bridge Creek allows for an exchange of surface water and groundwater. Within the coarse flood deposits are important aquifers that supply local wells. The Burnt Bridge Creek Surface Water/Ground Water Interactions and Near-Stream Groundwater Quality report (Sinclair and Kardouni, 2012) and other reports (Herrera and PGG, 2019; Mundorff, 1964; Swanson et al., 1993; McFarland and Morgan, 1996) provide detailed descriptions of the geology, groundwater resources, and surface water and groundwater exchange in the Burnt Bridge Creek watershed.

Flow from Burnt Bridge Creek enters Vancouver Lake through a culvert under a railroad trestle after passing through a broad valley of wetlands and ponds. Tidal influences from the Columbia River contribute to the exchange of water between the lake and the outflow ponds of the creek. Burnt Bridge Creek contributes approximately 2% of the water budget of Vancouver Lake which is primarily supported by flows from the Columbia River through Lake River (Sheibley et al., 2014).

Historic Streamflow Data

The U.S. Geological Survey (USGS) operated three continuous streamflow gages on Burnt Bridge Creek from 1998–2000. The highest streamflow occurred during winter months and the low-flow period occurred during the fall. Table 3 summarizes the maximum, minimum, and average streamflow at each gaging station.

Table 3. Historical (1998–2000) USGS streamflow gage summary.

Gage	River Mile	Max Flow (cfs)	Avg. Flow (cfs)	Min Flow (cfs)
USGS 14211902 near mouth	1.6	149	24.8	5.4
USGS 14211898 Burnt Bridge Creek at 18th St	5.9	96	18.6	4.4
USGS 14211895 Burnt Bridge Creek at 112th Ave	10.5	29	7.5	0.9

Climate

Burnt Bridge Creek is located within the West Coast Marine Climate Region and experiences mild, cool, wet winters and relatively dry, warm summers. Temperature in the watershed is influenced by both the Coast Range to the west and the Cascade Range to the east. Air temperature during the 2008–2009 sampling period was consistent with historic averages based on historical data from the Vancouver meteorological station (Station No. 458773, National Weather Service Cooperative Network). Peak temperatures occurred in July and August, and July temperatures in 2009 were a few degrees higher than average temperatures (Table 4).

Table 4. Average monthly historical air temperatures at Vancouver (Station 4, NNE) and average monthly temperatures (2008-2009).

Month	Historical Avg. (°C)	2008 Avg. (°C)	2009 Avg. (°C)
Jan	39	37	37
Feb	42	42	39
Mar	46	43	43
Apr	51	45	49
May	57	56	56
Jun	62	58	62
Jul	66	65	70
Aug	66	66	66
Sep	61	61	62
Oct	54	51	51
Nov	45	47	45
Dec	40	36	33

Figure 2 shows total monthly precipitation from 2008–2009. Precipitation data were obtained from Clark County for the rainfall gage at Orchards in the Burnt Bridge Creek watershed. Both years showed typical seasonal conditions consistent with historic rainfall patterns, with the dry season from June through October and wet season from November through May. Both years had lower precipitation than the historic annual precipitation average (39.5 inches, Western Regional Climate Center) with similar rainfall in 2008 and 2009 (30.9 and 31.8 total inches, respectively).

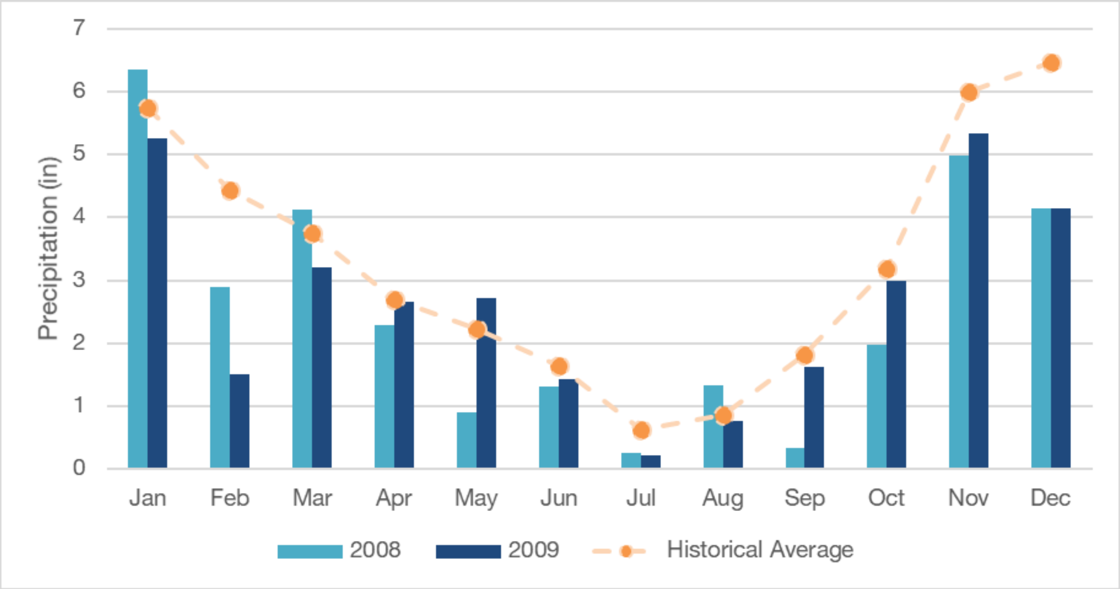

Figure 2. Total monthly precipitation (2008–2009) and historical average precipitation.

Land Use

The Burnt Bridge Creek watershed is an urban watershed with various types of land use (Figure 3). Burnt Bridge Creek flows through the City of Vancouver, the largest urban center in WRIA 28 with a recent population estimate of 183,000 (US Census Bureau, 2018).

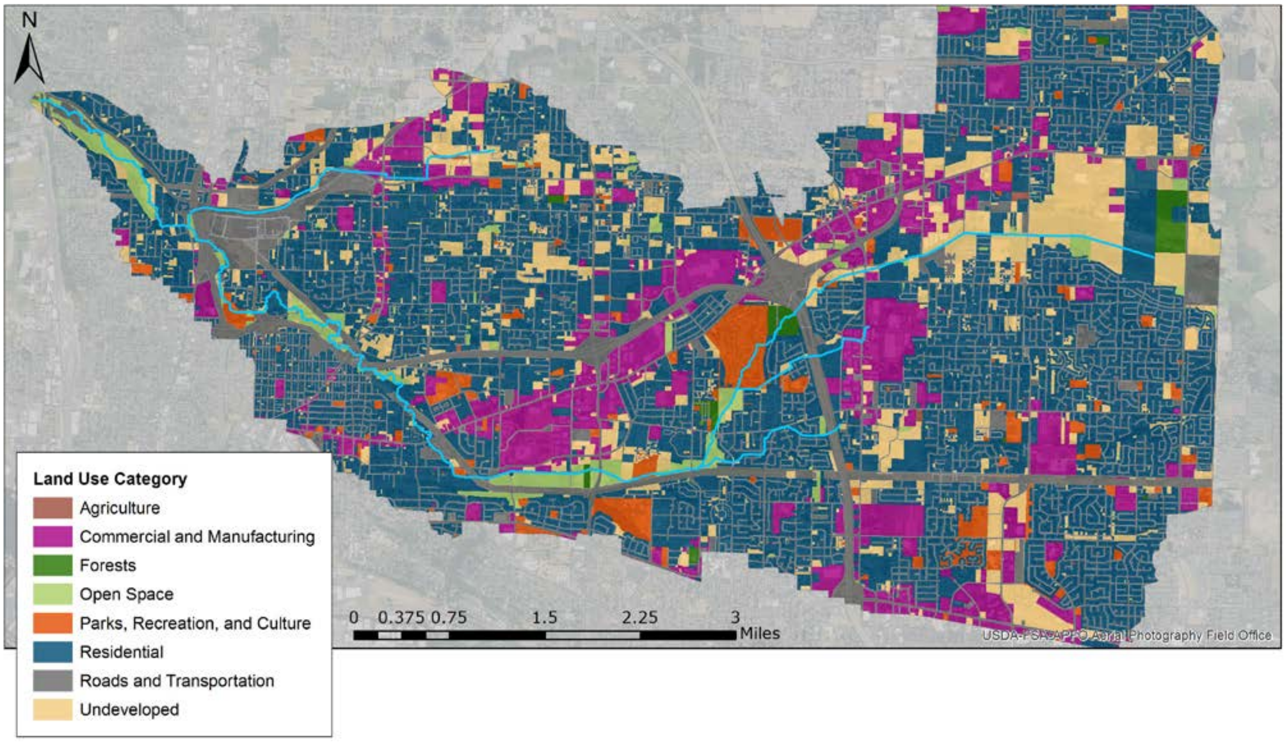

Figure 3. Map of land use (2010) in Burnt Bridge Creek watershed.

The Burnt Bridge Creek watershed is highly developed (Figure 4 and Table 5). Residential areas are the most prominent land use in the watershed (44% or 8,174 acres). Because the watershed is so highly developed, the second largest fraction of land use consists of roads and transportation corridors (24%) including Interstate-5 (I-5) and Interstate-205 (I-205). Undeveloped land along with commercial and manufacturing spaces make up a similar fraction of the watershed (12-13%).

Burnt Bridge Creek progresses through undeveloped, residential, commercial and manufacturing, and open space areas. The total fraction of the watershed that is forests, open space, and parks, recreation, and culture (7% total) is mainly concentrated along the riparian corridor. Undeveloped land, most of which is privately owned, is concentrated along the upper portion of Burnt Bridge Creek in the eastern portion of the watershed. There is mixed land use in the central portion of the watershed.

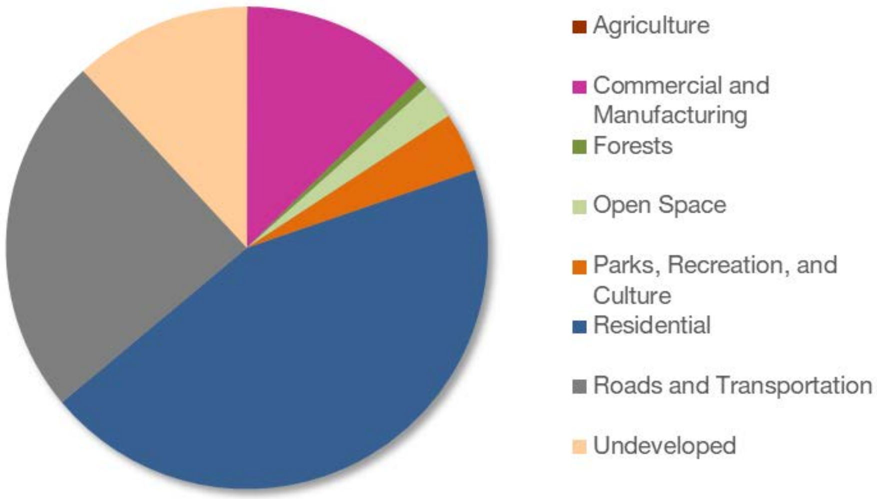

Figure 4. Pie chart of land use in Burnt Bridge Creek watershed.

Table 5. Summary of land use area in Burnt Bridge Creek watershed.

Land Use Category	Land Use (acre)	Land Use (%)
Agriculture	12	0%
Commercial and Manufacturing	2,333	13%
Forests	134	1%
Open Space	445	2%
Parks, Recreation, and Culture	736	4%
Residential	8,174	44%
Roads and Transportation	4,478	24%
Undeveloped	2,201	12%

For decades the City of Vancouver worked with a variety of partners to establish a greenway system in the Burnt Bridge Creek corridor. An extensive network of properties was acquired over the years and key reaches have undergone significant transformation through the Burnt Bridge Creek Greenway Project. An 8-mile regional trail now connects the lower and middle subbasins and is a widely used amenity by the community. Open space in the furthest downstream reaches in the western portion of the watershed includes a broad valley of ponds and wetlands before flows from Burnt Bridge Creek pass through a culvert and enter Vancouver Lake.

The majority of the land in the Burnt Bridge Creek watershed is privately owned. Publically owned lands make up approximately 11% of the watershed. The largest public entity landholders include the City of Vancouver (44% of public lands), schools (27%), and Clark County (10%; Table 6).

Table 6. Public lands in Burnt Bridge Creek watershed summary.

Public Entity	Land Area (acre)	Land Area (%)
City of Vancouver	901	44%
Clark County	215	10%
Schools	554	27%
WSDOT	54	3%
Federal Land	151	7%
Other	171	8%

Point Sources

Point sources refer to sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. The types of point source permits in the watershed include two individual permits (SEH America and Time Oil Co.), industrial stormwater general permits, and construction stormwater general permits (Table 7 and Figure 5).

Table 7. List of permits in Burnt Bridge Creek watershed.

Permit ID	Permit Category	Permit
WAR301324	Construction SW GP	~90
WA0039616	Industrial NPDES IP	SEH America Inc
WA0040967	Industrial NPDES IP	Time Oil Co NE Cherry Dr
WAR005582	Industrial SW GP	Trus Way Inc
WAR305395	Industrial SW GP	Marks Design
CNE304850	Industrial SW GP	City Bark & Recycling LLC
CNE307641	Industrial SW GP	Hy Pro Corporation
CNE307654	Industrial SW GP	Templar Granite LLC
CNE307405	Industrial SW GP	Heuvel Enterprises
CNE126328	Industrial SW GP	Lynnwood Kitchens Inc
WAR001186	Industrial SW GP	Boc Process Gas Solutions
WAR305409	Industrial SW GP	Fabrication Products Inc Minnehaha St
WAR308058	Industrial SW GP	Accra Fab Inc Vancouver
CNE304852	Industrial SW GP	Dewils Industries

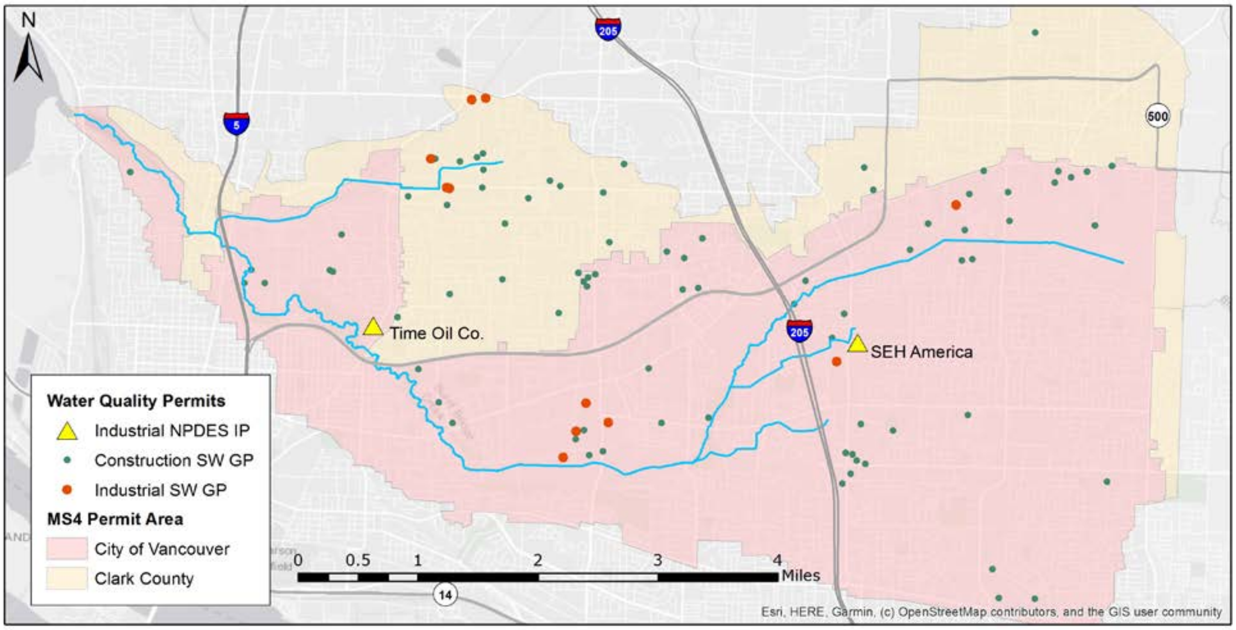

Figure 5. Map of point sources and municipal separate stormwater system (MS4) areas.

SEH America (SEH) manufactures and supplies silicon wafers to the semiconductor industry. SEH has multiple international silicon wafer production facilities, including one in Vancouver. SEH received its first NPDES permit in 1985. All of the process wastewater generated at the facility, approximately 3.1 cfs or 2.0 million gallons per day (mgd), is collected and discharged to the City of Vancouver's Marine Park wastewater treatment facility (City of Vancouver Industrial Pretreatment Permit Number 2004-03). Domestic wastewater generated at the plant is also discharged to the city treatment facility through a separate sanitary sewer connection. For this study, the process and domestic wastewater is not considered a point source because it does not discharge to Burnt Bridge Creek surface waters.

Within the study area, SEH is permitted to discharge non-process wastewaters to Peterson Channel, one of the tributaries to Burnt Bridge Creek, under the National Pollution Discharge Elimination System (NPDES) permit number WA0039616D. Non-process wastewaters include non-contact cooling water, reverse osmosis reject water, stormwater, and multimedia and filter backwash water. Wastewater flows through a series of three ponds that discharge to Outfall 001 into Peterson Channel, a man-made waterway originally constructed for the purpose of storm and irrigation tailwater drainage from agricultural activities. Peterson Channel flows into Burnt Bridge Creek near Royal Oak Drive and NE 93rd Avenue at approximately RM 8.7. The current NPDES discharge permit limits for temperature for Outfall 001 is a maximum of 21°C, although the state standard for temperature in Burnt Bridge Creek is now 17.5°C.

Time Oil Company is a gasoline service station that discharges treated groundwater to Burnt Bridge Creek near RM 4. Because of the nature of this facility and that the parameters monitored (e.g. benzene and lead) are not a focus of this study, this facility is not considered a potential source of temperature or bacteria pollution.

Stormwater

During significant precipitation events, rainwater washes the surface of the landscape and impervious surfaces such as roofs and paved areas, saturates soils, and raises water tables. This stormwater runoff can accumulate and transport pollutants, such as bacteria, via stormwater drains to receiving waters and potentially degrade water quality.

There are eleven industrial stormwater general permits (Table 7) throughout the study area, although some may discharge outside of the watershed. The industrial stormwater general permit requires that any stormwater discharged by a facility not cause or contribute to a violation of water quality standards in the receiving water. The current permit went into effect in 2020.

There are three municipal separate stormwater system (MS4) NPDES permits in Burnt Bridge Creek watershed: City of Vancouver (Phase II), Clark County (Phase I), and Washington State Department of Transportation (WSDOT). The majority of the watershed (70% or 13,030 acres), including most of Burnt Bridge Creek, is covered by the City of Vancouver MS4 permit (Figure 5). Areas in the northern portion of the watershed are covered by the Clark County MS4 permit, including the headwaters of Cold Creek and a small segment of Burnt Bridge Creek below Cold Creek.

Ecology issued the first MS4 NPDES Phase II Stormwater Permit to the City of Vancouver in 2007. Reissued approximately every five years, the current permit became effective in 2019. Under the Phase II permit, Vancouver must follow the prescribed guidelines to manage stormwater before it discharges to surface water. Permit requirements fall under eight basic categories: stormwater planning, public education and outreach, public involvement and participation, MS4 mapping and documentation, illicit discharge detection and elimination, the control of runoff from development, operations and maintenance, and source control for existing development.

The MS4 NPDES permits require development and documentation of a Stormwater Management Program (SWMP). The permit requires completion and submittal of an Annual Report to document how the permittee is complying with each section of the permit. These are available on the City of Vancouver Stormwater Management Plan[1] and Clark County Stormwater Management[2] websites.

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[1] https://www.cityofvancouver.us/publicworks/page/stormwater-management-plan

[2] https://www.clark.wa.gov/public-works/stormwater-management-regulations

The City of Vancouver established a citywide Stormwater, Surface Water, and Groundwater Utility (previously called Surface Water Utility) in 1996. The utility almost entirely manages the stormwater flowing into Burnt Bridge Creek. One significant exception with regard to this project is the Cold Creek tributary, which collects the majority of its flow in Clark County's permitted area. At this time the City's Surface Water Utility is well established with an existing surface water utility rate structure, and the City has implemented the required MS4 NPDES Permit program elements.

The Clark County Clean Water Division develops new stormwater facilities and implements updates to older facilities that collect and treat polluted storm runoff. These projects control stormwater flows and help reduce pollution in our water runoff, improve water quality treatment, reduce stream erosion and protect river habitat, and keep waterways safe for recreation and other uses. The Clark County Stormwater Management Program[3] protects surface water and groundwater resources from polluted storm water runoff and coordinates compliance with state and federal Clean Water regulations.

WSDOT's Highway Runoff Manual[4] is implemented statewide and is considered equivalent to Ecology's Municipal Stormwater Management Manual. WSDOT-maintained roads that potentially impact Burnt Bridge Creek through stormwater runoff include I-5, I-205, and State Highway 500.

Other Nonpoint Sources

Other nonpoint sources and land use practices within the Burnt Bridge Creek watershed that are not controlled by discharge permits and may be potential sources of pollution include:

- Failing onsite septic systems.
- Riparian residential development adjacent to the creek.
- Small areas of agricultural land including urban agriculture.
- Golf course runoff.
- Pet waste.
- Human waste.
- Wildlife.
- Groundwater discharge.

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[3] https://www.clark.wa.gov/sites/default/files/dept/files/public-works/Stormwater/Capital_Projects/Stormwater%20Capital%20Plan%202020-2025.pdf

[4] https://wsdot.wa.gov/Publications/Manuals/M31-16.htm

Habitat and Vegetation

The Burnt Bridge Creek watershed provides critical habitat for many aquatic and land species. According to two fish surveys conducted by the Pacific States Marine Fisheries Commission for the City of Vancouver during the winter of 2002 and the spring of 2003, Burnt Bridge Creek supports fish species such as coho salmon, chinook salmon, steelhead, trout, sculpin, red-sided shiners, sticklebacks, leopard dace, and lamprey ammocoetes (Ehlke, 2003). The watershed also supports various mammal, amphibian, and reptile species, along with resident and migratory birds that rely on riparian areas, wetlands, and open areas in the watershed and surrounding areas (Herrera and PPG, 2019; Kardouni and Brock, 2008).

Native riparian tree species include alder, cottonwood, maple, willow, western hemlock, Douglas fir, and western red cedar (Wade, 2000). Other native vegetation includes vine maple, huckleberry, salal, ferns, and devil’s club. The watershed also contains extensive areas with invasive blackberry bushes and reed canary grass.

Current Restoration Work

Since the original data collection period for this project was completed in 2009 there have been various stream and habitat restoration and clean-up activities implemented throughout the watershed. This section provides a brief overview of some of the restoration activities undertaken by the City of Vancouver and other local groups.

- The City of Vancouver’s Burnt Bridge Creek Greenway Improvement Project (Greenway Project). The Greenway Project began in 2004 and was designed to enhance water quality, wildlife habitat, wetlands, riparian vegetation, and recreation with stormwater best management practices (BMPs) such as infiltration basins and wetlands. The Greenway Project has included:
    - Restoring wetlands and adding stormwater ponds to improve water quality treatment.
    - Planting thousands of trees and shrubs to increase riparian shade and natural habitat along the creek.
    - An 8-mile recreational trail that parallels Burnt Bridge Creek through neighborhoods, forests, open areas, water quality treatment ponds, and other restored habitat.
    - A dedicated Greenway/Sensitive Lands crew for ongoing maintenance, planting, and restoration of riparian and wetland areas throughout the greenway.

- Watershed Alliance of Southwest Washington works to educate and engage community members in Southwest Washington to be active stewards of natural resources. The Watershed Alliance has a successful history working with private landowners in the Burnt Bridge Creek watershed through Project Restore. Project Restore is a public and private partnership funded by the City of Vancouver to improve water quality in Burnt Bridge Creek by assisting creek-side property owners to remove invasive plants, improve bank stability, and increase tree canopy and native vegetation on their properties.

- City of Vancouver Urban Forestry Strategy aims to maximize the environmental, social, and economic benefits that trees provide to city residents and visitors. Often referred to as “green infrastructure”, a thriving urban forest provides a clean and sustainable environment that assists in improving water quality. Through this program, the City recognizes the major watershed benefits of a health urban forest and has set a goal to reach 28% tree canopy citywide by 2030. Tree canopy throughout the watershed detains and cools stormwater runoff from summer rain events that can be carried to surface water adversely affect stream temperature.

- The Washington State Department of Transportation (WSDOT) has six mitigation sites within the Burnt Bridge Creek watershed: one active, four closed, and the Arnold Park site was turned over to the City of Vancouver for long-term management. These sites were established over the last 20 years to compensate for wetland and riparian impacts of various projects in the SR-500 corridor. These areas include 34 acres of currently protected wetland and riparian habitat in the Burnt Bridge Creek floodplain. Overall, mitigation performed by WSDOT includes 16 acres of wetland creation, restoration and enhancement (mostly scrub-shrub or forested wetland) and 18 acres of woody wetland buffer and riparian corridor preservation and restoration. These projects provide floodplain hydrological, water quality, and habitat functions, including stream shading, bio-filtration, and storage.
- Terrace Wetland Mitigation Bank was established in 2017. The 113-acre bank is located in the upper subbasin and is approved for mitigation use. Site actions include re-establishing, rehabilitating, and enhancing wetland functions across the site, along with improving channel complexity to Burnt Bridge Creek.

Ecology has funded multiple water quality projects for restoration efforts in the watershed through the Water Quality Combined Funding Program since 2014. Projects include:

- Burnt Bridge Creek Stormwater OSPREY Project (2019-2021): The Lower Columbia Estuary Partnership[5] (LCEP) is establishing a native riparian forest on three acres of Burnt Bridge Creek floodplain, while providing comprehensive stormwater education to the public. The goal is to restore the site to a healthy, self-sustaining, bottomland hardwood and wetland forest, by planting 6,000 native trees and shrubs.
- Lower Columbia River Estuary Enhancement Project (2019-2021): LCEP is improving water quality in tributaries of Burnt Bridge Creek by restoring approximately three acres of riparian area to help with reducing temperature and stormwater runoff in the watershed. The project also includes public outreach events. LCEP also intends to implement an additional riparian restoration project on City of Vancouver property near Alki Road, in the lower Burnt Bridge Creek watershed with the intent to add an additional 6,000 plants to the watershed at this site.
- Burnt Bridge Creek – Meadowbrook North: LCEP restored 3.75 acres of riparian plantings adjacent to Burnt Bridge Creek, using funding from Ecology and the Lower Columbia Fish Recovery Board[6].

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[5] https://www.estuarypartnership.org/

[6] https://www.lcfrb.gen.wa.us/

Field Methods

Ecology conducted field sampling and water quality measurements following procedures outlined in the study QAPP (Kardouni and Brock, 2008).

Fixed-Network Sampling

Ecology sampled a fixed-network of sites from May 2008–September 2009 (Figure 6 and Table 8). Field collection efforts included:

- FC samples.
- Stream temperature monitoring.
- Discrete water quality measurements (DO and pH).
- Hemispherical photography to estimate riparian shade.
- Instantaneous streamflow measurements.

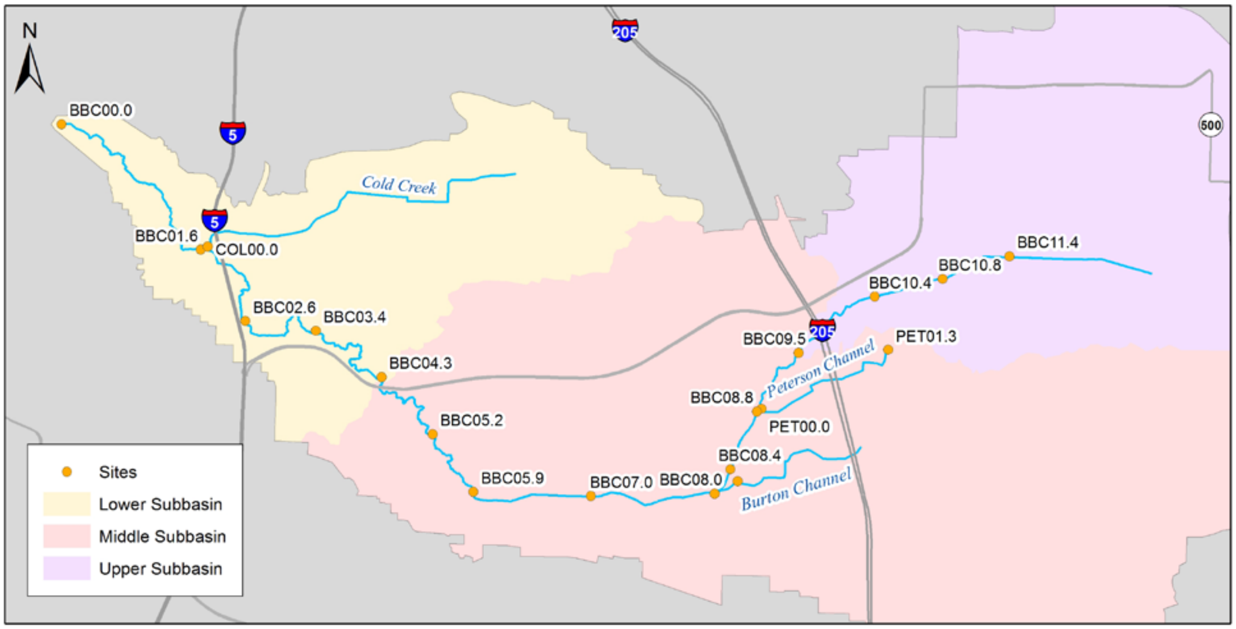

Figure 6. Map of fixed-network sampling sites in Burnt Bridge Creek watershed.

Routine monitoring of FC began in June 2008 and continued through August 2009. Samples were collected from Burnt Bridge Creek and its tributaries twice a month and analyzed for FC.

Temperature monitoring equipment was installed at fixed-network sites in May 2008 and removed in September 2009 with the following exceptions:

- BBC00.0 was installed in mid-July 2008, removed in October 2008, and reinstalled in May 2009.
- BBC08.0 was removed in October 2008.
- BUR00.0 was installed in June 2008, removed in October 2008, and reinstalled in May 2009.
- COL00.0 was removed in October 2008 and reinstalled in May 2009.
- PET01.3 was installed in June 2008.

Dissolved oxygen samples were collected at most sites during each bacteria-sampling run. Additionally, instantaneous DO, temperature, and pH were measured at each site.

Channel geometry surveys were conducted measuring widths and depths when taking instantaneous flow measurements at the fixed-network sites.

Two synoptic surveys were conducted in July and September 2008. Hydrolab field meters were installed at four sites (BBC11.4, BBC08.4, BBC05.9, BBC01.6) from 7/28/08–7/30/08 and from 9/22/08–9/24/08.

Table 8. Summary of fixed-network sites and subbasin.

Sampling Site	Subbasin
BBC11.4	Upper
BBC10.8	Upper
BBC10.4	Upper
BBC09.5	Upper
BBC08.8	Middle
PET01.3	Middle (Tributary)
PET00.0	Middle (Tributary)
BBC08.4	Middle
BUR00.0	Middle (Tributary)
BBC08.0	Middle
BBC07.0	Middle
BBC05.9	Middle
BBC05.2	Middle
BBC04.3	Middle
BBC03.4	Lower
BBC02.6	Lower
COL00.0	Lower (Tributary)
BBC01.6	Lower
BBC00.0	Lower

Storm Sampling

Ecology sampled five storm events from June 2008 through August 2009, where a storm event is defined as more than 0.3 inches of rainfall in the previous 24 hours. Ecology added an additional storm sampling date on October 14, 2009 to sample all fixed monitoring sites and five accessible storm drains. All sites were sampled for bacteria in the morning and afternoon (except two storm drains that were no longer flowing). Flows were measured at the mouths of each tributary and estimated with bucket flows at each storm drain.

Hemispherical Photographs

Hemispherical photographs were taken at sample sites and streambanks along Burnt Bridge Creek during August 2008 to estimate riparian shade. Hemispherical photographs were taken near the center of the stream looking upwards to account for vegetation canopy using a fish-eye lens and digital camera (Figure 7). Select sites had additional photographs taken on the streambanks. These photographs were then processed and analyzed to calculate effective shade and canopy cover.

Figure 7. Hemispherical photograph taken at BBC08.8

Continuous streamflow and groundwater studies

Ecology installed three continuous streamflow monitoring gages along Burnt Bridge Creek. Ecology also installed piezometer wells and conducted seepage surveys to evaluate surface water and groundwater exchange. The Burnt Bridge Creek Streamflow Summary (Myers, 2010) and Surface Water/Ground Water Interactions and Near-Stream Groundwater Quality report (Sinclair and Kardouni, 2012) provide further details for these separate Ecology studies.

Analytical Methods

Bacteria Analytical Framework

Analytical methods to assess FC pollution in the Burnt Bridge Creek watershed include descriptive summary statistics, statistical rollback analysis, and loading summaries using data collected by Ecology from 2008–2009. These analytical methods identify spatial and seasonal patterns of bacteria and will be used to guide implementation work.

The annual and seasonal (wet and dry seasons) geometric means were calculated for sites with more than ten samples. Concentrations of FC measured in environmental samples generally follow a lognormal distribution. In Washington State FC water quality exceedance studies, the upper limit statistic (i.e., not more than 10% of the samples shall exceed) has been interpreted to be comparable to the 90th percentile value of the log-normalized values (Cusimano and Giglio, 1995; Fields, 2016; Lee, 2008; McCarthy, 2018; Mathieu and James, 2011).

Statistical Rollback Analysis

The statistical rollback method (Ott, 1995) calculates FC reduction targets for stream segments. The rollback method compares statistics from the monitoring data distribution to the associated FC bacteria criteria, and calculates the difference as the percent reduction needed to meet the standards. The rollback method has been applied by Ecology in many other bacteria water quality exceedance studies (Coots, 2002; Fields, 2016; Joy, 2006; Joy and Swanson, 2005; Mathieu and James, 2011; McCarthy, 2020; McCarthy, 2018; Pelletier and Seiders, 2000; Swanson, 2009).

Ideally, at least 20 samples taken throughout the year are needed from a broad range of hydrologic conditions to determine an annual bacteria distribution. If bacteria sources vary significantly by season and create distinct critical seasons, seasonal targets are developed. Fewer data provide less confidence in bacteria reduction targets, but the rollback method is robust enough to provide pollutant allocations and targets for planning implementation measures using smaller data sets. Compliance with the most restrictive of the dual bacteria standard criteria determines the bacteria reduction needed at a stream sampling site. The rollback method is applied as follows:

The geometric mean (approximate median in a lognormal distribution) and 90th percentile statistics are calculated and compared to the water quality bacteria criteria. If one or both do not meet the criteria, the whole distribution is "rolled-back" to match the more restrictive of the two criteria. The 90th percentile criterion is usually the most restrictive.

The rolled-back geometric mean or 90th percentile bacteria value then becomes the recommended *target* bacteria value for the site. The term *target* is used to distinguish these estimated numbers from the actual water quality criteria. The degree to which the distribution of bacteria counts is *rolled-back* to the target value represents the estimated percent of bacteria reduction required to meet the bacteria water quality criteria and standards.

The bacteria targets are used to assist water quality managers in assessing the progress toward compliance with the bacteria water quality criteria. Compliance is ultimately measured as meeting both parts of the water quality standards criteria. Any water body with bacteria targets is expected to:

- Meet both the applicable geometric mean and “percent exceedance” criteria.
- Protect designated uses for the category.

Loading Summary

A load is defined as the mass of a substance that passes through a particular point of a river or stream (e.g., monitoring site) in a specified amount of time (e.g., daily) (Meals et al., 2013). A load is mathematically defined as the product of water discharge and the concentration of a substance in the water. For this study, FC loads were calculated by multiplying FC concentrations (cfu/100mL) by flow (cfs). These loads were then converted to represent billions of colony forming units per day (billions cfu/day) to allow for an easier comparison of large load numbers. Individual loads at each site were averaged seasonally to compare wet and dry season loading.

The loads calculated during the FC loading analysis were not used in determining the level of FC reduction need at sites. Instead, the loading patterns will be used to help understand areas with high seasonal loading patterns and identify potential sources of FC. This information can then be used for directing implementation. Cleaning up high FC loading sources will benefit downstream sites where the upstream loads are contributing to exceedance of water quality standards.

Shade Analysis

Effective shade is the fraction of the total possible solar radiation heat energy that is prevented from reaching the surface of the water. Effective shade is influenced by latitude and longitude, time of year, stream geometry, topography, and vegetative buffer characteristics, such as height, width, overhang, and density.

Ecology estimated effective shade along Burnt Bridge Creek using the following tools:

- TTools: ArcView extension that is used to determine physical and vegetation parameters for input for the effective shade analysis (Ecology, 2015).
- Ecology’s Shade model (Shade): estimates shade from riparian vegetation (Ecology, 2003).

Current Effective Shade

Effective shade along Burnt Bridge Creek is influenced by both riparian vegetation cover and river morphology. TTools estimates effective shade inputs for use in shade modeling programs. TTools is an ArcView extension originally developed by the Oregon Department of Environmental Quality and was adapted by Ecology (Ecology, 2015). The tool is used to develop GIS-based data from acquired polygon and grid coverages. It specifically uses these coverages to develop vegetation and topography data perpendicular to the stream channel and longitudinal stream-channel characteristics, such as the near-stream disturbance zone and elevation.

Data used in the TTools analysis for Burnt Bridge Creek included Digital Elevation Model (10-meter), LiDAR data files for bare earth (no vegetation or structures), and riparian vegetation characteristics along the creek. GIS coverages of riparian vegetation were extended to a 100-150 meter buffer along Burnt Bridge Creek. Within this buffer, polygons were created around distinct groups of vegetation. Each polygon represented a specific category of vegetation type, density, and overhang characteristics.

TTools sampled elevation, riparian vegetation, and channel morphology perpendicular to Burnt Bridge Creek at 50-meter intervals from BBC11.4 through the creek mouth (BBC00.0). Results from TTools are used as inputs to the Shade model.

Ecology's Shade model is a tool for estimating shade from riparian vegetation (Ecology, 2003). The model quantifies the potential daily solar load and generates the percent effective shade. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because vegetative cover and topography intercept it. The Shade model requires physical and vegetation parameters that were found through TTools sampling. The TTools output is used as input for the Shade model to generate longitudinal effective shade profiles.

Results from the shade analysis were compared with effective shade estimated from observations from field hemispherical photographs taken at sites along Burnt Bridge Creek.

System Potential Effective Shade

System-potential effective shade is the natural maximum level of shade that a given stream is capable of attaining with the growth of system-potential mature riparian vegetation. System-potential mature riparian vegetation refers to the vegetation that can grow and reach a climax succession (100 years) at a site without human disturbance, and given climate, elevation, soil properties, plant biology, and hydrologic processes.

System potential vegetation for Burnt Bridge Creek is based on 100-year average values from Clark County Soil Survey Geographic Database (SSURGO) data for mixed tree species (Douglas fir, grand fir, red cedar, hemlock, alder, and maple). The system potential height is 41 meters, overhang is 4.1 meters, and density is 85%. The watershed is comprised of mixed tree species (conifers and deciduous) and were used as the system potential vegetation for this analysis. Additionally, current restoration work focuses on planting natural riparian vegetation of deciduous varieties (e.g. Oregon ash, crabapple, red alder, black cottonwood, Pacific willow, and others).

For the potential shade analysis, areas of land that would not accommodate vegetation growth (i.e. built, pavement, and water areas) were kept intact. The system-potential vegetation for this study is therefore implied for areas along Burnt Bridge Creek that are not already developed.

HemiView Analysis

Hemispherical photographs that were taken in the field in August 2008 were processed using HemiView canopy analysis software (University of Kansas, 1996). These HemiView photos were used to estimate canopy cover and effective shade at the stream center. Canopy cover is the percentage of sky that is blocked by vegetation or topography. Annual canopy cover was calculated using the HemiView processing results as the difference of canopy cover from the VisSky value (visible sky) and multiplied by 100 to be represented as a percentage. Effective shade is influenced by canopy cover, but changes during the day depending on the position of the sun both spatially and temporally in relation to the canopy cover. Effective shade was calculated using the values for direct and diffuse radiation from the HemiView processing analysis.

Results for these calculations were used as an approximate comparison with Shade model results.

Data Quality Assessment

Ecology reviewed data collected during this study to ensure they met the project data quality objectives described in the QAPP (Kardouni and Brock, 2008). Data that did not meet quality objectives were either qualified or rejected. Reviewed data are available in Ecology's Environmental Information Management (EIM) database (Study ID = STEB0002).

Data Quality

Field sampling procedures and laboratory analyses inherently have associated uncertainty, which results in data variability. Measurement quality objectives (MQOs) set performance or acceptance criteria for the precision and bias of both field measurements and laboratory analyses.

Precision is the measure of variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Field samples are addressed by submitting replicate samples or collecting replicate measurements. Precision for replicates are expressed as percent relative standard deviation (% RSD).

Bias is the difference between the population mean and true value of the parameter being measured. Bias is typically addressed by calibrating field and laboratory instruments and also by analyzing lab control samples. Bias in field measurements was minimized by following sampling and handling protocols and submitting field blanks.

The targets for precision and bias are based on those defined in the project QAPP (Kardouni and Brock, 2008) and other Ecology guidance documents (Mathieu, 2006; McCarthy and Mathieu, 2017).

Field Measurements

Hydrolab Measurements

Hydrolab field meters were used for instream measurements of temperature, specific conductivity, pH, and DO. Ecology pre-calibrated all Hydrolab field meters in accordance with the manufacturer's instructions and following SOP EAP033 (Swanson, 2007). Certified standards were used for instrument calibration before each deployment. At the end of each sampling day the meters were rechecked against reference standards to confirm they had not drifted unacceptably from the pre-calibration. Any checks that exceeded the calibration range were either qualified as estimates or rejected based on the MQOs (Table 9). Results from post-checks are in Appendix C.

Table 9. MQOs for Hydrolab post-check criteria.

Parameter	Accept	Qualify	Reject
Temperature (°C)	≤ ± 0.2 °C	> ± 0.2 and ≤ ± 0.8 °C	> ± 0.8 °C
pH (S.U)	≤ ± 0.25 SU	> +0.25 and ≤ +0.5 SU	> +0.5 SU
Dissolved Oxygen	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%

Hydrolabs used in the study were also compared to each other by measuring side-by-side instream at the same site. The average percent RSD between the different Hydrolabs for each parameter is shown in the table below (Table 10). All of the Hydrolabs met the precision MQO for this side-by-side comparison.

Table 10. MQOs for Hydrolab measurements during instream comparisons.

Parameter	% RSD	Target Precision	Meets MQO?
Temperature	1%	20%	Pass
Specific Conductivity	12%	20%	Pass
pH	5%	20%	Pass
Dissolved Oxygen	3%	20%	Pass

Flow and Channel Measurements

Ecology measured streamflow with a Marsh McBirney Flow-Mate flow meter following procedures outlined in the QAPP. Flow data at certain sites during two dates (7/29/08 and 9/23/08) did not follow full QA procedures and were found to be erroneous. Because of this, flow and channel measurement data from these dates were flagged and not used in this analysis.

Continuous Temperature

Hobo Onset continuous temperature loggers were used to record temperature throughout the Burnt Bridge Creek watershed for this study. These instruments were assessed for quality through calibration check prior to initial use and again at the completion of recording following Ecology temperature monitoring protocols (Bilhimer and Stohr, 2009). This calibration check is used to document instrument bias or performance at representative temperatures. A NIST certified reference thermometer was used for the calibration check. Instruments that did not meet project acceptance criteria during the pre-deployment calibration check were not deployed. The post-check evaluation showed that all temperature loggers met the manufacturers specified accuracy range (±0.2°C) after deployment (Appendix C).

Temperature logger recordings were also verified with field checks during instrument deployment, regular site visits, and instrument retrieval. A summary comparison between field checks and data logger temperature measurements is shown in Table 11. These met the accuracy targets defined in the project QAPP (±0.2°C).

Table 11. MQOs for continuous water temperature measurements.

Site	Avg. RPD (%)	Avg. Difference (°C)
BBC2.6	0.52	0.06
BBC3.4	1.20	0.13
BBC5.9	0.51	0.04
BBC11.4	1.21	0.12

Winkler DO Samples

Dissolved oxygen samples were collected throughout the study period and analyzed using the Winkler Method to compare against Hydrolab DO measurements. A summary comparison of Hydrolab measurements and Winkler samples is below (Table 12). These results met the MQO targets (<10% RSD) from the project QAPP (Kardouni and Brock, 2008). The median difference between Hydrolab measurements and Winkler samples was 0.25 mg/L.

Table 12. MQOs for dissolved oxygen Winkler samples.

Winkler DO Sample Comparison	Result
Count (n)	230
Average RSD (%)	5.40
Median Difference (mg/L)	0.25

Lab Results

All lab samples were analyzed in the Manchester Environmental Laboratory (MEL). All sampling procedures and protocols complied with the procedures outlined in the QAPP (Kardouni and Brock, 2008) and following MEL guidance (MEL, 2016).

Data results were reviewed and finalized before being uploaded into Ecology’s EIM system following field collection. Data were validated in reference to the measurement quality objectives outlined in the QAPP (2008). Data qualifiers for the results were also included. While some FC results were qualified due to the lab analysis occurring beyond the 24-hour holding time, an Ecology holding time study that showed that FC samples analyzed by MEL within 30 hours were comparable to samples analyzed within 6-8 hours (Mathieu, 2005). The qualified results were used in the calculated statistics.

Precision for Bacteria Field Replicates

Total precision for field sampling and laboratory analysis was assessed by collecting replicate samples, which are two samples taken from the environment at the same time and place using the same protocols. Precision for field replicates is expressed as percent relative standard deviation (%RSD).

The QAPP for this project (Kardouni and Brock, 2008) set the MQO for FC precision as a median relative standard deviation (RSD) of less than or equal to 30%. Newer recommendations for FC MQOs require that the median RSD of the replicate pairs is less than or equal to 20% and that at least 90% of the replicate pairs have a RSD of 50% or less (Mathieu, 2006). Replicate pairs with a mean of 20 cfu/100 mL or less are excluded from the analysis.

Bacteria field replicates were evaluated using both MQO methods and met both the original and new criteria (Table 13).

Table 13. MQOs for bacteria samples.

Parameter	MQO Criteria	% Samples Meeting MQO	Meets MQO?
Fecal Coliform	30% RSD (median)	16% RSD (median)	Yes
	50% of replicate pairs <20%RSD	60%	Yes
	90% of replicate pairs <50%RSD	96%	Yes

Precision for Lab Duplicates

Precision for laboratory analysis is measured through analyzing duplicate samples. Duplicate laboratory analysis uses aliquots in the lab taken from a single sample container. MEL routinely duplicates sample analyses in the laboratory to determine laboratory precision. The results for laboratory duplicates provide an estimate of lab analytical precision, including the homogeneity of the sample matrix (MEL, 2016). The laboratory duplicate MQO is 40% average relative percent difference (RPD).

Overall, the majority of laboratory duplicate results (84%) with FC concentrations greater than 20 cfu/100 mL were within 40% RPD and met the MQO. Any of the samples that did not meet the MQO for lab duplicates were qualified as estimates. After a data quality review, the qualified results were used in the calculated statistics.

Results

Fecal Coliform Bacteria

FC results are summarized seasonally (wet and dry seasons) to evaluate FC seasonal variations. Seasons were determined by reviewing precipitation data from 2008–2009 in the Burnt Bridge Creek watershed. Based on precipitation and sampling dates during the study duration, the dry season is defined as June through September and the wet season as October through May. One June sampling event (6/3/08–6/4/08) was more representative of wet season conditions and qualified as a storm event with a high total amount of rainfall (0.84 inches) and was therefore grouped with the wet season. FC sampling dates and daily precipitation that coincided with wet and dry seasons are shown in Figure 8. Storm events refer to dates with more than 0.3 inches of precipitation in 24 hours.

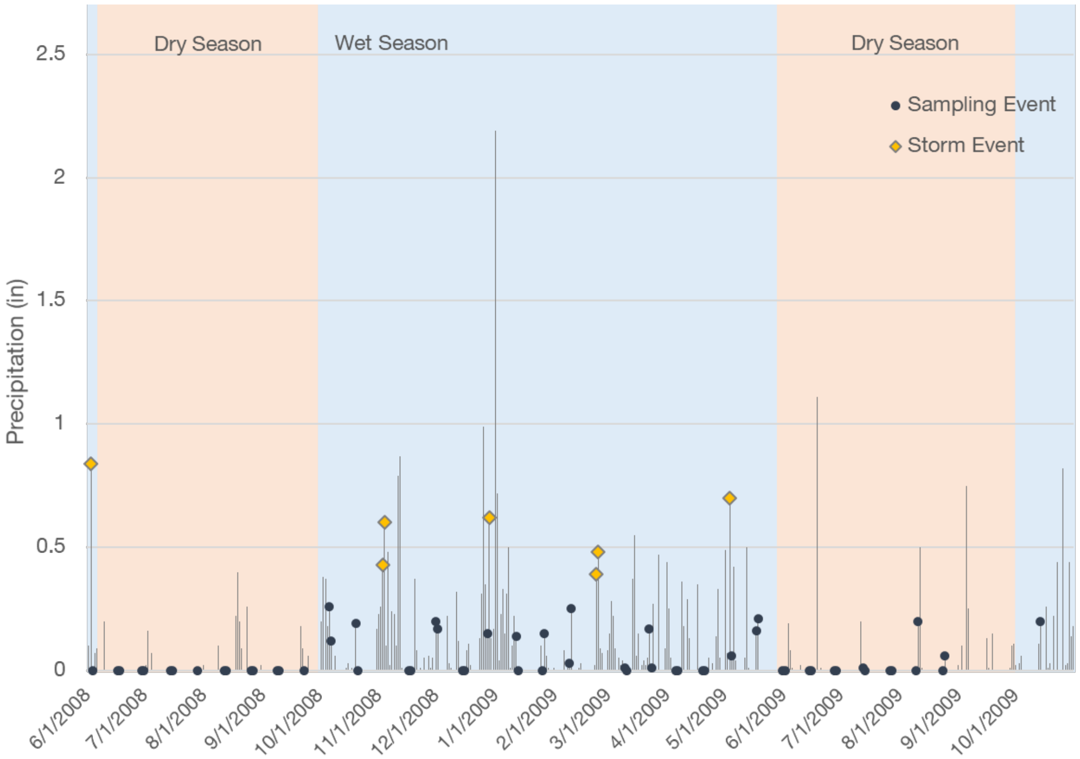

Figure 8. Daily total precipitation (lines), sampling dates (dots), and sampling dates coincided with storm events (diamonds).

Wet season (blue) from October–May and dry season (orange) from June–September.
Note: 6/3/08 – 6/4/08 are categorized as wet season.

FC results are summarized as seasonal geometric mean concentrations and percent of samples above 200 cfu/100 mL to assess compliance with water quality standards (Table 14).

Table 14. Summary of 2008–2009 FC results.

Bolded values indicate exceedance of water quality criteria.

Site	Dry Season Count (n)	Dry Season GeoMean	Dry Season % Excd	Wet Season Count (n)	Wet Season GeoMean	Wet Season %excd
BBC11.4	15	63	0%	18	23	11%
BBC10.8	15	63	0%	18	24	11%
BBC10.4	15	130	27%	18	47	22%
BBC09.5	15	75	7%	18	36	22%
BBC08.8	15	76	7%	18	34	11%
PET01.3	14	9	7%	18	6	11%
PET00.0	15	310	87%	18	219	50%
BBC08.4	15	215	47%	18	90	17%
BUR00.0	15	260	40%	18	183	39%
BBC08.0	15	162	40%	18	107	22%
BBC07.0	14	98	21%	18	87	39%
BBC05.9	15	107	13%	18	74	28%
BBC05.2	15	132	20%	18	129	50%
BBC04.3	15	164	27%	18	122	39%
BBC03.4	15	138	20%	18	126	39%
BBC02.6	15	236	60%	18	118	39%
COL00.0	15	484	87%	18	150	44%
BBC01.6	15	215	60%	18	128	44%
BBC00.0	13	19	0%	17	49	24%

Results from Ecology's 2008–2009 FC sampling indicate:

- All sites exceeded either the geometric mean (100 cfu/mL) or percent exceedance criteria (more than 10% of samples greater than 200 cfu/100 mL) during sampling.
- Geometric mean concentrations were generally higher during the dry season.
- The highest geometric mean concentrations were found at tributary sites during the dry season at COL00.0 (484 cfu/100 mL), PET00.0 (310 cfu/100 mL), and BUR00.0 (260 cfu/100 mL). PET00.0 and COL00.0 had the highest percent of samples exceeding criteria (87%).
- Burnt Bridge Creek mainstem sites with the highest geometric mean concentrations were BBC02.6 (236 cfu/100 mL), BBC08.4 (215 cfu/100 mL), and BBC01.6 (215 cfu/100 mL) during the dry season.

Loading Summary

FC loads are used to represent the amount of FC that enters Burnt Bridge Creek during a defined time. Loads were calculated for the wet and dry seasons (Table 15). Due to the large numbers of bacteria, loads are reported as billion cfu per day (b.cfu/day).

Table 15. Summary of average seasonal FC loading (2008–2009).

Site	Dry Season Avg Flow	Wet Season Avg Flow	Dry Season Avg Load	Wet Season Avg Load
BBC11.4	2.4	4.3	6	38
BBC10.8	2.2	4.7	5	23
BBC10.4	2.2	5.5	10	40
BBC09.5	2.9	6.6	6	68
BBC08.8	2.2	6.3	4	99
PET00.0	2.2	3.0	23	57
BBC08.4	4.0	9.2	71	117
BUR00.0	0.1	0.7	1	48
BBC08.0	4.8	10.8	43	173
BBC07.0	4.7	11.6	16	178
BBC05.9	4.9	14.6	25	154
BBC05.2	5.0	14.7	21	125
BBC04.3	5.2	15.3	24	179
BBC03.4	5.2	14.1	19	96
BBC02.6	5.1	15.1	31	758
COL00.0	0.4	1.2	6	8
BBC01.6	5.3	17.4	30	1,002
BBC00.0	4.9	16.5	6	73

- During the wet season when flows are higher, BBC01.6 and BBC02.6 had the overall largest FC loads (1,002 and 758 b.cfu/day), and these FC loads were much higher than other Burnt Bridge Creek sites. BBC00.0 had relatively low FC loads compared to loading upstream. The highest FC loads during the dry season were at BBC08.4 (71 b.cfu/day) and BBC08.0 (43 b.cfu/day). For tributaries, Peterson Channel had the largest FC load, and Burton Channel had the lowest FC load.
- Maps of seasonal FC loading (Figure 9) show that FC loads are smaller during the dry season than in the wet season. The lowest loads are from tributaries and upper Burnt Bridge Creek sites (upstream of BBC09.5). Further discussion of spatial FC loading patterns are in the Subbasin Summary section.

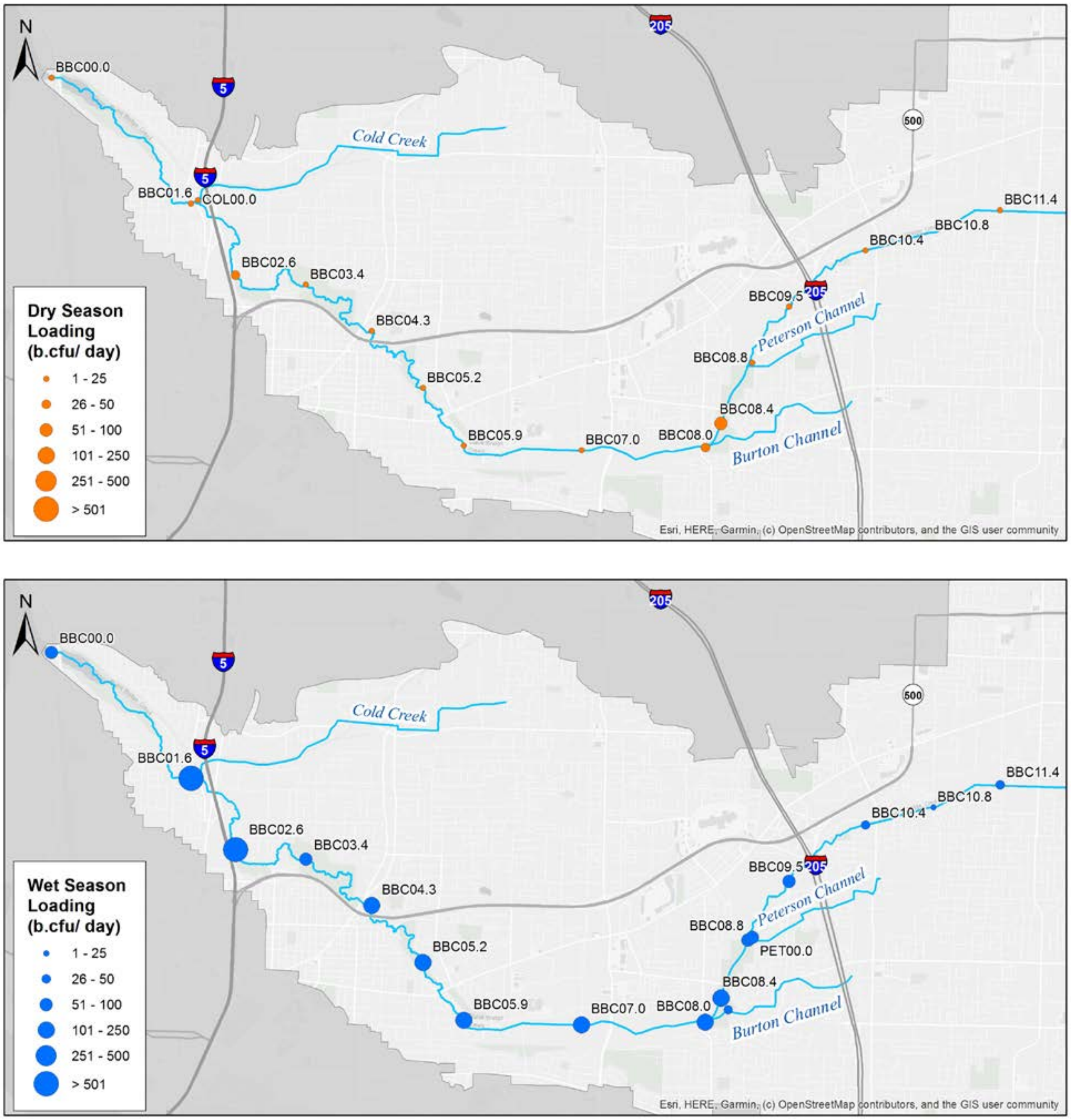

Figure 9. Maps of dry season FC loading (above) and wet season FC loading (below).

Storm Events Results

Ecology collected FC samples during storm events with heavy rainfall throughout the sampling duration. Days where storm events (>0.3 inches of rain within 24 hours) coincided with FC sampling include: 6/3/08, 11/3/08, 11/4/08, 12/29/08, 2/23/09, 2/24/09, and 5/4/09. Due to timing of precipitation and sampling, dates that represent heavy rainfall include 6/3/08, 11/4/08, 12/29/08, and 2/24/09.

Ecology also sampled one additional heavy rainfall event on 10/14/09 (five storm events sampled total). This storm event occurred outside the project sampling collection duration in order to allow for an opportunity to capture all fixed-networking sampling locations along with a set of storm drains. Precipitation totaled 0.2 inches on 10/14/09 and 0.1 inches on 10/13/09. The week prior received no rainfall. Samples were collected at sites once during the morning and once in the afternoon (Table 16).

Table 16. FC data from 10/14/09 storm event.

Site	FC - AM (cfu/100 mL)	FC - PM (cfu/100 mL)	FC Average (cfu/100 mL)
BBC11.4	60	180	120
BBC10.8	54	100	77
SD18031	230	100	165
SD18027	510	1,200	855
BBC10.4	340	330	335
SD17959	85	480	283
BBC09.5	230	330	280
BBC08.8	240	180	210
PET01.3	130	43	87
PET00.0	700	1,800	1,250
BBC08.4	390	300	345
BUR00.0	2,900	1,700	2,300
BBC08.0	250	220	235
BBC07.0	200	240	220
BBC05.9	130	410	270
SD06233	--	31,000	31,000
SD06235	4,900	--	4,900
BBC05.2	560	470	515
BBC04.3	1,500	480	990
BBC03.4	4,400	1,000	2700
BBC02.6	1,700	1,200	1,450
COL00.0	3,200	1,300	2,250
BBC01.6	1600	1,100	1,350
BBC00.0	360	80	220

During the October storm event, the highest FC concentrations were observed at a storm drain (SD06233) in the middle reaches of Burnt Bridge Creek between BBC07.0 and BBC05.2 with 31,000 cfu/100 mL. Another storm drain (SD06235) at the same location draining catch basins to the west also had high bacteria concentrations sampled during the morning (4,900 cfu/100 mL). Based on this data from the 2008 study, the City of Vancouver applied for and was awarded grant funds in 2012 to construct a bioretention facility to provide water quality treatment to all flows to Burnt Bridge Creek from SD06233 (east side outfall) and to install water quality treatment vaults at catch basins draining to SD06235 (west side outfall). City monitoring has shown a reduction in FC at BBC05.2, downstream of the two storm drains that now receive water quality treatment (Table 24).

Along the Burnt Bridge Creek mainstem, BBC03.4 had the highest FC concentration in the morning (4,400 cfu/100 mL), and BBC02.6 had the highest FC concentration in the afternoon (1,200 cfu/100 mL). At the tributaries, Burton Channel and Cold Creek had very high bacteria concentrations in the morning (2,900 and 3,200 cfu/100 mL). In the afternoon, Peterson Channel (PET00.0) was the tributary with the highest bacteria concentrations (1,800 cfu/100 mL).

Statistical Rollback Results

Results from the statistical rollback analysis are presented as FC reductions, or the percentage necessary for FC concentrations to be “rolled back” in order to meet water quality criteria. The limiting criteria for each site was the percent exceedance criteria (200 cfu/100 mL). In Table 17, FC reduction values are highlighted by a classification of the magnitude of reduction needed. FC load reduction targets are set for geographic areas upstream of each study site.

The largest overall FC reductions (90%) are needed at BUR00.0 during the wet season to meet water quality criteria. All of the tributary outlet sites (PET00.0, BUR00.0, and COL00.0) required high FC reductions (58–90%) during both seasons. During the wet season, all sites from BBC00.0 through BBC8.4, including the tributary outlets, require FC reductions. The mainstem sites that need the highest FC reductions (78–85%) in the wet season are in the lower reaches of the creek (BBC01.6–BBC04.3).

For the Burnt Bridge Creek mainstem, all sites except BBC10.8 require FC reductions during the wet season. Wet season FC reductions were higher than dry season reductions, except for BBC08.4 and COL00.0. Sites that required similar seasonal FC reductions are PET00.0 and BBC08.0.

Table 17. FC percent reductions needed during wet and dry seasons to meet water quality criteria.

Site	Dry FC % Reduction	Wet FC % Reduction
BBC11.4	0%	24%
BBC10.8	0%	0%
BBC10.4	37%	43%
BBC09.5	0%	46%
BBC08.8	0%	34%
PET01.3	0%	0%
PET00.0	76%	79%
BBC08.4	81%	56%
BUR00.0	72%	90%
BBC08.0	69%	70%
BBC07.0	51%	80%
BBC05.9	28%	71%
BBC05.2	35%	73%
BBC04.3	43%	78%
BBC03.4	30%	83%
BBC02.6	62%	85%
COL00.0	85%	58%
BBC01.6	57%	84%
BBC00.0	0%	24%

The spatial distribution of FC reductions is compared seasonally in Figure 10. During the dry season, the highest FC reductions are focused in the tributaries, Cold Creek and Peterson Channel. Reducing bacteria levels in Peterson Channel is expected to improve water quality conditions downstream, including between BBC08.0 and BBC08.4. In the wet season, almost the entirety of the watershed requires FC reductions, particularly at the tributaries (Cold Creek and Peterson Channel) and between BBC01.6 and BBC05.2, along with between BBC07.0 and BBC08.0. These reductions can be used to guide implementation and restoration activities. As bacteria reductions are achieved upstream, water quality conditions are expected to improve.

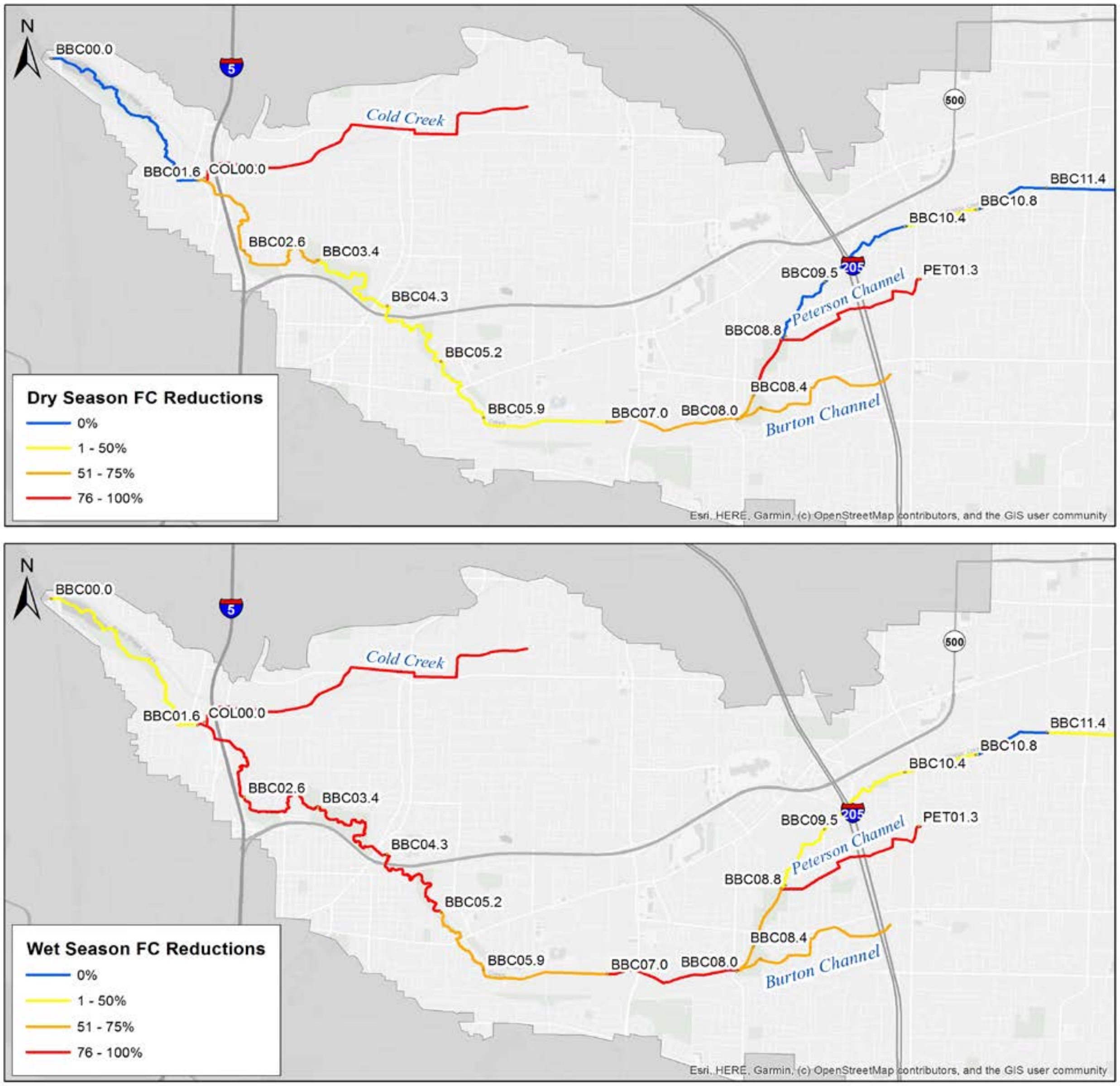

Figure 10. Maps of FC reductions needed to meet water quality criteria during the dry season (above) and wet season (below).

Streamflow and Hydrogeometry

Average field measurements from 2008–2009 for channel width, depth, and flow measurements along the mainstem of Burnt Bridge Creek sites are shown in Figure 11. Burnt Bridge Creek is shallow with average depths ranging from 0.5 feet (BBC08.4) to 2.0 feet (BBC07.0). The overall average depth of the mainstem is approximately 1 foot. Channel width varies throughout the creek with an average width of 13 feet. Burnt Bridge Creek is widest near BBC07.0 and BBC01.6 (approximately 16 feet). While BBC00.0 has the lowest width measurements, this site is physically restricted by a culvert, and therefore the narrowest natural portion of the creek is between BBC05.9 and BBC03.4.

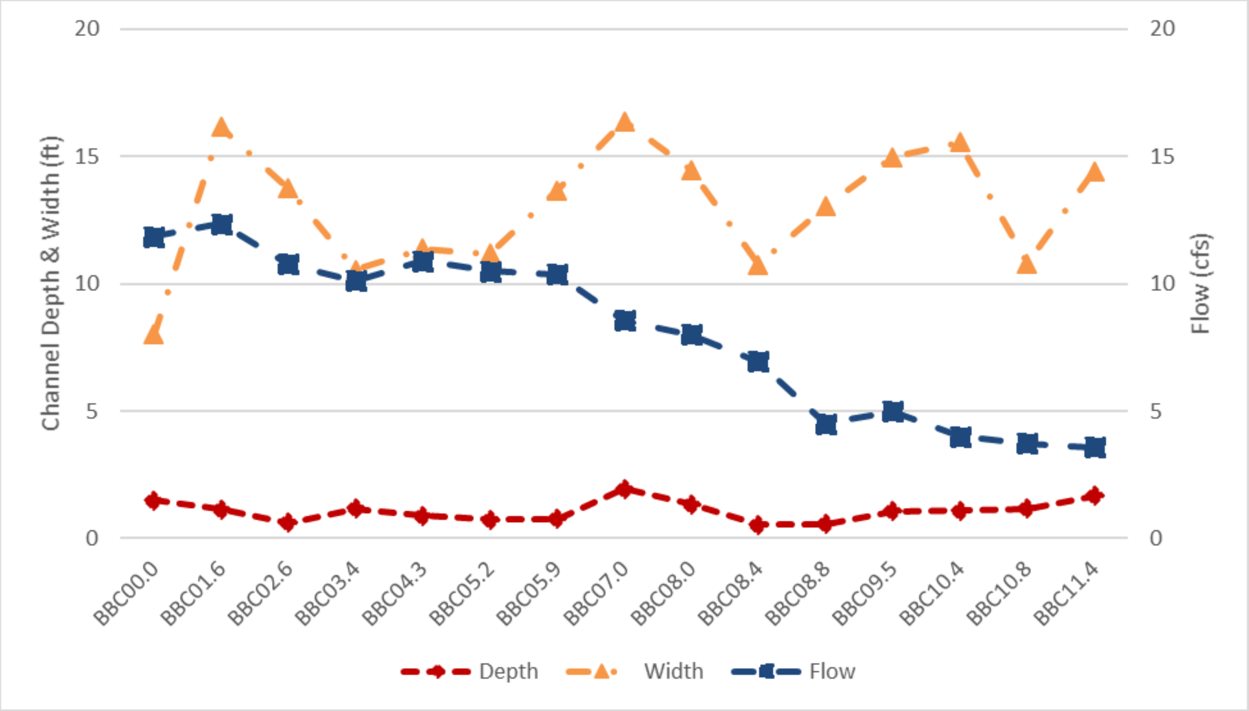

Figure 11. Average discrete streamflow and channel measurements along Burnt Bridge Creek.

Streamflow is lowest in the upper reaches of Burnt Bridge Creek and increases as the creek progresses downstream, reaching a maximum at BBC01.6 and a slight decrease at BBC00.0 after flows have spread out over the valley floor.

Discrete streamflow measurements were collected during both wet and dry seasons. Flows were higher during the wet season at all sites (Table 18). Both wet and dry seasons showed similar streamflow patterns along Burnt Bridge Creek with lower flows in the upper reaches and higher flows moving downstream. Peak flows were at BBC01.6 during both seasons. Flow peaked at BBC01.6 rather than the furthest downstream site, BBC00.0. Directly upstream of BBC00.0, the creek spreads out through a series of pools and wetlands before discharging through the culvert into Vancouver Lake. Tidal fluctuations that impact the Columbia River and Vancouver Lake allow water to flow in both directions through this culvert, which may also influence flows measured at BBC00.0.

Table 18. Discrete streamflow summary.

Site	Dry Season Flow (n)	Wet Season Flow (n)	Dry Season Avg Flow (cfs)	Wet Season Avg Flow (cfs)
BBC11.4	10	17	2.4	4.3
BBC10.8	11	17	2.2	4.7
BBC10.4	12	15	2.2	5.5
BBC09.5	13	17	2.9	6.6
BBC08.8	13	17	2.2	6.3
PET00.0	13	17	2.2	3.0
BBC08.4	12	16	4.0	9.2
BUR00.0	12	17	0.1	0.7
BBC08.0	13	15	4.7	10.8
BBC07.0	13	16	4.8	11.6
BBC05.9	13	17	4.9	14.6
BBC05.2	13	17	5.0	14.7
BBC04.3	13	17	5.2	15.3
BBC03.4	13	16	5.2	14.1
BBC02.6	13	17	5.1	15.1
COL00.0	13	17	0.4	1.2
BBC01.6	12	17	5.3	17.4
BBC00.0	10	15	4.9	16.5

The largest tributary inputs are from Peterson Channel, which contributes 2.2 cfs and 3.0 cfs during the dry season and wet season, respectively. Flow in Peterson Channel is influenced by discharge from the SEH America facility located about 1.3 miles above its confluence with Burnt Bridge Creek (outfall near PET01.3). Burton Channel is the smallest tributary to Burnt Bridge Creek (averaging 0.1 cfs in dry season and 0.7 cfs in wet season) discharging near RM 8. Cold Creek discharges an average of 1.2 cfs to Burnt Bridge Creek during the wet season and 0.4 cfs during the dry season.

Temperature

Table 19 presents a summary of results from instream temperature monitoring from May 2008–September 2009. All sites in Burnt Bridge Creek, Peterson Channel, and Burton Channel exceeded the temperature criterion (7-DADMax <17.5°C). Cold Creek (COL00.0) was the only site to meet water quality criteria throughout the entire duration of temperature monitoring.

Sites with the highest count of days that exceeded temperature were in the middle reaches of Burnt Bridge Creek, BBC0.7 (230), and BBC05.9 (222). The sites with the highest percent of days exceeding temperature 7-DADMax criterion were BBC00.0 (92%), BBC08.0 (69%), and

BUR00.0 (54%). The upper Burnt Bridge Creek sites (BBC11.4, BBC10.8, and BBC10.4) had lower temperatures compared to sites downstream. BBC00.0 had the highest overall temperature daily maximum (34.7°C) and 7-DADMax (32.7°C). Flow reversals from Vancouver Lake into the wetlands and ponds at the mouth of Burnt Bridge Creek may influence temperature measurements at this site.

Table 19. Temperature results summary.

Site	Daily Max (°C)	Max – 7-DADMax (°C)	Days Measured	Days Exceedance	% Days Exceedance
BBC11.4	20.8	20.3	478	82	17%
BBC10.8	23.2	22.3	478	76	16%
BBC10.4	21.8	21.2	478	62	13%
BBC09.5	24.0	23.0	478	98	21%
BBC08.8	29.2	28.2	477	198	42%
PET01.3	26.0	23.9	443	202	46%
PET00.0	21.3	20.3	477	180	38%
BBC08.4	26.0	24.8	477	212	44%
BBC08.0	23.2	22.1	138	95	69%
BUR00.0	28.0	26.6	236	128	54%
BBC07.0	33.0	31.3	477	230	48%
BBC05.9	28.2	27.2	476	222	47%
BBC05.2	27.0	25.5	476	209	44%
BBC04.3	27.5	25.9	476	202	42%
BBC03.4	27.8	26.3	477	212	44%
BBC02.6	26.6	25.3	480	211	44%
COL00.0	18.9	16.9	265	0	0%
BBC01.6	25.4	24.0	479	202	42%
BBC00.0	34.7	32.7	207	191	92%

During the temperature monitoring period from May 2008–September 2009, the dates in 2008 and 2009 with the highest count of seasonal maximum temperatures were 8/16/08 (10 sites) and 7/29/09 (13 sites). Figure 12 shows a longitudinal profile of stream temperatures on 8/16/08. Stream temperature increases as Burnt Bridge Creek progresses downstream from the headwaters and reaches a temperature peak near RM 7. Stream temperature decreases from RM 7 to RM 3 with a small increase near Leverich Park. (RM 2.5). Stream temperature increased below RM 2 to the mouth of the creek with an overall maximum temperature at BBC00.0. Temperature inputs from Cold Creek and Burton Channel were lower than stream temperature in Burnt Bridge Creek. Temperature was slightly higher in Peterson Channel than in the creek.

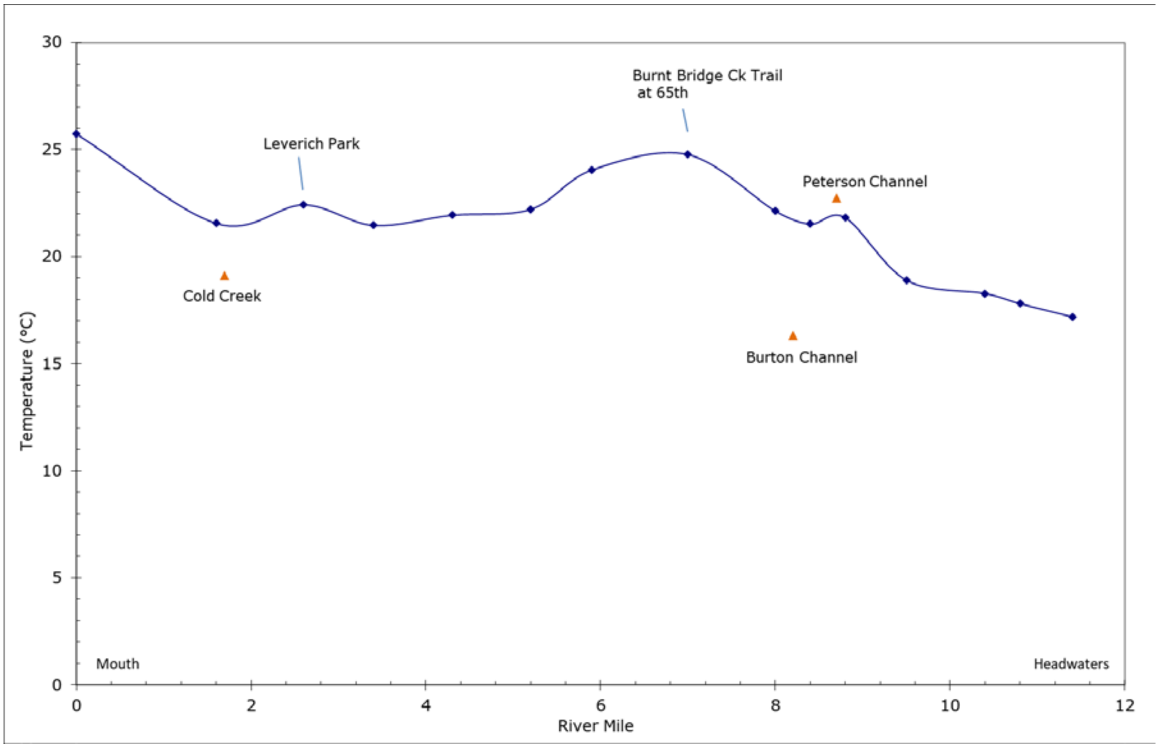

Figure 12. Longitudinal profile of stream temperature (7-DADMax) on 8/16/08.

SEH America Facility

SEH America (SEH) is a manufacturing facility that discharges non-process wastewaters through an outfall (Outfall 001) at the headwaters of Peterson Channel. SEH provided Ecology with provisional end-of-pipe flow data for the study duration including the dates with instantaneous flow measurements at PET00.0 (Appendix F). Flow in Peterson Channel is strongly influenced by discharge from SEH, which contributes over half (63%) of the flow measured at PET00.0. Along with this discharge, flow in Peterson Channel is also influenced by shallow groundwater and stormwater.

Ecology installed a temperature logger (PET01.3) near the SEH America Outfall 001 from June 2008 to August 2009. Maximum daily temperature is shown in Figure 13. Temperature at the mouth of Peterson Channel (PET00.0) is lower than the temperature near the SEH outfall (PET01.3). On average, the maximum temperature at the mouth of Peterson Channel is 1.2°C lower than at PET01.3 near the SEH outfall. Temperature differences between the two sites are largest during summer months.

Current temperature water quality standards for the Burnt Bridge Creek watershed state that the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average. For SEH, permitted discharge temperature criteria is a maximum of 21°C.

Figure 13 displays periods when PET01.3 (near outfall of SEH America) is above the SEH discharge permit temperature criteria (maximum of 21°C). Because SEH has a temperature sensor that automatically closes the valve when temperatures exceed their criteria, many of the dates with temperatures above 21°C occurred when the outfall valve was closed. There were four instances when temperature was above that criterion; however two of these recorded temperatures were within the thermistor accuracy (±0.02°C). The other two temperature exceedances occurred on 8/16/08 and 8/17/08. Appendix F provides a full summary of temperature exceedances.

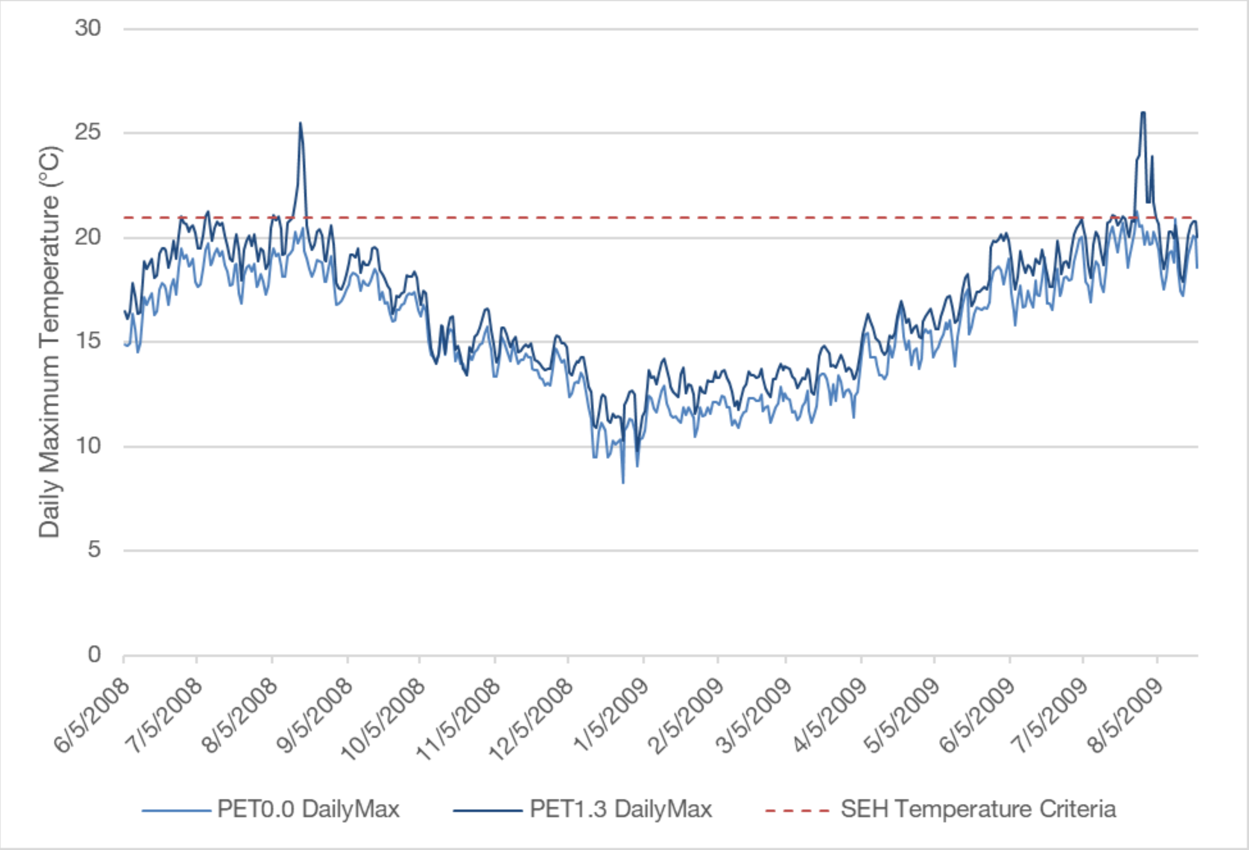

Figure 13. Peterson Channel continuous temperature results at PET01.3 near SEH America facility Outfall 001 and at channel mouth (PET00.0).

Shade Results

Vegetation polygons within the 100-150 meter riparian buffer along Burnt Bridge Creek used for the TTools sampling analysis were compiled to evaluate major vegetation types, height, and density along the riparian corridor (Table 20).

Table 20. Vegetation and land use in riparian corridor used in TTools sampling analysis.

Vegetation or Land Use Type	Vegetation Height (m)	Vegetation Density	Fraction of Overall Area
Water	0	-	4%
Developed and paved	0	-	19%
Pasture	0.2	75%	36%
Golf course, scattered trees	22	25%	4%
Extra small trees	4	25–75%	1%
Small trees	10	25–75%	11%
Medium and large trees, low density	14 - 19	25%	2%
Medium and large trees, medium density	14 - 19	50%	6%
Medium and large trees, dense	14 - 19	75%	19%
Extra-large trees, very dense	27	85%	2%

Overall, land use within the riparian buffer of Burnt Bridge Creek is largely pastureland (36%), developed and paved areas (19%), and areas with dense medium and large trees (19%). Pastureland refers to open areas with dense, short (0.2 m) grassland vegetation and is found throughout various reaches of Burnt Bridge Creek (above RM 11, from RM 8–10, and sporadic areas from RM 1–2). Developed and paved areas along the riparian corridor are found intermittently from RM 3–7 and above RM 10. Vegetated areas of varying heights and densities are found throughout the remainder of the riparian corridor.

Ecology’s Shade model was used to estimate shade for Burnt Bridge Creek at 50-meter intervals. These estimates were then smoothed using a 500-meter rolling average. Effective shade was first modeled for one date (8/1/08) to compare with effective shade calculated from hemispherical photograph field observations (Figure 14). Differences between modeled effective shade and measured shade from hemispherical photographs are because the shade model produces average shade values along a reach, while the hemispherical photos are from precise locations.

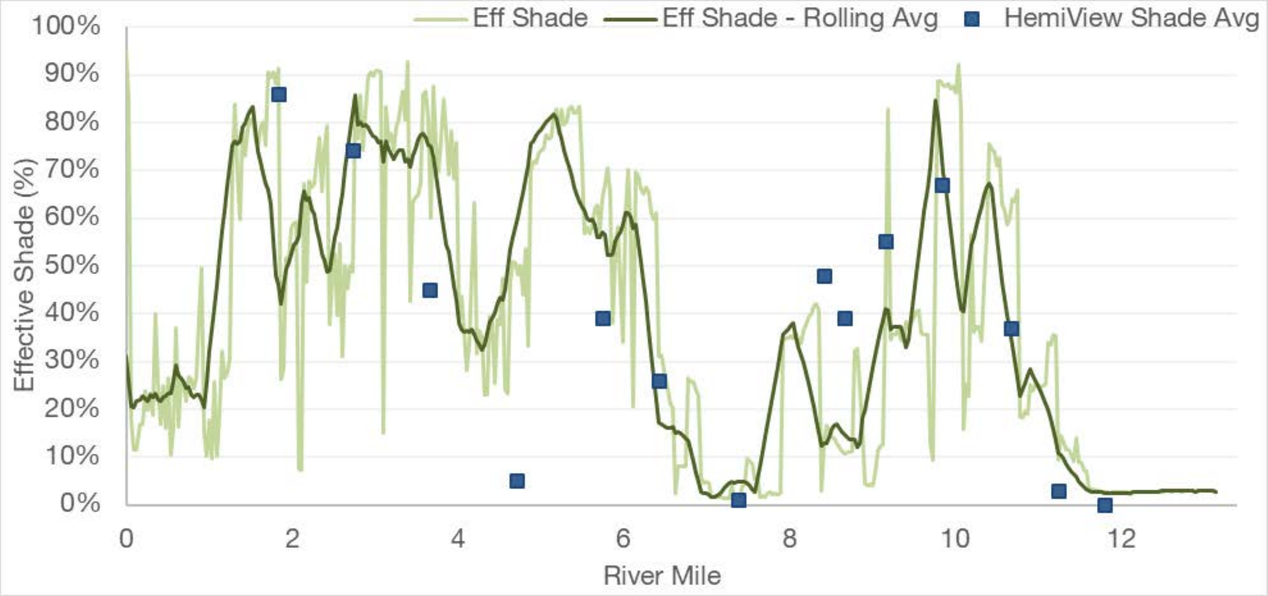

Figure 14. Existing effective shade compared to hemispherical photo shade measurements (8/1/08).

The Shade model was also used to simulate both existing shade and system potential shade from July–September 2008 to calculate average shade during the summer months. The system potential shade estimates effective shade from mature vegetation that is allowed to grow to its maximum height and density. Existing shade and system potential shade throughout the stream are compared in Figure 15.

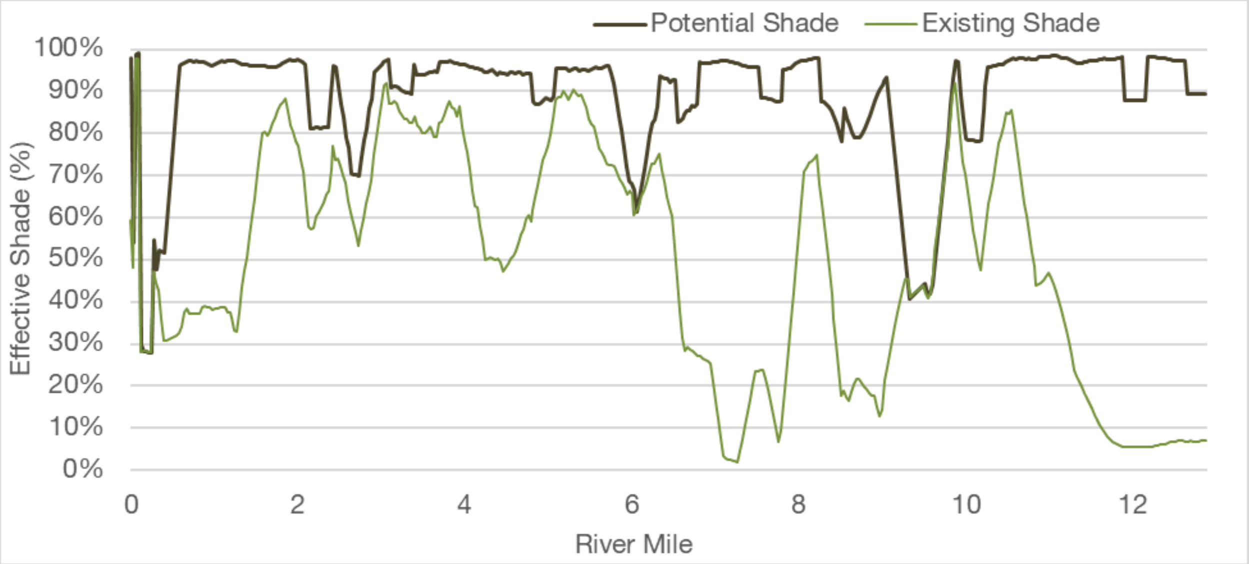

Figure 15. Existing effective shade and system potential shade (July-September 2008).

A shade deficit was calculated by taking the difference of system potential shade and current effective shade. Figure 16 is a map of the shade deficit along Burnt Bridge Creek showing the spatial variation of the average shade deficit from July–September.

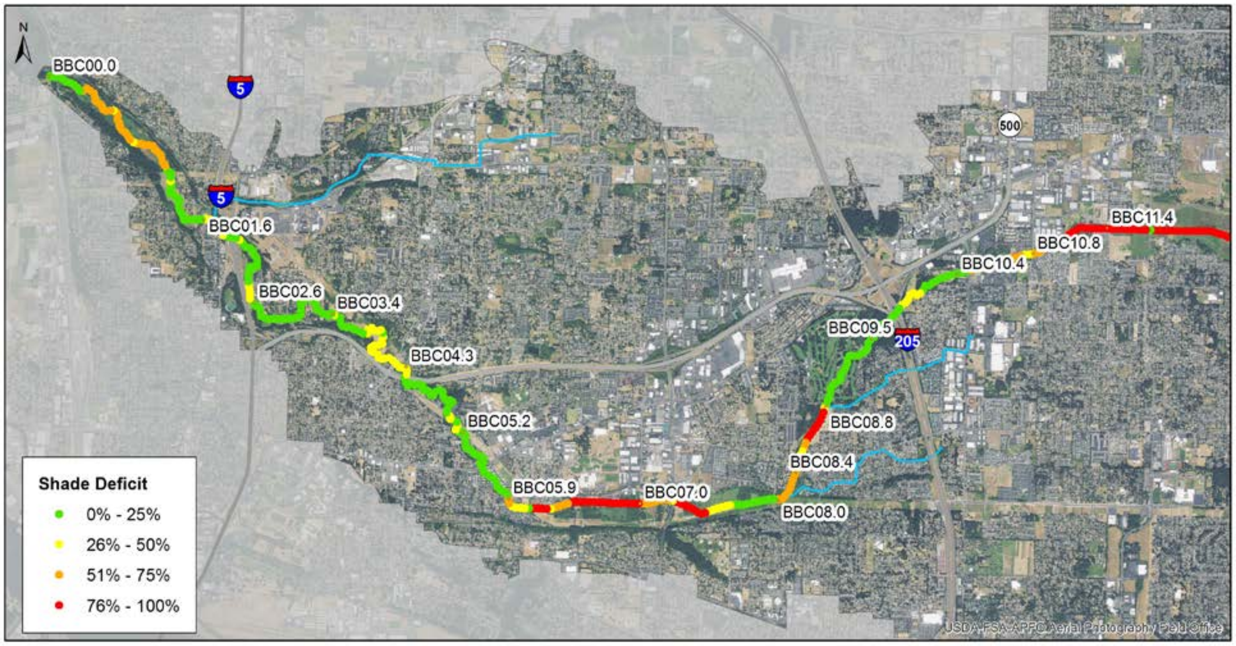

Figure 16. Map of shade deficit along Burnt Bridge Creek.

Table 21 summarizes average existing shade, potential shade, and shade deficit for each river mile. The upper reaches of Burnt Bridge Creek (upstream of RM 11, including BBC11.4) are in pastures with sparse vegetation and effective shade. This segment of the creek has the largest shade deficit, from 73–87% (Table 21). From RM 7–8 (including BBC07.0) there is low existing effective shade (12%) and a large shade deficit (83%). Reaches with the highest existing effective shade are from RM 1–6 (51–84%) and from RM 10–11 (66%). Shade decreases in the last mile before the creek reaches its confluence with Vancouver Lake.

Table 21. Shade summary by river mile.

River Mile	Existing Shade	Potential Shade	Shade Deficit
0-1	40%	83%	43%
1-2	66%	97%	31%
2-3	67%	84%	17%
3-4	84%	94%	10%
4-5	57%	93%	36%
5-6	81%	91%	11%
6-7	51%	85%	35%
7-8	12%	94%	83%
8-9	43%	88%	44%
9-10	46%	66%	21%
10-11	66%	92%	26%
11-12	25%	98%	73%
12-13	6%	93%	87%

Dissolved Oxygen Summary

Summary statistics of DO measurements from the study period are in Table 22. Because DO was generally measured instantaneously, except during the synoptic surveys at select sites, the minimum DO values do not reflect the full diel range.

- Most sites, except BBC04.3 and COL00.0, had at least one day of noncompliance with DO concentrations below water quality criteria (< 8 mg/L).
- Sites with the highest count of noncompliant days are in the upper watershed (BBC09.5–BBC11.4) and middle watershed (BBC07.0 and BBC05.9).
- The sites with the lowest measured DO were BBC11.4 (0.6 mg/L) and BBC07.0 (0.0 mg/L). Both of these sites also had the overall lowest average DO (4.1 and 1.6 mg/L, respectively).
- Minimum DO values were generally observed during July, August, or September.

Table 22. Summary of dissolved oxygen results.

Bolded values indicate noncompliance (<8 mg/L).

Site	Days Count (n)	Average DO (mg/L)	Minimum DO (mg/L)	Date & Time of Minimum DO	Days Non-compliance
BBC11.4	36	4.1	**0.6**	8/10/2009 10:45	26
BBC10.8	29	5.7	**1.6**	8/10/2009 11:17	24
BBC10.4	30	6.5	**3.2**	8/10/2009 11:50	22
BBC09.5	36	6.2	**3.4**	8/1/2008 10:00*	21
BBC08.8	29	10.3	**7.4**	7/29/2008 7:14	1
BBC08.4	33	7.7	**6.4**	9/23/2008 7:06	12
BBC08.0	26	8.9	**7.2**	9/23/2008 7:06	7
BBC07.0	32	1.6	**0.0**	9/26/2008 2:45	19
BBC05.9	32	6.1	**2.7**	7/28/2009 9:47*	25
BBC05.2	31	9.6	**7.6**	7/28/2009 10:21	1
BBC04.3	28	9.9	8.2	7/28/2009 10:59	0
BBC03.4	30	9.7	**7.6**	7/28/2009 11:43	3
BBC02.6	28	9.8	**7.7**	7/28/2009 12:58	1
BBC01.6	33	8.7	**5.9**	7/31/2008 8:30*	3
BBC00.0	29	12.9	**7.6**	8/27/2008 12:12	1
PET01.3	30	9.1	**7.1**	11/17/2008 13:04	5
PET00.0	27	8.7	**7.9**	7/13/2009 16:07	3
COL00.0	29	10.4	8.8	6/29/2009 15:29	0
BUR00.0	29	8.5	**6.6**	7/29/2008 6:00	11

*Minimum DO measured during synoptic survey not as instantaneous measurement.

pH Summary

Summary statistics of pH measurements during the study period are presented in Table 23. As pH was generally measured instantaneously, typically during the morning or afternoon, the minimum and maximum values do not fully capture the diel pH range.

- Most sites had low counts of noncompliant days (≤ 3 days), except for BBC00.0 (12 days).
- Sites that met pH criteria include BBC08.8, BBC08.0, BBC05.2, PET00.0, and PET01.3.
- Overall minimum and maximum pH values were measured in Burton Channel (6.1 and 9.8 s.u., respectively).
- The lowest pH values along the Burnt Bridge Creek mainstem were in the upper subbasin (BBC09.5–BBC11.4). These sites recorded minimum pH values below criteria (< 6.5 s.u.).
- The majority of minimum pH values were measured on dates with heavy rainfall (5/5/09 and 10/14/09).
- Maximum pH values were typically observed during July, August, and September.

Table 23. Summary of pH results.

Bolded values indicate noncompliance with criteria (<6.5 or >8.5 s.u.).

Site	Days Count (n)	Avg pH (s.u.)	Minimum pH (s.u)	Maximum pH (s.u.)	Days Noncompliance
BBC11.4	36	6.8	**6.3**	7.9	3
BBC10.8	28	6.8	**6.3**	7.7	2
BBC10.4	28	6.9	**6.3**	7.6	2
BBC09.5	34	7.2	**6.4**	8.0	1
BBC08.8	28	7.6	6.7	8.5	0
BBC08.4	31	7.6	6.6	**9.0**	1
BBC08.0	27	7.6	6.5	8.4	0
BBC07.0	28	7.5	6.6	**9.3**	3
BBC05.9	30	7.4	6.5	**8.6**	1
BBC05.2	28	7.7	6.9	8.3	0
BBC04.3	28	7.9	7.1	**8.9**	1
BBC03.4	27	7.9	7.1	**9.2**	3
BBC02.6	27	7.9	7.1	**9.0**	1
BBC01.6	31	7.7	7.2	**8.9**	1
BBC00.0	31	8.4	6.9	**9.5**	12
PET01.3	28	7.6	7.0	8.2	0
PET00.0	27	7.4	6.6	7.9	0
COL00.0	27	8.0	7.1	**9.0**	1
BUR00.0	27	7.5	**6.1**	**9.8**	3

City of Vancouver Water Quality Monitoring

City of Vancouver Annual Monitoring Data and Report

The City of Vancouver monitors water quality in Burnt Bridge Creek on an annual basis by monitoring and sampling stations throughout Burnt Bridge Creek monthly from May through October to capture dry season conditions. These sites are the same as the study sites used during Ecology's 2008–2009 monitoring, with the exception of BBC00.0 (Figure 6; Table 8). Samples are compared with the data collected in prior years to assess improving or degrading water quality throughout the creek.

Field procedures are outlined in each monitoring year's corresponding Quality Assurance Project Plans and addendums. Parameters monitored include temperature, DO, pH, and specific conductivity. Parameters sampled and lab analyzed include turbidity, total suspended solids, phosphorus, nitrogen, FC, and E. coli bacteria (since 2018). The full field and sampling procedures, data quality assessment, data analysis, and comparisons can be found in the City of Vancouver's annual Burnt Bridge Creek Water Quality Monitoring Reports for the years 2011–2018 on the City of Vancouver's Stormwater Management Water Quality Reports webpage[7].

The 2017 Trend Analysis Report (Herrera, 2018) analyzed surface water monitoring data collected from 2011–2017. Kendall's Tau correlation test was used to identify temporal trends in the different parameters. Water quality data collected from 2004–2007 at four stations were used to identify significant differences between historical (2004–2007) and recent (2011–2017) data using the Mann-Whitney U test. Table 24 is a summary table from the 2017 Trend Analysis Report that shows significant water quality improvement or declines at the different monitoring stations.

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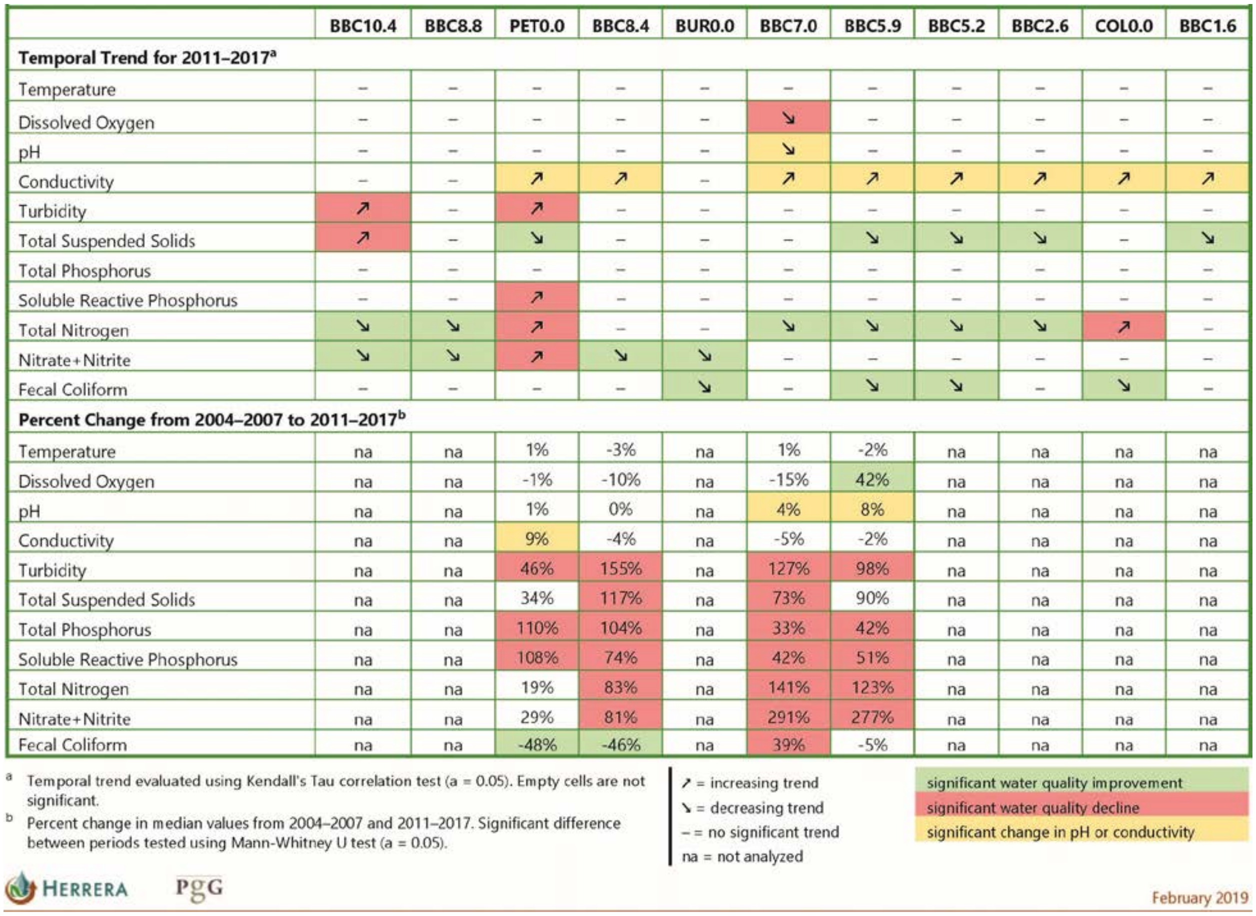
[7] https://www.cityofvancouver.us/publicworks/page/stormwater-management-plan

Table 24. Temporal trend analysis summary from City of Vancouver 2017 Trend Analysis Report (Herrera, 2018).



	BBC10.4	BBC8.8	PET0.0	BBC8.4	BUR0.0	BBC7.0	BBC5.9	BBC5.2	BBC2.6	COL0.0	BBC1.6
Temporal Trend for 2011–2017[a]											
Temperature	–	–	–	–	–	–	–	–	–	–	–
Dissolved Oxygen	–	–	–	–	–	↘	–	–	–	–	–
pH	–	–	–	–	–	↘	–	–	–	–	–
Conductivity	–	–	↗	↗	–	↗	↗	↗	↗	↗	↗
Turbidity	↗	–	↗	–	–	–	–	–	–	–	–
Total Suspended Solids	↗	–	↘	–	–	–	↘	↘	↘	–	↘
Total Phosphorus	–	–	–	–	–	–	–	–	–	–	–
Soluble Reactive Phosphorus	–	–	↗	–	–	–	–	–	–	–	–
Total Nitrogen	↘	↘	↗	–	–	↘	↘	↘	↘	↗	–
Nitrate+Nitrite	↘	↘	↗	↘	↘	–	–	–	–	–	–
Fecal Coliform	–	–	–	–	↘	–	↘	↘	–	↘	–
Percent Change from 2004–2007 to 2011–2017[b]											
Temperature	na	na	1%	-3%	na	1%	-2%	na	na	na	na
Dissolved Oxygen	na	na	-1%	-10%	na	-15%	42%	na	na	na	na
pH	na	na	1%	0%	na	4%	8%	na	na	na	na
Conductivity	na	na	9%	-4%	na	-5%	-2%	na	na	na	na
Turbidity	na	na	46%	155%	na	127%	98%	na	na	na	na
Total Suspended Solids	na	na	34%	117%	na	73%	90%	na	na	na	na
Total Phosphorus	na	na	110%	104%	na	33%	42%	na	na	na	na
Soluble Reactive Phosphorus	na	na	108%	74%	na	42%	51%	na	na	na	na
Total Nitrogen	na	na	19%	83%	na	141%	123%	na	na	na	na
Nitrate+Nitrite	na	na	29%	81%	na	291%	277%	na	na	na	na
Fecal Coliform	na	na	-48%	-46%	na	39%	-5%	na	na	na	na

[a] Temporal trend evaluated using Kendall's Tau correlation test (a = 0.05). Empty cells are not significant.

[b] Percent change in median values from 2004–2007 and 2011–2017. Significant difference between periods tested using Mann-Whitney U test (a = 0.05).

↗ = increasing trend
↘ = decreasing trend
– = no significant trend
na = not analyzed

🟩 significant water quality improvement
🟥 significant water quality decline
🟨 significant change in pH or conductivity

February 2019

Results from the temporal trend analysis indicated significant water quality declines at BBC10.4, PET0.0, BBC7.0, and COL0.0, which were attributed to nutrients, DO, turbidity, or total suspended solids (TSS). For FC, four sites (BUR0.0, BBC5.9, BBC5.2, COL0.0) showed significant trends in water quality improvement. The remainder of the sites showed no significant FC trends. None of the sites had a significant trend, either improving or declining, for temperature.

Historical changes from 2004–2007 and 2011–2017 showed significant declines in water quality for nutrients, turbidity, and TSS at four sites (PET0.0, BBC8.4, BBC7.0, BBC5.9). Two of these sites (PET0.0 and BBC08.4) had significant decreases in FC, even though there was no significant temporal trend.

Temperature patterns observed in 2018 were similar to previous years including those in 2008–2009, with high temperatures in the middle reaches and a maximum temperature at BBC07.0. Because BBC00.0 is not a routine sampling site for the City of Vancouver, a comparison of temperatures cannot be made. Similar to 2008–2009 results, Burton Channel and Cold Creek tributary temperatures were lower than mainstem temperatures, whereas Peterson Channel temperatures during the summer were higher than the mainstem.

The most recent water quality monitoring report (2018) compared samples that were collected from May–October 2018 with samples collected in prior years, 2011–2017. E. coli sampling was added in 2018 to allow for comparison with Ecology's updated rulemaking that identifies E. coli as the new bacterial indicator in freshwater rather than FC (Ecology, 2019).

Sites continue to exceed FC criteria throughout Burnt Bridge Creek and its tributaries. Two sites that showed significant declines in FC include Burton Channel (BUR0.0) and Cold Creek (COL0.0) that had some of the highest FC concentrations during 2008–2009 sampling. During 2018 when E. coli was added as a sampling parameter, all sites except for BBC10.4 exceeded the recently adopted E. coli standards.

Results from these recent water quality monitoring reports from the City of Vancouver support using data collected by Ecology from 2008–2009 for this report. All sites in 2018 continue to exceed temperature and FC criteria.

Watershed Health Assessment Report

The Integrated Scientific Assessment Report: Vancouver Watershed Health Assessment (referred to as WHA) was prepared for the City of Vancouver in 2019 by Herrera Environmental Consultants, Inc. and Pacific Groundwater Group (Herrera and PGG, 2019). The WHA used available data to evaluate the ecological condition of Vancouver's watersheds, identify data gaps, and help the City of Vancouver prioritize watershed management programs and activities.

The WHA also included a spatial statistical analysis to evaluate whether certain landscape conditions (e.g., land use, terrain, and septic system density) and watershed management activities (e.g., stormwater facilities and habitat restoration) showed statistically significant correlations with water quality in the Burnt Bridge Creek watershed.

Results from the spatial analysis indicated that septic systems are likely increasing FC and nitrogen concentrations, and FC concentrations may be linked with residential use. Urban development (commercial/industrial land use and impervious cover) is likely increasing phosphorus concentrations. Stormwater management (detention, filtration, and infiltration) facilities were correlated with improving stream temperatures. Additional stormwater management facilities in commercial/industrial areas could improve surface water quality in this watershed.

Subbasin Summary

Upper Burnt Bridge Creek

Upper Burnt Bridge Creeks refers to the watershed area upstream of BBC09.5 through the headwaters (RM 10-13). The upper subbasin includes the fixed-network sites BBC11.4, BBC10.8, BBC10.4, and up to BBC09.5 (Figure 17). Headwaters of Burnt Bridge Creek originate near NE 162nd Ave. The creek travels through open undeveloped land with little vegetation. Between sampling sites BBC11.4 and BBC10.4, the creek flows through residential and commercial areas then passes below Interstate-205 to BBC09.5 at Beaver Marsh Natural Area.

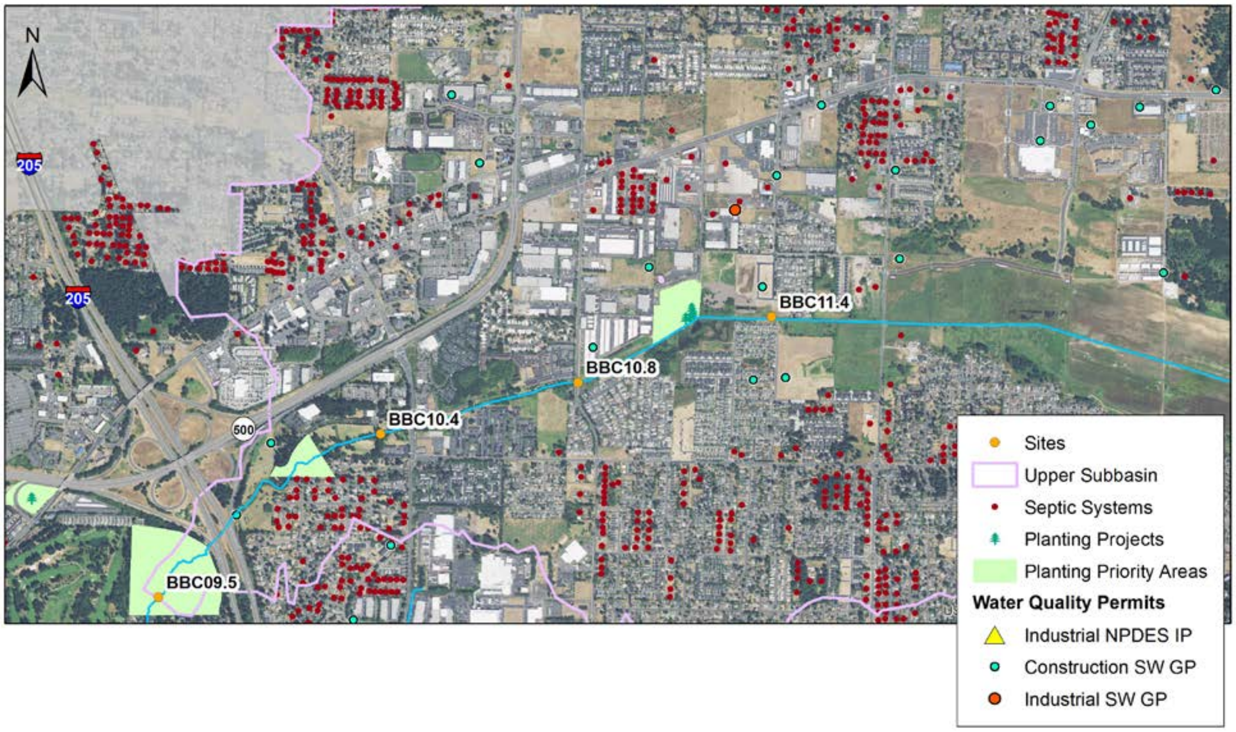


Figure 17. Map of upper Burnt Bridge Creek subbasin.

Land use in the upper subbasin is mainly residential, undeveloped, and roads and transportation (Figure 18). Small portions (91 acres) of the upper watershed are agriculture and forests (Table 25). Along the riparian area, land use is mainly open, undeveloped areas with small pockets of residential and commercially developed land. There are over 1,000 septic systems in the upper subbasin. Approximately 8% of land is publically owned and 92% is privately owned.

The City of Vancouver and Clark County MS4 permit area each cover approximately half of the upper subbasin. Upper reaches of Burnt Bridge Creek are within the City of Vancouver MS4 permit area. Various construction stormwater and industrial stormwater permits are spread throughout the upper subbasin (Figure 17).

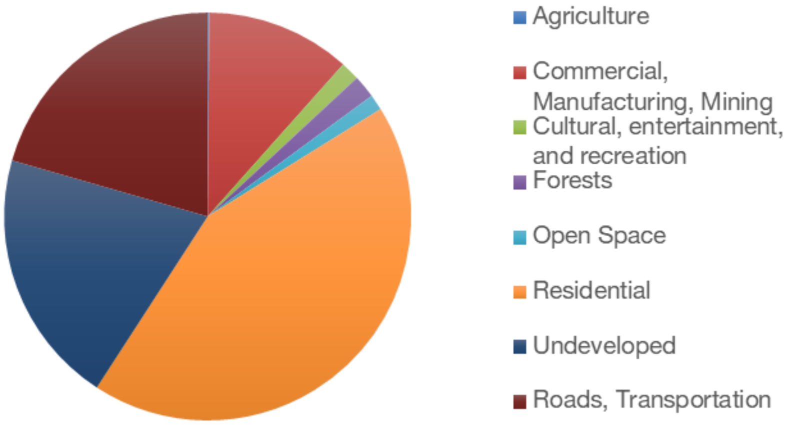


Figure 18. Upper subbasin land use.

Table 25. Land use area summary for upper subbasin.

Land Use Category	Area (acre)	Area (%)
Agriculture	6	0%
Commercial, Manufacturing, Mining	542	11%
Cultural, Entertainment, Recreation	71	2%
Forests	85	2%
Open Space	59	1%
Residential	2030	43%
Undeveloped	957	20%
Roads, Transportation	971	21%

Fecal Coliform Bacteria

In the upper Burnt Bridge Creek subbasin, FC concentrations were generally lower than concentrations in the middle and lower sections of the watershed (Table 14). Distribution of FC and the geometric mean were similar between the two furthest upstream sites, BBC11.4 and BBC10.8 (Figure 19). BBC10.4 had the highest FC geometric mean during the dry and wet seasons (130 and 47 cfu/100 mL, respectively). Geometric means at each upper subbasin site were higher during the dry season than during the wet season. The FC distribution was larger at each site during the wet season indicating more variability in wet season bacteria levels.

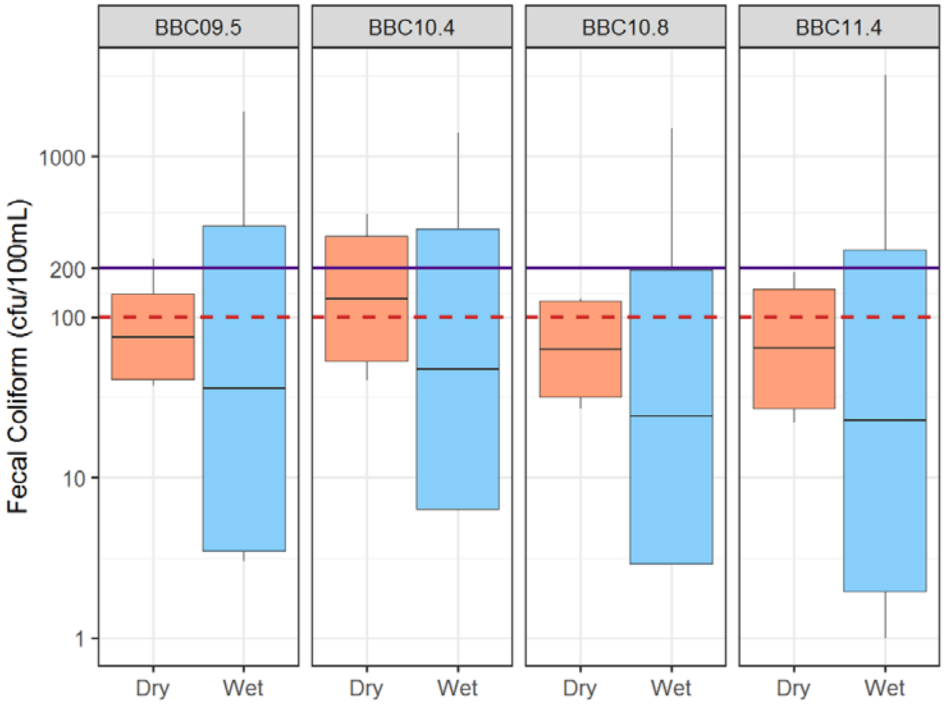


Figure 19. FC distribution at upper sites.

Box plots show distribution of FC concentrations where horizontal line represents the geometric mean and top of the box indicates 90th percentile.

FC loading results in the upper subbasin show higher FC loads during the wet season than during the dry season (Table 26). During the dry season, FC loads are similar at BBC11.4, BBC10.8, and BBC09.5 (5 b.cfu/day) with a slightly higher average load at BBC10.4 (9 b.cfu/day). During the wet season, FC loads vary throughout the upper reaches. The greatest increase in FC loads was from BBC10.4 to BBC09.5 in the wet season (28 b.cfu/day increase).

Table 26. Upper subbasin seasonal FC loading and FC reductions (%) needed to meet water quality criteria.

Site	Dry Season Avg Flow	Dry Season Avg Load	Dry Season FC % Reduction	Wet Season Avg Flow	Wet Season Avg Load	Wet Season FC % Reduction
BBC11.4	2.4	5	0%	4.3	38	24%
BBC10.8	2.5	5	0%	4.7	23	0%
BBC10.4	2.3	9	37%	5.5	40	43%
BBC09.5	2.9	5	0%	6.6	68	46%

FC reductions from the rollback analysis at the upper subbasin sites indicated that BBC10.4 and BBC09.5 need the largest reductions in FC to meet water quality criteria (43–46%) during the wet season. During the dry season, BBC10.4 requires the largest reduction to meet criteria (37%). While these reductions are generally lower than sites throughout the rest of the watershed, by reducing bacteria in the upper reaches, water quality conditions downstream are expected to improve.

Temperature and Shade

Stream temperatures in the upper reaches of Burnt Bridge Creek are generally lower than the remainder of the creek. Stream temperatures increased moving downstream from BBC11.4 to BBC09.5 with maximum temperatures in the upper subbasin measured at BBC09.5. Temperatures at the upper sites exceeded criteria from 13-21% of days monitored (Table 19). BBC09.5 had the highest count of days exceeding temperature criteria (98 days).

The overall average of the shade deficit, the difference between system potential and current effective shade, in the upper reaches of Burnt Bridge Creek is 62% with the largest deficit from RM 12-13 (87%; Table 27). This is the largest average shade deficit when compared with the middle and lower subbasins. There are a few sections of City of Vancouver priority planting areas along with planting projects in the upper watershed along Burnt Bridge Creek (Figure 17). Because of the large shade deficit in the upper reaches of Burnt Bridge Creek, implementing restoration and vegetation plantings is expected to improve shade and reduce water temperatures in the upper segments of the creek that will benefit downstream conditions. Partnerships and outreach to private landowners will be necessary to encourage and establish plantings that provide shade and lower water temperatures in this reach.

Table 27. Average current effective shade, potential shade, and shade deficit for upper subbasin sites.

River Mile	Existing Shade	Potential Shade	Shade Deficit
10-11	66%	92%	26%
11-12	25%	98%	73%
12-13	6%	93%	87%
Average	32%	94%	62%

Middle Burnt Bridge Creek

The middle portion of the Burnt Bridge Creek watershed is from RM 5-10 and includes sampling sites BBC04.3 through BBC09.5, Peterson Channel, and Burton Channel (Figure 20). Southeast of BBC09.5 (Beaver Marsh Natural Area), Burnt Bridge Creek flows through the Royal Oaks Country Club golf course, receives input from Peterson Channel and Burton Channel, and then flows through sections of developed commercial and residential areas with open spaces that contain the central portion of the Greenway Project restoration area. The creek flows below State Route-500 before reaching the end of the middle subbasin at BBC04.3

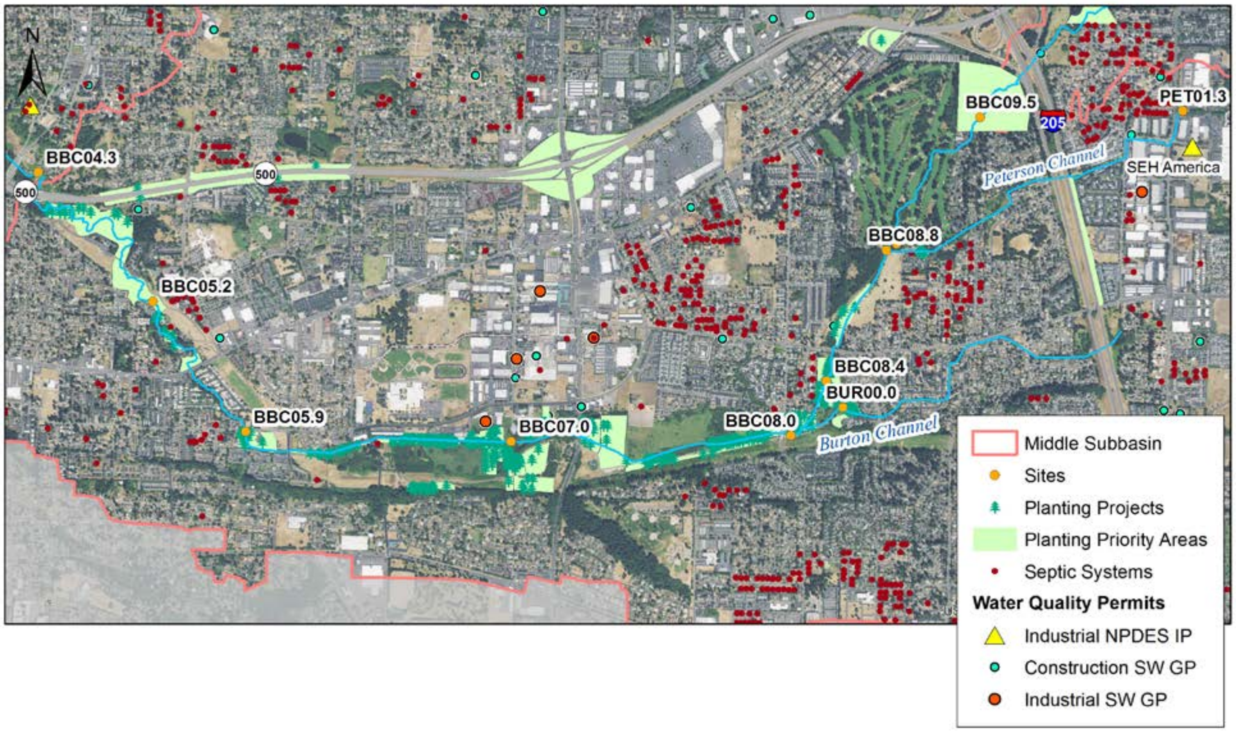


Figure 20. Map of middle Burnt Bridge Creek subbasin.

Just under half (45%) of the land area in the middle Burnt Bridge Creek subbasin is residential (Figure 21; Table 28). The middle subbasin has the highest count of septic systems (about 2,000 systems). Other major land use categories include commercial, roads and transportation, undeveloped and natural spaces. Along the riparian corridor, land use includes forests and recreation areas (e.g. golf course), residential and commercial areas, and an expansive central corridor of open space between BBC05.9 and BBC08.0, where the reach has been transformed with native vegetation, reconnected floodplains, stormwater ponds, and a regional trail system. Publically owned land makes up about 11% of the middle watershed with the City of Vancouver owning over half of the publically owned land.

Peterson Channel delivers discharge from the SEH America facility and flows through commercial and residential properties before its confluence with the creek below the Royal Oaks golf course. Burton Channel originates near commercial properties and flows through a heavily residential area before entering Burnt Bridge Creek at Meadowbrook Marsh.

The City of Vancouver MS4 permit area covers almost all of the middle subbasin, and the entirety of the creek corridor. A small section in the northern portion of the watershed is covered by the Clark County MS4 permit, and WSDOT permit covers major roadways in this subbasin. In addition to the SEH America industrial individual permit on Peterson Channel, there are multiple industrial and construction stormwater general permits in the northern sections of the middle watershed (Figure 20).

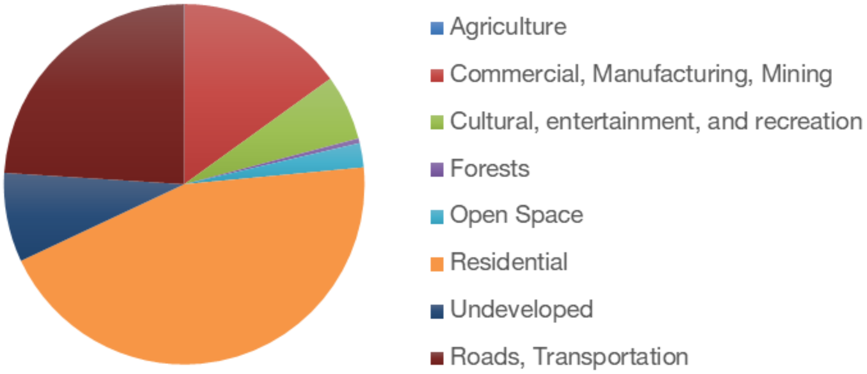


Figure 21. Middle subbasin land use.

Table 28. Land use area summary for middle subbasin.

Land Use Category	Area (acre)	Area (%)
Agriculture	5	0%
Commercial, Manufacturing, Mining	1486	15%
Cultural, Entertainment, Recreation	581	6%
Forests	42	0%
Open Space	216	2%
Residential	4411	45%
Undeveloped	792	8%
Roads, Transportation	2378	24%

Fecal Coliform Bacteria

The middle Burnt Bridge Creek sampling sites had high FC concentrations with generally higher geometric mean concentrations during the dry season than during the wet season (Figure 22). The highest FC concentrations were found at tributary sites PET00.0 and BUR00.0. The mainstem site with the highest FC concentration was BBC08.4. FC distributions were generally larger during the wet season, demonstrating variability in wet season FC concentrations.

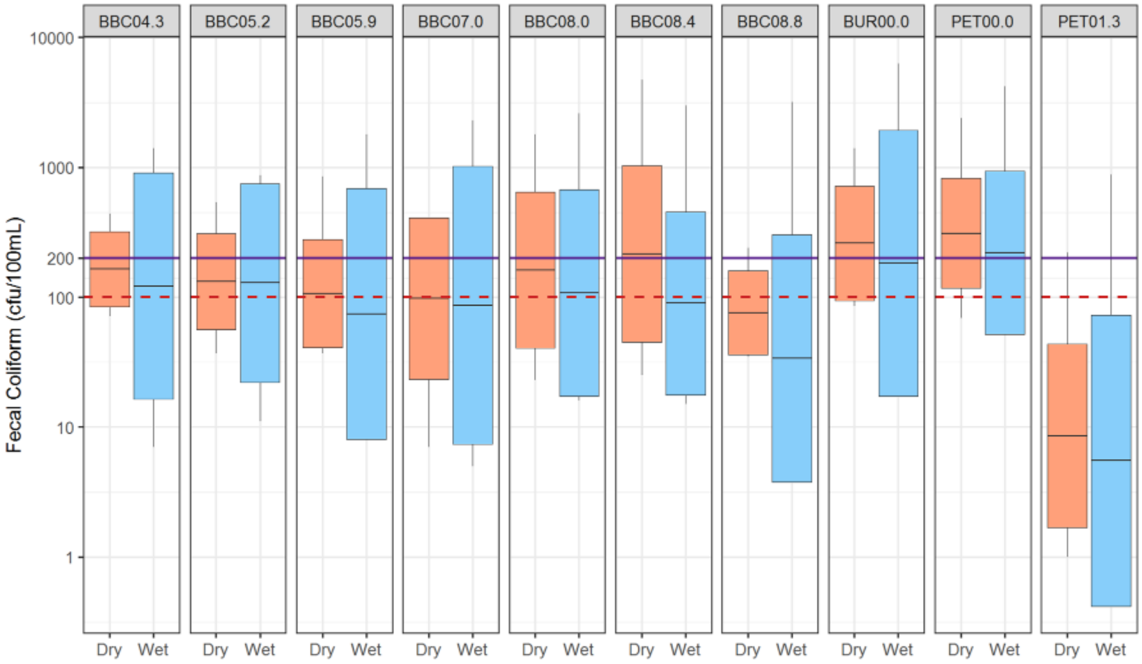


Figure 22. FC distribution at middle sites.

Box plots show distribution of FC concentrations where horizontal line represents the geometric mean and top of the box indicates 90th percentile

Seasonal variation in FC loads shows much higher wet season FC loads than during the dry season at all sites (Table 29). FC loads fluctuate moving downstream during both seasons with no strong spatial pattern. The greatest change in FC loads during the dry season is an increase between BBC08.8 and BBC08.4 (67 b.cfu/day). This creek segment includes the inflow from Peterson Channel. During the wet season, the greatest change in FC loads is between BBC08.4 and BBC08.0 (increase in 56 b.cfu/day), which includes the input from Burton Channel. BBC08.4 has the highest FC load (71 b.cfu/day) in the dry season, and BBC07.0 has the highest FC load in the wet season (178 b.cfu/day). Peterson Channel contributes higher FC loads to Burnt Bridge Creek during both seasons than Burton Channel.

Middle subbasin results from the rollback analysis indicate the amount of FC reduction (%) needed to meet water quality criteria are also in Table 29. Burton Channel requires the largest FC reduction (90% in the wet season) to meet criteria. Burton Channel primarily flows through residential land with its headwaters near I-205. During the dry season, BBC08.4 requires the largest FC reduction (81%). Generally, FC reductions are larger during the wet season than the dry season. PET00.0 and BBC08.0 need similar FC reductions in both seasons.

While PET01.3 had low bacteria concentrations, PET00.0 needs reductions during both seasons (76% dry season; 79% wet season) indicating a source of FC between PET01.3 and PET00.0 that should be further investigated. Peterson Channel begins in commercial and manufacturing areas, flows below I-205, and then through mixed land use (residential, parks and recreation, and open space) before reaching the mainstem of Burnt Bridge Creek.

Table 29. Middle subbasin seasonal FC loading and FC reductions (%) needed to meet water quality criteria.

Site	Dry Season Avg Flow (cfs)	Dry Season Avg Load (b.cfu/day)	Dry Season FC Reduction (%)	Wet Season Avg Flow (cfs)	Wet Season Avg Load (b.cfu/day)	Wet Season FC Reduction (%)
BBC08.8	2.2	4	0%	6.3	99	34%
PET01.3	--	--	0%	--	--	0%
PET00.0	2.2	23	76%	3.0	57	79%
BBC08.4	4.0	71	81%	9.2	117	56%
BUR00.0	0.1	1	72%	0.7	48	90%
BBC08.0	4.8	43	69%	10.8	173	70%
BBC07.0	4.8	16	51%	11.6	178	80%
BBC05.9	4.9	25	28%	14.6	154	71%
BBC05.2	4.9	21	35%	14.7	125	73%
BBC04.3	5.2	24	43%	15.3	179	78%

Temperature and Shade

Temperature results from the Burnt Bridge Creek middle subbasin monitoring sites are generally higher temperatures than the rest of the creek, except for BBC00.0. All sites exceeded temperature criteria. The maximum daily temperature (33.0°C) and 7-DADMax (31.3°C) in the middle watershed was observed at BBC07.0 during the temperature monitoring period for this study (Table 30).

The longitudinal profile of Burnt Bridge Creek on 8/16/08 showed increasing stream temperatures until BBC07.0 (Figure 12). Temperatures decreased downstream of BBC07.0. Over half of the days during the temperature monitoring period exceeded temperature criteria at BBC08.0 and BUR00.0.

Peterson Channel discharges into Burnt Bridge Creek and is largely influenced by flow from SEH America facility. Temperatures at the mouth of Peterson Channel are lower than near the SEH outfall (Figure 13). In order to more fully understand the impact of SEH discharge on temperature in both Peterson Channel and Burnt Bridge Creek, a separate study is needed. This type of study will require collecting additional flow and temperature data, along with investigating the influence of groundwater. The study would be used to better evaluate permit temperatures for the SEH America facility which are currently set higher than state temperature standards for Burnt Bridge Creek and Peterson Channel.

Shade varied throughout the middle section of Burnt Bridge Creek with an average shade deficit of 39% (Table 26). The lowest current effective shade is from RM 7-8 (12%), which includes BBC07.0. From RM 5-6 (including BBC05.2), existing shade was the highest (81%) with a small shade deficit (11%).

Table 30. Average current effective shade, potential shade, and shade deficit for middle subbasin sites.

River Mile	Existing Shade	Potential Shade	Shade Deficit
5-6	81%	91%	11%
6-7	51%	85%	35%
7-8	12%	94%	83%
8-9	43%	88%	44%
9-10	46%	66%	21%
Average	47%	85%	39%

Many areas along the riparian corridor of the middle Burnt Bridge Creek watershed are designated priority planting areas with planting projects already started or completed in these areas (Figure 20). These planting projects will increase effective shade and help reduce temperatures in Burnt Bridge Creek, particularly those that are concentrated near areas with high shade deficits, such as around BBC07.0.

Lower Burnt Bridge Creek

Lower Burnt Bridge Creek is the section of the watershed downstream of RM 5.0 reaching to the confluence with Vancouver Lake (Figure 23). This portion of the watershed includes Cold Creek and the fixed-network sites: BBC03.4, BBC02.6, BBC01.6, BBC00.0, and COL00.0.

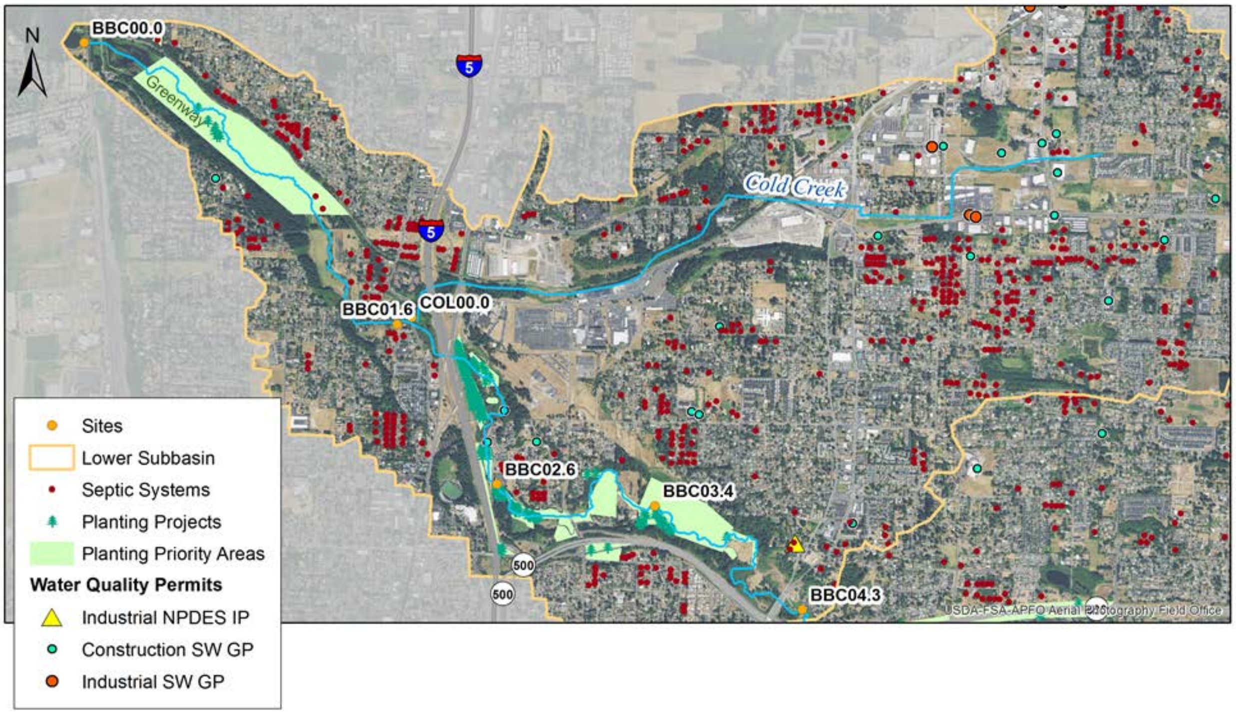


Figure 23. Map of lower Burnt Bridge Creek subbasin.

The lower reaches of Burnt Bridge Creek flow through parcels with mixed land-use. The major land use categories in the lower Burnt Bridge Creek watershed include residential areas (45%), roads and transportation (29%), and undeveloped land (12%; Table 31 and Figure 24). There are approximately 700 septic systems throughout the lower watershed, dispersed along the Burnt Bridge Creek riparian corridor and in upper Cold Creek. Approximately 16% of land in the lower watershed is publically owned.

The riparian corridor of the lower reaches of the creek is another priority area for vegetation plantings and restoration activities for the City of Vancouver. Restoration projects targeting the lower subbasin have also been implemented in coordination with the Lower Columbia Estuary Partnership. Sections along the lower reaches of the greenway are maintained by the City and eight miles of paved trail connects the lower and middle basins, providing recreational opportunity for the community.

The MS4 permit area in the lower Burnt Bridge Creek subbasin are split between the City of Vancouver and Clark County, with highway areas covered by WSDOT. There are multiple industrial and construction stormwater general permits and one individual NPDES permit in the lower watershed.

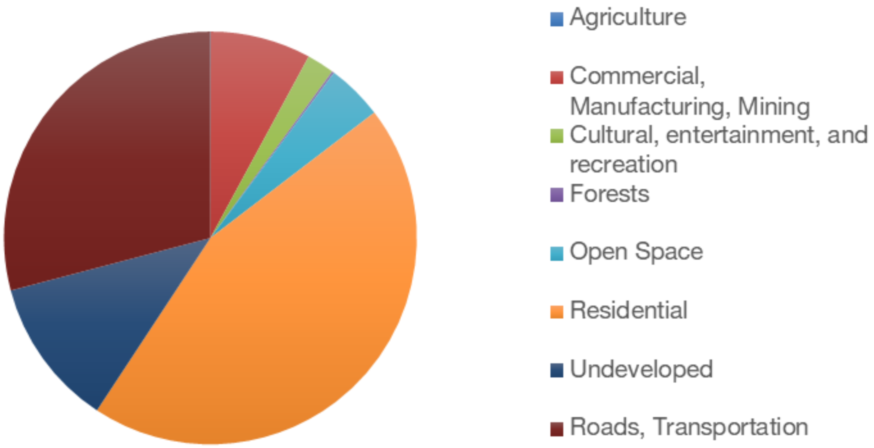


Figure 24. Lower subbasin land use.

Table 31. Land use area summary for lower subbasin.

Land Use Category	Land Use (acre)	Land Use (%)
Agriculture	2	0%
Commercial, Manufacturing, Mining	305	8%
Cultural, Entertainment, Recreation	84	2%
Forests	7	0%
Open Space	170	4%
Residential	1733	45%
Undeveloped	452	12%
Roads, Transportation	1129	29%

Fecal Coliform Bacteria

All FC sampling sites in the lower Burnt Bridge Creek subbasin exceeded water quality criteria during the wet season, and all sites except BBC00.0 exceeded criteria during the dry season (Figure 25). Geometric means were higher during the dry season at all sites except BBC00.0. The Cold Creek site (COL00.0) had the highest geometric mean during both seasons, with higher FC concentrations during the dry season. Cold Creek travels through commercial and manufacturing, undeveloped, and roads and transportation areas. The upstream half of Cold Creek is within the Clark County MS4 permit area and the downstream portion is within the City of Vancouver MS4 permit area; multiple industrial and construction stormwater permits are in the upper reaches of the creek.

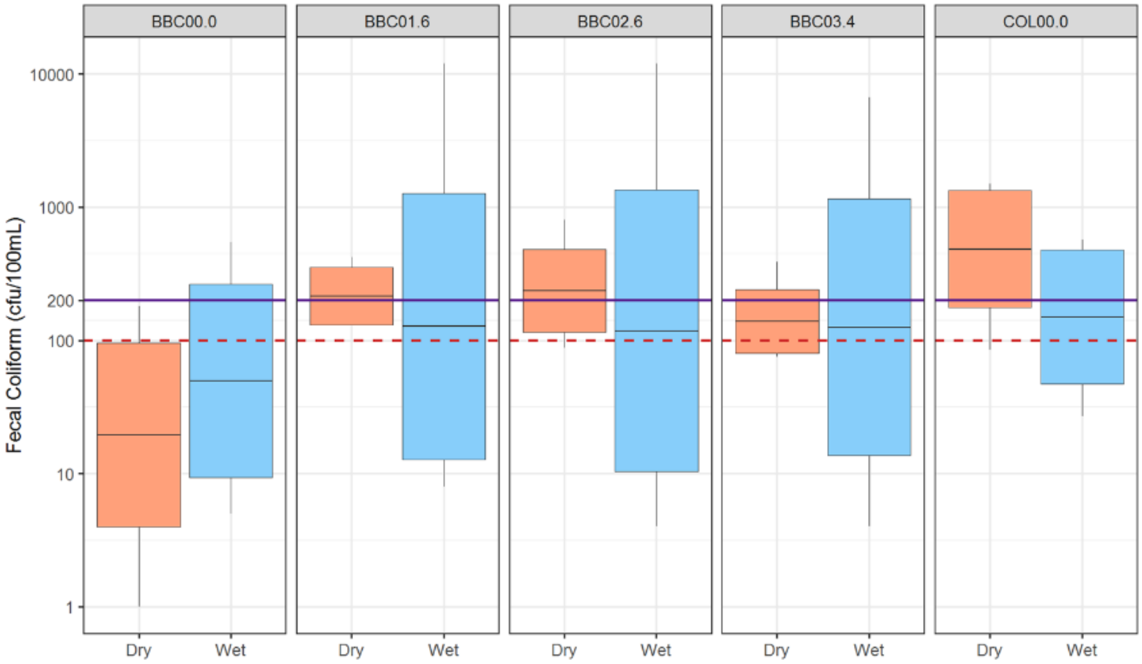


Figure 25. FC distribution at lower sites.

Box plots show distribution of FC concentrations where horizontal line represents the geometric mean and top of the box indicates 90th percentile.

FC loads in the lower subbasin were higher in the wet season than in the dry season (Table 32). The highest FC load during the wet season was at BBC01.6 (1,002 b.cfu/day). This average load was much higher than the remainder of loads throughout the rest of the lower subbasin. FC loads were greatly reduced between BBC01.6 and BBC00.0 (929 b.cfu/day). During the dry season, BBC01.6 and BBC02.6 have similar FC loads (30-32 b.cfu/day) with lower loads at BBC03.4 and BBC00.0 (19 and 6 b.cfu/day, respectively). Despite high bacteria concentrations, Cold Creek had the smallest FC load in the lower subbasin during both seasons (6-8 b.cfu/day).

Table 32. Upper subbasin seasonal FC loading and FC reductions (%) needed to meet water quality criteria.

Site	Dry Season Avg Flow (cfs)	Dry Season Avg Load (b.cfu/day)	Dry Season FC Reduction (%)	Wet Season Avg Flow (cfs)	Wet Season Avg Load (b.cfu/day)	Wet Season FC Reduction (%)
BBC03.4	5.2	19	30%	14.1	96	83%
BBC02.6	5.1	31	62%	15.1	758	85%
COL00.0	0.4	6	85%	1.2	8	58%
BBC01.6	5.3	30	57%	17.4	1,002	84%
BBC00.0	4.9	6	0%	16.5	73	24%

Most of the lower subbasin sites require more than 50% FC reductions in order to meet water quality criteria during both seasons, except for BBC00.0 (both seasons) and BBC03.4 (dry season). The highest FC reduction in the lower subbasin during the dry season is needed at COL00.0 (85%). During the wet season, mainstem sites (BBC03.4, BBC02.6, BBC01.6) require similar large FC reductions (83-85%) to meet criteria.

Temperature and Shade

Temperature monitoring results in the lower Burnt Bridge Creek subbasin showed that maximum temperatures observed along the entirety of Burnt Bridge Creek were at BBC00.0. At BBC00.0, 92% of days (191 days) with temperature monitoring during the study period exceeded water quality criteria. This may be attributed to the unique morphology in the lower reach of Burnt Bridge Creek and the influence of Vancouver Lake. Right upstream of BBC00.0, the creek widens into pools and wetlands which may influence flow and temperature. Field notes and discussions with field personnel also indicate the influence of tidal water from the Columbia River pushing through Vancouver Lake and influencing conditions at BBC00.0. Cold Creek had the lowest observed temperatures and met water quality criteria throughout the entire study duration.

The average existing shade in the lower subbasin is 63% and shade deficit is 27% (Table 33). Between RM 2 and the outlet of Burnt Bridge Creek (including BBC01.6) is a large, open area with little vegetation. This section of the riparian corridor along Burnt Bridge Creek was identified as a priority area for the City of Vancouver to plant vegetation and restore riparian habitat (Figure 23). By implementing vegetation plantings and increasing shade, temperatures are expected to be reduced in the lower reaches of the creek including BBC00.0.

Table 33. Average current effective shade, potential shade, and shade deficit for lower subbasin sites.

River Mile	Existing Shade	Potential Shade	Shade Deficit
0-1	40%	83%	43%
1-2	66%	97%	31%
2-3	67%	84%	17%
3-4	84%	94%	10%
4-5	57%	93%	36%
Average	63%	90%	27%

Conclusions

Results from this Source Assessment report will be used to guide a TMDL Alternative and Implementation Plan to improve water quality in the Burnt Bridge Creek watershed.

Fecal Coliform Bacteria

Fecal coliform bacteria (FC) results from this study support the following conclusions:

- All FC sampling sites exceeded FC water quality criteria during the study period.
- Geometric mean concentrations were generally higher during the dry season than during the wet season. The highest geometric mean concentrations were found at tributary sites during the dry season at Cold Creek, Peterson Channel, and Burton Channel.
- FC loading was higher during the wet season than during the dry season at all sites.
- The highest FC loads were in the lower subbasin at BBC01.6 and BBC02.6 during the wet season.
- The tributary with the highest FC load is Peterson Channel.
- The following sites all require more than a 75% reduction in FC levels to meet water quality criteria based on the results from the statistical rollback analysis:
    - All of the tributary outlet sites (PET00.0 during both seasons; BUR00.0 during the wet season; COL00.0 during the dry season).
    - Middle subbasin sites (BBC08.4 during the dry season; BBC07.0 during the wet season).
    - Lower subbasin sites (BBC04.3, BBC03.4, BBC02.6, and BBC01.6 during the wet season).

The FC reductions may be used to guide pollution identification and clean-up efforts. As sources of FC are identified and corrected, downstream water quality conditions are expected to improve.

Temperature and Shade

Temperature monitoring results from this study support the following conclusions:

- All sites exceeded temperature criteria, except for the site at the outlet of Cold Creek.
- The overall maximum temperatures were observed at BBC00.0. During the temperature monitoring period, 92% of days at BBC00.0 exceeded criteria.
- Sites with the highest count of dates with temperature above water quality criteria were in the middle subbasin (BBC07.0 with 230 days and BBC05.9 with 222 days).
- In Peterson Channel, discharge from SEH America comprises over half of the flow in the tributary. Maximum temperatures were higher at PET01.3 (near SEH America outfall) than the tributary outlet (PET00.0) by an average of 1.2°C. Temperature differences between the two sites are largest during summer months.

Results from the shade analysis conclude:

- Along the riparian corridor of Burnt Bridge Creek, approximately 36% of the area is pastureland, 19% is built or paved, and 45% is a mix of varying tree heights and densities.
- The largest shade deficit (difference between current effective shade and system potential shade) is in the upper subbasin (average of 62%). The average shade deficit in the middle watershed is 39% and in the lower watershed is 27%.
- Identifying areas along the riparian corridor with large shade deficits will be useful for guiding restoration activities and vegetation plantings to improve shade along Burnt Bridge Creek and reduce stream temperatures.

Dissolved Oxygen

Results from DO measurements support the following conclusions:

- Most sites, except for BBC04.3 and COL00.0, had at least one day of noncompliance with DO concentrations below water quality criteria during the study period.
- Sites with the highest count of noncompliant days are in the upper watershed (BBC11.4 and BBC10.8) and middle watershed (BBC07.0 and BBC05.9).
- Minimum DO values were generally observed during July, August, or September.
- Because DO at most sites was generally measured instantaneously with sampling during the morning or afternoon, DO results do not fully represent the full diel range.

Reducing stream temperatures by increasing riparian vegetation and shade in the watershed are expected to improve DO conditions throughout Burnt Bridge Creek.

pH

Results from pH measurements support the following conclusions:

- Most sites had low counts of noncompliant days (≤ 3 days), except for BBC00.0 (12 days).
- Sites that met pH criteria include BBC08.8, BBC08.0, BBC05.2, PET00.0, and PET01.3.
- There were a range of pH values throughout Burnt Bridge Creek watershed with overall minimum and maximum pH values in Burton Channel (6.1 and 9.8 s.u., respectively).
- The lowest pH values along the Burnt Bridge Creek mainstem were in the upper subbasin (BBC09.5–BBC11.4). The mainstem site with the highest observed pH was located furthest downstream (BBC00.0).
- The majority of minimum pH values were measured on dates with heavy rainfall (5/5/09 and 10/14/09). Maximum pH values were typically observed during July, August, and September.
- Except at select sites during the synoptic surveys, pH was measured instantaneously during the morning or afternoon, and therefore the pH results do not fully capture the full diel range for all sites.

Recommendations

Ecology recommends the following to improve water quality conditions in Burnt Bridge Creek:

Water Quality Monitoring

- Continue water quality monitoring by the City of Vancouver to evaluate changes in water quality over time, including sampling E. coli bacteria to compare with the updated bacterial indicator and water quality standards.
- Implement investigative water quality sampling at areas with high bacteria concentrations to support nonpoint source control.
- Continue to implement pollution identification and correction activities, including bacteria source control, and other illicit discharge detection and elimination programming.
- Complete a formal effectiveness monitoring study by 2030 to evaluate how improvement projects and recommended activities have impacted water quality.

Stormwater

- Continue stormwater management through the implementation of appropriate best management practices (BMPs).
- Achieve a high level of stormwater management in the Burnt Bridge Creek watershed by implementing structural retrofits and non-structural stormwater BMPs to manage runoff from impervious surfaces. Prioritize implementation of BMPs on effective impervious surfaces, directly discharging to Burnt Bridge Creek from pollutant generating land use types, businesses, and activities. Focus implementation of stormwater BMPs on residential and transportation land uses, which make up a significant portion of land use in the watershed.
- Prioritize the implementation of illicit discharge detection and elimination (IDDE) programming in areas with dry season bacteria exceedances. Initial IDDE efforts should target Burnt Bridge Creek tributaries.
- Conduct investigative stream walks along Burnt Bridge Creek and its tributaries to identify and sample unknown or unmapped outfalls. These stream walks should be prioritized at tributaries and areas with water quality criteria exceedances to investigate potential sources of bacteria.
- Focus stormwater source control program implementation in areas with bacteria generating land uses and businesses. This includes implementation of bacteria source control BMPs for pet and goose waste in parks and recreation areas, and nutrient source control BMPs at golf courses in the watershed.
- Prioritize construction stormwater inspections to areas with pH exceedances.
- Establish a partnership between the City of Vancouver, Clark County, and the Washington Department of Transportation to work collaboratively across jurisdictions to maximize stormwater outcomes in Burnt Bridge Creek.

- Implement stormwater education programs that generate public awareness, inspire stewardship, and affect behavior change to improve water quality. Utilize community based social marketing practices to identify and target priority populations for stormwater education with culturally specific and appropriate messaging. Stormwater education should focus on best practices for pet waste disposal, fertilizer application, source control, and what landowners can do to protect water quality. Utilize Clark County's Canines for Clean water program and the Stormwater Partners for Southwest Washington group for stormwater education.

Septic Systems and Wastewater

- Increase outreach to homeowners with public sewer availability who are eligible for the Sewer Connection Incentive Program (SCIP) to encourage and facilitate septic system owners to connect to the public wastewater system.
- Prioritize Sewer Collection Capital Improvement Projects to critical sewerage areas where the most septic system owners can benefit from municipal sewer services.
- Increase septic system inspections and maintenance in the Burnt Bridge Creek watershed. Prioritize outreach, investigation, and enforcement to areas with known bacteria problems and the highest density of septic systems that are past due for inspection. Septic system outreach and implementation should initially be targeted to the middle watershed, which has 2,000 septic systems, as well as Burnt Bridge Creek tributaries, which have documented dry season bacteria issues. Clark County Public Health should work in partnership with the City of Vancouver to identify priority areas to improve water quality.
- Support the development and implementation of a new septic system rebate, discount, or coupon program to provide financial assistance for septic system inspections, tank pumping, and maintenance.
- Utilize pollution, identification, and correction methods to support long-term identification and correction of septic systems contributing to bacteria pollution.
- Host more Septic System Inspection and Maintenance workshops, to increase homeowner's knowledge of septic system maintenance and inspection needs.
- Support Clark County's participation in the Craft3 Regional Loan Program, which provides financial assistance for septic system repair and replacement.
- Implement BMPs to reduce FC loading from nonpoint sources, particularly in the tributaries of Burnt Bridge Creek. Provide technical and financial assistance to landowners with waterfront property to implement BMPs.
- Proactively investigate and identify properties with nonpoint source water quality concerns in the Burnt Bridge Creek watershed.
- Complete watershed evaluation, windshield surveys, and desktop analysis to identify properties with nonpoint source water quality issues that would benefit from a site visit, technical assistance, conservation planning, or BMP implementation. Refer agricultural

landowners to Ecology, Clark Conservation District, Washington State University Extension, or local code enforcement to address bacteria pollution.

- Develop and implement new urban agriculture programs to educate and assist landowners with urban agricultural challenges.
- Implement appropriate livestock BMPs on properties in the Burnt Bridge Creek with NPS water quality concerns. These include off-stream watering, livestock feeding, waste management BMPs, livestock exclusion fencing, and riparian restoration and planting. Reference the Voluntary Clean Water Guidance for Agriculture for guidance on BMPs.

Riparian Restoration

- Achieve system potential riparian vegetation of 85% tree canopy in the Burnt Bridge Creek watershed wherever possible.
- Implement riparian forest restoration on all priority planting areas in the Burnt Bridge Creek watershed where the soils and hydrology support forested conditions.
- Prioritize the river miles with the highest shade deficits for riparian restoration.
- In the upper watershed, efforts to plant vegetation should be pursued to reduce stream temperatures. Partnerships and outreach to private landowners will be necessary to encourage and establish plantings that provide shade and lower water temperatures in this reach.
- In the middle watershed, riparian restoration efforts should be targeted from RM 7 to RM 8 (including BBC07.0) due to this section having the largest shade deficit (83%).
- In the lower watershed, the average shade deficit is 25%. However, between RM 0–2 (includes BBC00.0 and BBC01.6) there is a large, open area with little vegetation. This section of the riparian corridor has been identified as a priority planting area by the City of Vancouver.
- Continue to increase restoration activities and vegetation plantings in riparian areas to increase shade. Focus these restoration activities in areas with large shade deficits in the upper and middle watershed, as determined through the shade analysis.
- Continue implementation of restoration and conservation programs led by the City of Vancouver and Clark County; partner with other local stakeholders to improve water quality in the watershed. These include programs implemented by the Watershed Alliance of Southwest Washington, Clark Conservation District, Columbia Springs, Lower Columbia Estuary Partnership, Washington State University Extension, Lower Columbia Fish Enhancement Group, Lower Columbia Fish Recovery Board, Friends of Trees, and the Vancouver Water Resources Education Center.
- Protect and restore natural flood plains, riparian habitats, and microclimate enhancements that increase the number of cold-water refuges available and improve the overall habitat quality for salmonids and other fish species.
- Implement creek restoration projects that enhance channel complexity.

Groundwater and Streamflow

- Complete additional studies to identify priority areas for streamflow restoration activities to promote infiltration and groundwater recharge in the Burnt Bridge Creek watershed.
- Complete a more comprehensive groundwater modeling study in the Burnt Bridge Creek watershed to understand groundwater/surface water exchange and how stormwater, municipal water supply, and the SEH America discharge is impacting Peterson Channel and Burnt Bridge Creek.
- In relation to SEH America, Ecology recommends conducting a separate field and modeling study to characterize the response of the system to SEH America discharges. The study should include the following:
- Developing QAPP for study design and review by permitting authority.
- Flow and temperature measurements at all discharge points and at downstream locations in Burnt Bridge Creek and Peterson Channel.
- Collecting sufficient data for model calibration and validation.
- Operational measurements that accurately reflect levels of SEH America operation and data concurrent to the field measurements.
- Discharges to surface water need to be brought into compliance with state temperature standards.

Public Education and Outreach

- Provide public outreach and education activities throughout the local watershed community about the effects of nonpoint pollution to water quality and human health. This includes nonpoint pollution from pet waste and recreational activities at parks and greenways on the waterfront of Burnt Bridge Creek and its tributaries.
- Increase outreach to private landowners to encourage voluntary implementation of water quality BMPs on streamside properties. These outreach efforts should be targeted towards the following audiences:
- Agricultural landowners with properties adjacent to Burnt Bridge Creek and its tributaries. Agricultural landowners in areas where there are known bacteria issues are a priority for outreach.
- Homeowners with septic systems that are past due for inspection and maintenance on properties adjacent to Burnt Bridge Creek and its tributaries. Septic system owners in areas where there are known bacteria issues are a priority for outreach, as well as, homeowners that are eligible for Vancouver’s Sewer Connection Incentive Program (SCIP) .
- Public and private landowners with riparian properties adjacent to the highest shade deficits on the Burnt Bridge Creek mainstem and tributaries. Outreach to these landowners to promote tree planting and riparian restoration is a priority.

- Homeowners Associations (HOAs) with private stormwater facilities and residential landowners with impervious surfaces on their properties that would help improve water quality by implementing pollution prevention and source control activities.

The City of Vancouver and other local watershed partners are currently implementing many of these recommendations. Ecology recommends continuing these implementation and restoration activities.

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Glossary, Acronyms, and Abbreviations

Glossary

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

Critical conditions: When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

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

Diel: Of, or pertaining to, a 24-hour period.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10- to 10,000-fold over a given period. The calculation is performed by either: (1) taking the n^{th} root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

Hyporheic: The area beneath and adjacent to a stream where surface water and groundwater intermix.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

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

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

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

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

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

Reach: A specific portion or segment of a stream.

Riparian: Relating to the banks along a natural course of water.

Salmonid: Fish that belong to the family *Salmonidae*. Species of salmon, trout, or char.

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

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

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

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

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

7-DADMax or 7-day average of the daily maximum temperatures: The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date.

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every 10 years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

BMP	best management practice
City	City of Vancouver
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
FC	fecal coliform bacteria
GIS	Geographic Information System software
GP	general permit
LCEP	Lower Columbia Estuary Partnership
MEL	Manchester Environmental Laboratory
MQO	measurement quality objective

MS4	municipal separate stormwater system
NPDES	National Pollutant Discharge Elimination System (see glossary)
QAPP	quality assurance project plan
RM	river mile
RPD	relative percent difference
RSD	relative standard deviation
SEH	SEH America Inc.
SOP	standard operating procedures
SW	stormwater
TMDL	Total Maximum Daily Load (see glossary)
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

Units of Measurement

b.cfu/day	billion colony forming units per day
°C	degrees centigrade
cfs	cubic feet per second
cfu	colony forming units
ft	feet
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
s.u.	standard units

Appendices

Appendix A. Site Summary

Table A-1. Summary of site descriptions.

Site	Group	Description
BBC11.4	Upper	Burnt Bridge Ck at 131st Ave
BBC10.8	Upper	Burnt Bridge Ck at NE 121st Ave
BBC10.4	Upper	Burnt Bridge Ck at NE 110th Ave
BBC09.5	Upper	Beaver Marsh Open Space Park; Burnt Bridge Creek located on the northern end of NE 98th Avenue upstream of the golf course, approximately 40 feet upstream of trail bridge over creek. Associated air sampling: stake on water side of top of bank, almost in water, roughly 4 feet from path in reed canary grass, approximately 10 feet downstream of spiraea.
BBC08.8	Middle	Burnt Bridge Ck above Peterson Ditch at NE 93rd Ave
BBC08.4	Middle	Burnt Bridge Creek located at NE Burton Road just west of NE 90th Avenue
BBC08.0	Middle	Burnt Bridge Creek located near eastern end of 41st Circle; north side of dead end where multi-use path begins. Monitoring point is about 10 feet down dirt path.
BBC07.0	Middle	Burnt Bridge Creek located at the southern end of NE 65th Avenue
BBC05.9	Middle	Burnt Bridge Creek located at E. 18th Street east of Bryant Street
BBC05.2	Middle	Burnt Bridge Ck at Rossiter Ln, Rossiter Street Apartments
BBC04.3	Middle	Burnt Bridge Ck upstream of Saint Johns Blvd
BBC03.4	Lower	Approximately 100 feet upstream of 86th/87th Avenue bridge over Burnt Bridge Creek. Path to loggers next to hawthorn, oxeye daisy along trail.
BBC02.6	Lower	Burnt Bridge Creek located in Leverich Park near lower parking lot
BBC01.6	Lower	Burnt Bridge Ck at 2nd Ave near Alki Rd
BBC00.0	Lower	Burnt Bridge Ck downstream of Fruit Valley Rd
PET01.3	Tributary (Middle)	SEH outfall 001 to Peterson Ditch at 102nd Ave.
PET00.0	Tributary (Middle)	Peterson Channel located at the northern end of NE 93rd Avenue
COL00.0	Tributary (Lower)	Cold Creek at Hazel Dell Ave at Burnt Bridge Creek RM 1.6
BUR00.0	Tributary (Middle)	Burton Channel located at NE 92nd Avenue and 19th Circle
SD18031	Stormdrain	Storm drain to Burnt Bridge Creek on the downstream side of 121st Ave (near BBC11.4)
SD18027	Stormdrain	Storm drain to Burnt Bridge Creek on the downstream side of 121st Ave (near BBC11.4)
SD17959	Stormdrain	Storm drain ditch to Burnt Bridge Creek at NE 51st Circle (below BBC10.4)
SD06233	Stormdrain	Storm drain to Burnt Bridge Creek on the downstream side of E 18th Street (near BBC05.9)
SD06235	Stormdrain	Storm drain to Burnt Bridge Creek on the downstream side of E 18th Street (near BBC05.9)

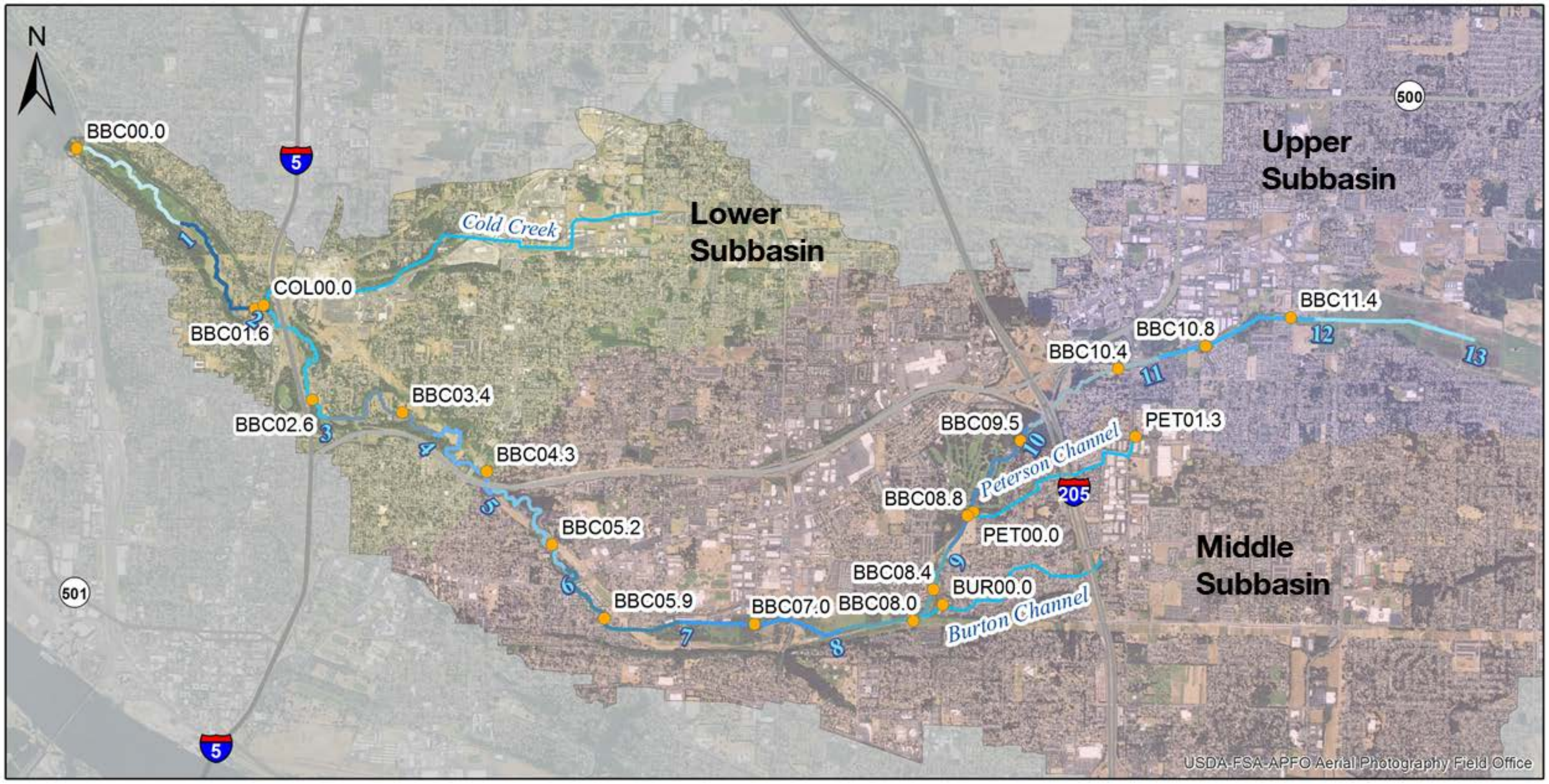

Figure A-1. Map of Burnt Bridge Creek study area with sites, subbasins, and river mile segments.

Appendix B. Bacteria Results

Table B-1. FC results for upper subbasin sites.

Date	Season	BBC09.5	BBC10.4	BBC10.8	BBC11.4
6/3/2008	Wet	1900*	1400*	1500*	3200*
6/17/2008	Dry	46	92	85	120
6/30/2008	Dry	92	160	110	190
7/15/2008	Dry	81	100	96	80*
7/29/2008	Dry	37	40	93	46
8/12/2008	Dry	100	220	47	22
8/26/2008	Dry	71	150*	63*	69*
9/9/2008	Dry	41	40	31*	29*
9/23/2008	Dry	51	69	28	57
10/6/2008	Wet	88*	190*	41	26
10/20/2008	Wet	430	280	20	35
11/3/2008	Wet	210	120	20*	47
11/17/2008	Wet	15	14	5*	11
12/1/2008	Wet	7	10	6	3
12/15/2008	Wet	8	29	7*	7
12/28/2008	Wet	680	560	200*	400
1/12/2009	Wet	20	23	9	6
1/26/2009	Wet	3	11*	8*	4*
2/9/2009	Wet	41	7*	6*	43*
2/23/2009	Wet	100	230	9	11*
3/10/2009	Wet	10	7*	3*	1*
3/23/2009	Wet	5	17	12	8
4/6/2009	Wet	17	27	34	31*
4/20/2009	Wet	10	43	260*	7
5/4/2009	Wet	34	31	77	150
5/18/2009	Wet	15	39	65	64
6/1/2009	Dry	87	150	96	170
6/15/2009	Dry	51	440	130	57
6/28/2009	Dry	76	100	84	36
7/13/2009	Dry	230	280	82	110
7/27/2009	Dry	80	330	31	33*
8/10/2009	Dry	140	100	27	110*
8/24/2009	Dry	80	150	59	36

*Analyte was positively identified. The reported result is an estimate.

Table B-2. FC results for middle subbasin sites.

Date	Season	BBC05.2	BBC05.9	BBC07.0	BBC08.0	BBC08.4	BBC08.8
6/3/2008	Wet	--	1800*	--	2600*	3000*	3200*
6/4/2008	Wet	870	--	2300	--	--	--
6/17/2008	Dry	300	850	--	110	25	38
6/30/2008	Dry	--	--	120	74	96	65
7/1/2008	Dry	92*	92*	--	--	--	--
7/15/2008	Dry	--	--	63	67	140	35
7/16/2008	Dry	210*	96*	--	--	--	--
7/29/2008	Dry	65	66	120	61	85	44
8/12/2008	Dry	--	--	--	77	100	75
8/13/2008	Dry	84*	79*	160*	--	--	--
8/26/2008	Dry	--	180	49	96	100	110
8/27/2008	Dry	200*	--	--	--	--	--
9/9/2008	Dry	--	--	7	160	120	40
9/10/2008	Dry	140*	100*	--	--	--	--
9/23/2008	Dry	200	66	15	23	180	37
10/6/2008	Wet	--	--	44*	79	100	63*
10/7/2008	Wet	77	46*	--	--	--	--
10/20/2008	Wet	--	--	--	790*	300*	180*
10/21/2008	Wet	56	46	96*	--	--	--
11/3/2008	Wet	--	--	--	69	110	140
11/4/2008	Wet	520	620*	400*	--	--	--
11/17/2008	Wet	--	--	--	62	110	26
11/18/2008	Wet	100	21*	5*	--	--	--
12/1/2008	Wet	--	--	--	16	110	21
12/2/2008	Wet	350*	160*	290*	--	--	--
12/15/2008	Wet	--	--	--	47	15	13
12/16/2008	Wet	26*	13*	17*	--	--	--
12/28/2008	Wet	--	--	--	350	300	570
12/29/2008	Wet	600	100	260*	--	--	--
1/12/2009	Wet	--	--	--	37	34	17
1/13/2009	Wet	31*	47*	6*	--	--	--
1/26/2009	Wet	--	9*	--	20	34	8
1/27/2009	Wet	21*	--	15*	--	--	--
2/9/2009	Wet	--	--	--	37	25*	21
2/10/2009	Wet	240*	10	15	--	--	--
2/23/2009	Wet	--	--	--	77	150	6
2/24/2009	Wet	360	490	290*	--	--	--
3/10/2009	Wet	--	9	9	27	29	7*
3/11/2009	Wet	250	--	--	--	--	--
3/23/2009	Wet	--	--	--	--	--	11

Date	Season	BBC05.2	BBC05.9	BBC07.0	BBC08.0	BBC08.4	BBC08.8
3/24/2009	Wet	87	66	84	95*	110*	--
4/6/2009	Wet	--	--	--	--	21	4
4/7/2009	Wet	26	25	81	88	--	--
4/20/2009	Wet	--	--	--	--	37	17
4/21/2009	Wet	11	22	61	200*	--	--
5/4/2009	Wet	--	--	--	--	200	43
5/5/2009	Wet	580	890	1200	1400*	--	--
5/18/2009	Wet	--	--	--	150	120	41
5/19/2009	Wet	430	730	1700*	--	--	--
6/1/2009	Dry	--	--	--	1800*	4700*	89
6/2/2009	Dry	84	37	350*	--	--	--
6/15/2009	Dry	--	--	--	--	660	110
6/16/2009	Dry	180*	300	130*	550*	--	--
6/28/2009	Dry	--	--	--	220	340	160
6/29/2009	Dry	120	100	100	--	--	--
7/13/2009	Dry	--	--	--	480	830	100
7/14/2009	Dry	88	91	130	--	--	--
7/27/2009	Dry	--	--	--	300	230	96
7/28/2009	Dry	120	84	280	--	--	--
8/10/2009	Dry	--	--	--	200	310	240
8/11/2009	Dry	37	60	160	--	--	--
8/24/2009	Dry	--	--	--	--	--	100
8/25/2009	Dry	540	110	360	250	250	--

*Analyte was positively identified. The reported result is an estimate.

Table B-3. FC results for lower subbasin sites.

Date	Season	BBC00.0	BBC01.6	BBC02.6	BBC03.4	BBC04.3
6/4/2008	Wet	--	670	1000	830	1100
6/18/2008	Dry	--	130	280	75	130*
7/1/2008	Dry	9	140	120	110	130
7/16/2008	Dry	65	420	230	110	120
7/29/2008	Dry	17	140*	330	100*	110
8/13/2008	Dry	13	140	170	88	100*
8/27/2008	Dry	180	160	220	140*	190*
9/10/2008	Dry	37	260	280	270	270
9/23/2008	Dry	29	260	180	150	200
10/7/2008	Wet	36	270	120	170	150
10/21/2008	Wet	18*	120	110	92	170
11/4/2008	Wet	240	330	310	340	480
11/18/2008	Wet	10	34	18	29	40
12/2/2008	Wet	33	440	500*	480	600*
12/16/2008	Wet	22*	63	49	80*	43*
12/29/2008	Wet	230*	12000*	12000*	6700*	1400
1/13/2009	Wet	23	8	16	96	24
1/27/2009	Wet	43	36	33	43	54*
2/10/2009	Wet	31	40	51*	48	53
2/24/2009	Wet	150	310	440	560	330
3/11/2009	Wet	25*	32*	29	14	7
3/24/2009	Wet	75	60	64	51	88
4/7/2009	Wet	5	10	4*	4	16
4/21/2009	Wet	29	44	35	37	28
5/5/2009	Wet	360	740	760	570	660
5/19/2009	Wet	550	450	390	280	430
6/2/2009	Dry	--	280	280	210	250
6/16/2009	Dry	15	230	140	150	180
6/29/2009	Dry	1	140	88	110	71
7/14/2009	Dry	59	220	180	150	440
7/28/2009	Dry	11*	300	290	120	160*
8/11/2009	Dry	11	340	550	120	92
8/25/2009	Dry	22	300	800	390	360

*Analyte was positively identified. The reported result is an estimate.

Table B-4. FC results for tributary sites.

Date	Season	BUR00.0	COL00.0	PET00.0	PET01.3
6/3/2008	Wet	3900*	--	4200*	880*
6/4/2008	Wet	--	380	--	--
6/17/2008	Dry	230	--	130	8**
6/18/2008	Dry	--	85	--	--
6/30/2008	Dry	140	--	69	5
7/1/2008	Dry	--	180	--	--
7/15/2008	Dry	130	--	220	18
7/16/2008	Dry	--	510	--	--
7/29/2008	Dry	170	470	220	27
8/12/2008	Dry	200	--	320	1**
8/13/2008	Dry	--	420	--	--
8/26/2008	Dry	990	--	270	11
8/27/2008	Dry	--	300	--	--
9/9/2008	Dry	160	--	250	13
9/10/2008	Dry	--	260	--	--
9/23/2008	Dry	200	260	550	3
10/6/2008	Wet	290	--	370	16
10/7/2008	Wet	--	220	--	--
10/20/2008	Wet	6300*	--	1100	3
10/21/2008	Wet	--	160	--	--
11/3/2008	Wet	130	--	280	19
11/4/2008	Wet	--	340	--	--
11/17/2008	Wet	100	--	250	280*
11/18/2008	Wet	--	100	--	--
12/1/2008	Wet	430	--	700	3**
12/2/2008	Wet	--	180	--	--
12/15/2008	Wet	57	--	63	1
12/16/2008	Wet	--	37	--	--
12/28/2008	Wet	330	--	85	--
12/29/2008	Wet	--	350*	--	29*
1/12/2009	Wet	23	--	120	1
1/13/2009	Wet	--	27	--	--
1/26/2009	Wet	27	--	80	3
1/27/2009	Wet	--	110	--	--
2/9/2009	Wet	150	--	67	1
2/10/2009	Wet	--	260	--	--
2/23/2009	Wet	160	--	300	8
2/24/2009	Wet	--	220	--	--
3/10/2009	Wet	24*	--	96	1**
3/11/2009	Wet	--	33	--	--

Date	Season	BUR00.0	COL00.0	PET00.0	PET01.3
3/23/2009	Wet	470	--	160	1**
3/24/2009	Wet	--	88	--	--
4/6/2009	Wet	23	--	80	1**
4/7/2009	Wet	--	180	--	--
4/20/2009	Wet	34	--	100	1**
4/21/2009	Wet	--	69	--	--
5/4/2009	Wet	5800*	--	570*	12
5/5/2009	Wet	--	380	--	--
5/18/2009	Wet	92	--	230	4
5/19/2009	Wet	--	570	--	--
6/1/2009	Dry	300	--	400	6
6/2/2009	Dry	--	1500*	--	--
6/15/2009	Dry	190	--	370	6*
6/16/2009	Dry	--	1300	--	--
6/28/2009	Dry	700	--	330	--
6/29/2009	Dry	--	600	--	2
7/13/2009	Dry	1400	--	2400	220*
7/14/2009	Dry	--	720	--	--
7/27/2009	Dry	180	--	270*	--
7/28/2009	Dry	--	670	--	--
8/10/2009	Dry	85	--	320	9
8/11/2009	Dry	--	970	--	--
8/24/2009	Dry	--	--	440	10*
8/25/2009	Dry	430*	1100	--	--

*Analyte was positively identified. The reported result is an estimate.

Table B-5. 10/14/09 storm event FC data.

Site	Time	FC (cfu/100mL)	Data Qualifier
BBC00.0	8:00:00	360	J
BBC00.0	14:38:00	80	--
BBC01.6	9:45:00	1600	--
BBC01.6	15:23:00	1100	--
BBC10.4	9:30:00	340	--
BBC10.4	15:17:00	330	--
BBC10.8	8:58:00	54	J
BBC10.8	15:00:00	100	--
BBC11.4	7:56:00	60	J
BBC11.4	14:36:00	180	--
BBC02.6	10:16:00	1700	--
BBC02.6	15:41:00	1200	--
BBC03.4	10:40:00	4400	--
BBC03.4	15:59:00	1000	--
BBC04.3	11:11:00	1500	J
BBC04.3	16:19:00	480	--
BBC05.2	11:37:00	560	--
BBC05.2	16:40:00	470	--
BBC05.9	12:11:00	130	--
BBC05.9	16:59:00	410	--
BBC07.0	13:07:00	200	J
BBC07.0	17:12:00	240	--
BBC08.0	13:02:00	250	--
BBC08.0	17:17:00	220	--
BBC08.4	12:46:00	390	--
BBC08.4	17:00:00	300	--
BBC08.8	11:52:00	240	--
BBC08.8	16:25:00	180	--
BBC09.5	11:00:00	230	--
BBC09.5	15:46:00	330	J
BUR00.0	12:25:00	2900	J
BUR00.0	16:50:00	1700	--
COL00.0	9:12:00	3200	--
COL00.0	15:12:00	1300	--
PET00.0	11:44:00	700	--
PET00.0	16:20:00	1800	--
PET01.3	10:23:00	130	--
PET01.3	14:17:00	43	--
SD06235	12:46:00	4900	J
SD06233	12:30:00	31000	J

Site	Time	FC (cfu/100mL)	Data Qualifier
SD17959	9:50:00	85	--
SD17959	15:27:00	480	--
SD18027	8:30:00	510	J
SD18027	14:52:00	1200	--
SD18031	8:37:00	230	J
SD18031	14:51:00	100	--

J= Analyte was positively identified. The reported result is an estimate.

Appendix C. Data Quality Assessment

Table C-1. Hydrolab post-calibration checks for dissolved oxygen.

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value	Hydrolab post-check value (before calibration)	Difference	Conclusion
6/17&18/08	6/19/08	15	100%	no data	--	reject
6/30&7/01/08	6/30/08	17	100%	100.5%	0.5%	accept
7/15&16/08	7/17/08	18	100%	97.1%	-2.9%	accept
7/28 - 8/1/08	8/2/08	16	100%	100.1%	0.1%	accept
7/28 - 8/1/08	8/2/08	21	100%	100.0%	0.0%	accept
7/28 - 8/1/08	8/2/08	33	100%	100.0%	0.0%	accept
7/28 - 8/1/08	8/2/08	26	100%	100.8%	0.8%	accept
7/28 - 8/1/08	8/2/08	5	100%	no data	--	reject
7/28 - 8/1/08	8/2/08	4	100%	no data	--	reject
7/28 - 8/1/08	8/2/08	25	100%	98.6%	-1.4%	accept
7/28 - 8/1/08	8/2/08	23	100%	103.1%	3.1%	accept
7/28 - 8/1/08	8/2/08	17	100%	100.2%	0.2%	accept
7/28 - 8/1/08	8/2/08	18	100%	100.0%	0.0%	accept
8/12&8/13/08	8/14/08	18	100%	99.9%	-0.1%	accept
8/26&27/08	8/28/08	18	100%	100.6%	0.6%	accept
9/09&10/08	9/10/08	23	100%	100.7%	0.7%	accept
9/22 - 26/08	9/26/08	27	100%	97.1%	-2.9%	accept
9/22 - 26/08	9/26/08	17	100%	104.4%	4.4%	accept
9/22 - 26/08	9/26/08	18	100%	102.0%	2.0%	accept
9/22 - 26/08	9/26/08	23	100%	102.6%	2.6%	accept
9/22 - 26/08	9/26/08	25	100%	98.3%	-1.7%	accept
9/22 - 26/08	9/26/08	26	100%	107.3%	7.3%	estimate
9/22 - 26/08	9/26/08	33	100%	failed	--	reject
9/22 - 26/08	9/26/08	16	100%	100.0%	0.0%	accept
10/6&7/08	10/8/08	25	100%	101.8%	1.8%	accept
10/20&21/08	10/22/08	25	100%	97.3%	-2.7%	accept
11/3&4/08	11/5/08	25	100%	102.6%	2.6%	accept
11/17&18/08	11/20/08	25	100%	97.5%	-2.5%	accept
12/01&02/08	12/4/08	25	100%	101.7%	1.7%	accept
12/15&16/08	12/18/08	25	100%	101.2%	1.2%	accept
12/28&29/08	12/30/08	25	100%	103.3%	3.3%	accept
1/12&13/09	1/14/09	25	100%	95.8%	-4.2%	accept
1/26&27/09	1/29/09	25	100%	100.1%	0.1%	accept
2/9&10/09	2/11/09	25	100%	101.4%	1.4%	accept
2/23&24/09	2/26/09	25	100%	96.4%	-3.6%	accept

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value	Hydrolab post-check value (before calibration)	Difference	Conclusion
3/10&11/09	3/12/09	25	100%	130.0%	30.0%	reject
3/23&24/09	3/26/09	18	100%	102.1%	2.1%	accept
4/6&7/09	4/8/09	25	100%	95.0%	-5.0%	estimate
4/20&21/09	4/24/09	25	100%	100.5%	0.5%	accept
5/4&5/09	5/6/09	25	100%	100.1%	0.1%	accept
5/18&19/09	5/21/09	25	100%	101.9%	1.9%	accept
6/1&2/09	6/3/09	25	100%	99.4%	-0.6%	accept
6/15&16/09	6/18/09	25	100%	103.7%	3.7%	accept
6/28&29/09	7/1/09	25	100%	97.8%	-2.2%	accept
7/13&14/09	7/15/09	25	100%	100%	0%	accept
7/27&28/09	7/30/09	21	100%	105%	5%	accept
8/10&11/09	8/13/09	25	100%	104%	4%	accept
8/24&25/09	8/26/09	21	100%	98%	-2%	accept
10/14/09	10/15/09	25	100%	103%	3%	accept
10/14/09	10/15/09	26	100%	105%	5%	estimate

Table C-2. Hydrolab post-calibration checks for pH (Reference Standard = 7 s.u).

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value (ph 7 s.u.)	Hydrolab post-check value (before calibration)	Difference	Conclusion
6/30&7/01/08	7/30/08	17	6.97	6.85	-0.12	accept
7/15&16/08	7/17/08	18	6.98	7.04	0.06	accept
7/28 - 8/1/08	8/2/08	16	6.97	6.97	0.00	accept
7/28 - 8/1/08	8/2/08	21	6.97	6.97	0.00	accept
7/28 - 8/1/08	8/2/08	33	7.00	7.00	0.00	accept
7/28 - 8/1/08	8/2/08	26	7.00	7.00	0.00	accept
7/28 - 8/1/08	8/2/08	5	7.00	7.00	0.00	estimate
7/28 - 8/1/08	8/2/08	4	failed	--	--	reject
7/28 - 8/1/08	8/2/08	25	7.00	7.00	0.00	accept
7/28 - 8/1/08	8/2/08	23	6.97	6.97	0.00	accept
7/28 - 8/1/08	8/2/08	17	6.97	6.97	0.00	accept
7/28 - 8/1/08	8/2/08	18	6.97	6.97	0.00	accept
8/12&8/13/08	8/14/08	18	6.97	6.96	-0.01	accept
8/26&27/08	8/28/08	18	6.97	7.03	0.06	accept
9/09&10/08	9/10/08	23	6.97	7.02	0.05	accept
9/22 - 26/08	9/26/08	27	6.97	6.99	0.02	accept
9/22 - 26/08	9/26/08	17	6.97	6.97	0.00	accept
9/22 - 26/08	9/26/08	18	6.97	6.95	-0.02	accept
9/22 - 26/08	9/26/08	23	6.97	7.03	0.06	accept
9/22 - 26/08	9/26/08	25	6.97	7.04	0.07	accept
9/22 - 26/08	9/26/08	26	6.97	6.95	-0.02	accept
9/22 - 26/08	9/26/08	33	6.97	6.93	-0.04	accept
9/22 - 26/08	9/26/08	16	6.97	7.04	0.07	accept
10/6&7/08	10/8/08	25	7.01	7.05	0.04	accept
10/20&21/08	10/22/08	25	7.01	6.98	-0.03	accept
11/3&4/08	11/5/08	25	6.98	6.99	0.01	accept
11/17&18/08	11/20/08	25	7.06	7.04	-0.02	accept
12/01&02/08	12/4/08	25	7.04	7.05	0.01	accept
12/15&16/08	12/18/08	25	7.06	7.04	-0.02	accept
12/28&29/08	12/30/08	25	7.06	7.01	-0.05	accept
1/12&13/09	1/14/09	25	7.06	7.02	-0.04	accept
1/26&27/09	1/29/09	25	7.06	7.05	-0.01	accept
2/9&10/09	2/11/09	25	6.98	6.94	-0.04	accept
2/23&24/09	2/26/09	25	6.97	7.02	0.05	accept
3/10&11/09	3/12/09	25	6.97	7.00	0.03	accept
3/23&24/09	3/26/09	18	6.97	6.99	0.02	accept
4/6&7/09	4/8/09	25	6.98	6.97	-0.01	accept
4/20&21/09	4/24/09	25	6.98	7.00	0.02	accept

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value (ph 7 s.u.)	Hydrolab post-check value (before calibration)	Difference	Conclusion
5/4&5/09	5/6/09	25	6.98	6.95	-0.03	accept
5/18&19/09	5/21/09	25	6.98	6.95	-0.03	accept
6/1&2/09	6/3/09	25	6.97	7.25	0.28	estimate
6/15&16/09	6/18/09	25	6.98	7.29	0.31	estimate
6/28&29/09	7/1/09	25	6.98	7.03	0.05	accept
7/13&14/09	7/15/09	25	6.97	7.07	0.10	accept
7/27&28/09	7/30/09	21	6.97	6.47	-0.50	estimate
8/10&11/09	8/13/09	25	6.97	7.04	0.07	accept
8/24&25/09	8/26/09	21	6.97	6.39	-0.58	reject
10/14/09	10/15/09	25	7.02	7.08	0.06	accept
10/14/09	10/15/09	26	7.02	6.91	-0.11	accept

Table C-3. Hydrolab post-calibration checks for pH (Reference Standard = 10 s.u).

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value (pH 10 s.u.)	Hydrolab post-check value (before calibration)	Difference	Conclusion
6/30&7/01/08	7/30/08	17	9.15	8.83	-0.32	estimate
7/15&16/08	7/17/08	18	9.15	9.13	-0.02	accept
7/28 - 8/1/08	8/2/08	16	9.15	9.15	0.00	accept
7/28 - 8/1/08	8/2/08	21	9.15	9.15	0.00	accept
7/28 - 8/1/08	8/2/08	33	10.01	10.01	0.00	accept
7/28 - 8/1/08	8/2/08	26	10.01	10.01	0.00	accept
7/28 - 8/1/08	8/2/08	4	failed	--	0.00	reject
7/28 - 8/1/08	8/2/08	25	10.01	10.01	0.00	accept
7/28 - 8/1/08	8/2/08	23	9.15	9.15	0.00	accept
7/28 - 8/1/08	8/2/08	17	failed	--	--	reject
7/28 - 8/1/08	8/2/08	18	9.15	9.15	0.00	accept
8/12&8/13/08	8/14/08	18	9.17	9.11	-0.06	accept
8/26&27/08	8/28/08	18	9.18	9.18	0.00	accept
9/09&10/08	9/10/08	23	9.17	9.05	-0.12	accept
9/22 - 26/08	9/26/08	27	9.18	9.08	-0.10	accept
9/22 - 26/08	9/26/08	17	9.18	8.99	-0.19	accept
9/22 - 26/08	9/26/08	18	9.18	9.18	0.00	accept
9/22 - 26/08	9/26/08	23	9.18	9.09	-0.09	accept
9/22 - 26/08	9/26/08	25	9.18	9.06	-0.12	accept
9/22 - 26/08	9/26/08	26	9.18	9.12	-0.06	accept
9/22 - 26/08	9/26/08	33	9.18	9.52	0.34	estimate

Field Use Date/s	Post-Check Date	Sonde #	Reference standard value (pH 10 s.u.)	Hydrolab post-check value (before calibration)	Difference	Conclusion
9/22 - 26/08	9/26/08	16	9.18	9.17	-0.01	accept
10/6&7/08	10/8/08	25	10.04	10.07	0.03	accept
10/20&21/08	10/22/08	25	10.05	10.11	0.06	accept
11/3&4/08	11/5/08	25	9.18	8.97	-0.21	accept
11/17&18/08	11/20/08	25	10.05	10.02	-0.03	accept
12/01&02/08	12/4/08	25	10.40	10.30	-0.10	accept
12/15&16/08	12/18/08	25	10.40	10.06	-0.34	accept
12/28&29/08	12/30/08	25	10.04	10.06	0.02	accept
1/12&13/09	1/14/09	25	10.05	9.97	-0.08	accept
1/26&27/09	1/29/09	25	10.04	10.04	0.00	accept
2/9&10/09	2/11/09	25	10.04	10.16	0.12	accept
2/23&24/09	2/26/09	25	10.04	10.07	0.03	accept
3/10&11/09	3/12/09	25	10.04	10.04	0.00	accept
3/23&24/09	3/26/09	18	9.18	9.33	0.15	accept
4/6&7/09	4/8/09	25	10.05	10.05	0.00	accept
4/20&21/09	4/24/09	25	9.18	9.12	-0.06	accept
5/4&5/09	5/6/09	25	9.18	9.09	-0.09	accept
5/18&19/09	5/21/09	25	9.18	9.09	-0.09	accept
6/1&2/09	6/3/09	25	9.16	9.18	0.02	accept
6/15&16/09	6/18/09	25	9.18	9.10	-0.08	accept
6/28&29/09	7/1/09	25	10.05	10.06	0.01	accept
7/13&14/09	7/15/09	25	10.04	10.05	0.01	accept
7/27&28/09	7/30/09	21	9.15	9.17	0.02	accept
8/10&11/09	8/13/09	25	9.15	9.15	0.00	accept
8/24&25/09	8/26/09	21	9.15	9.28	0.13	estimate
10/14/09	10/15/09	25	10.05	10.07	0.02	accept
10/14/09	10/15/09	26	10.05	10.06	0.01	accept

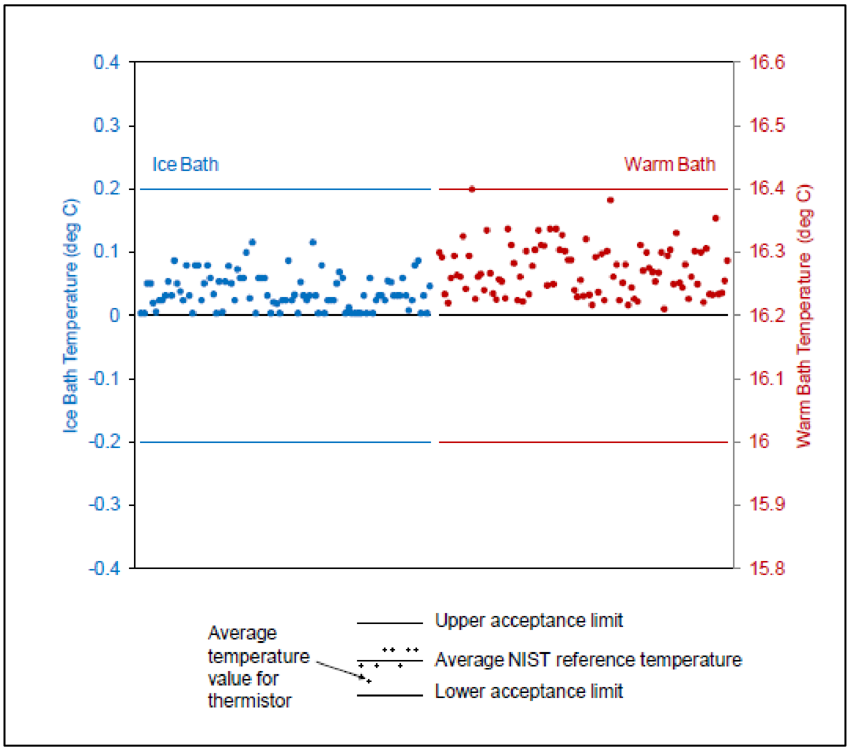

Figure C-1. Post-deployment thermistor calibration check graph (Kardouni and Sinclair, 2012). Thermistor accuracy within ± 2.0°C.

Appendix D. Statistical Rollback Results

The following pages show graphical results from the statistical rollback analysis. Each graph includes:

- Current conditions represented by data points, 90th percentile, and geometric mean (orange).
- Target values for the 90th percentile and target geometric mean (blue).
- Greatest target percent reduction needed to meet water quality criteria (green).
- If the data follows a lognormal distribution and if it passes the Shapiro-Wilk Test (cannot reject H0 or p value). While some sites do not follow a lognormal distribution, percent FC reductions are still included in this report in order to help guide implementation activities and improve water quality.
- Sites that do not require a FC reduction meet both water quality criteria.

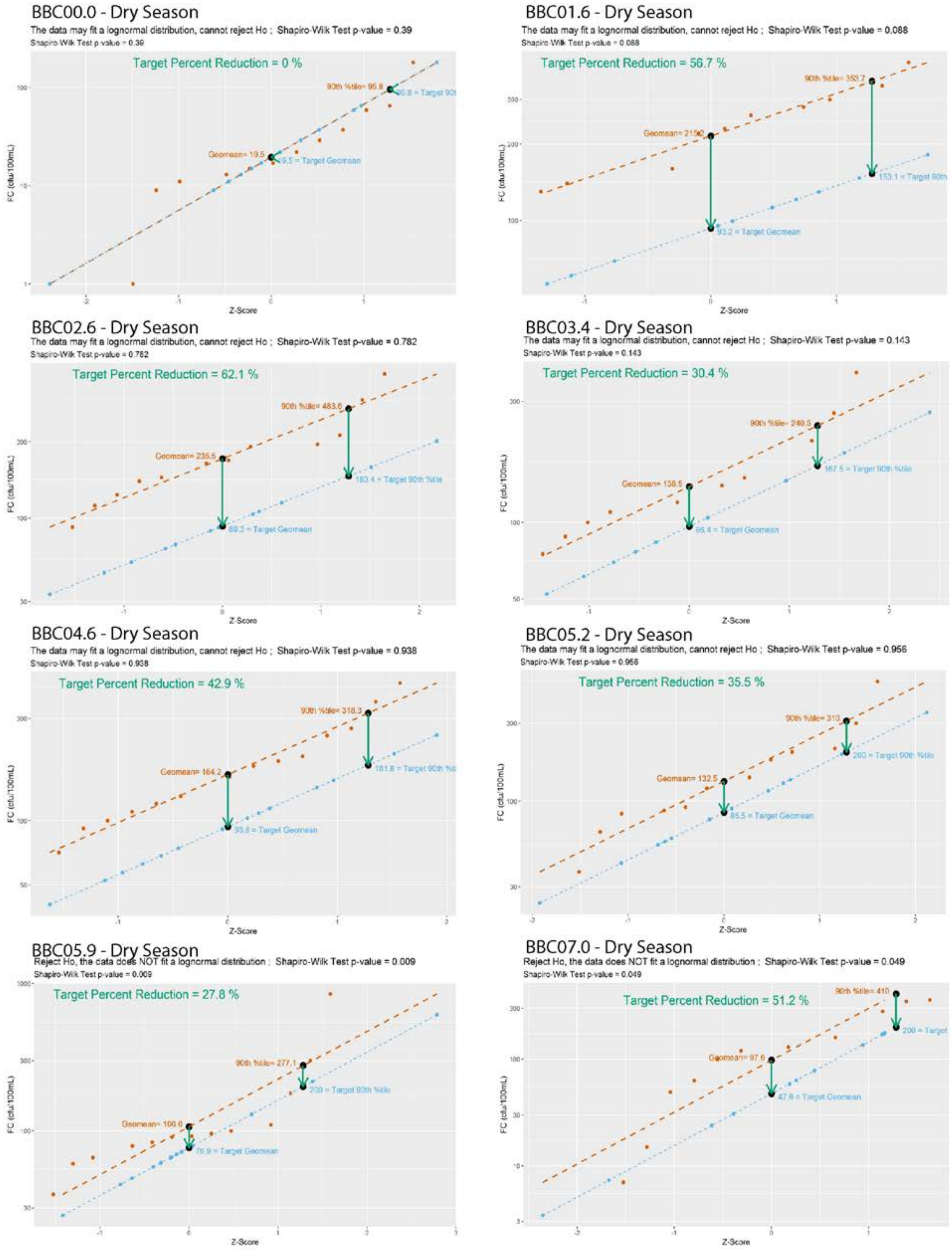

Figure D-1. Statistical rollback analysis graphical results.

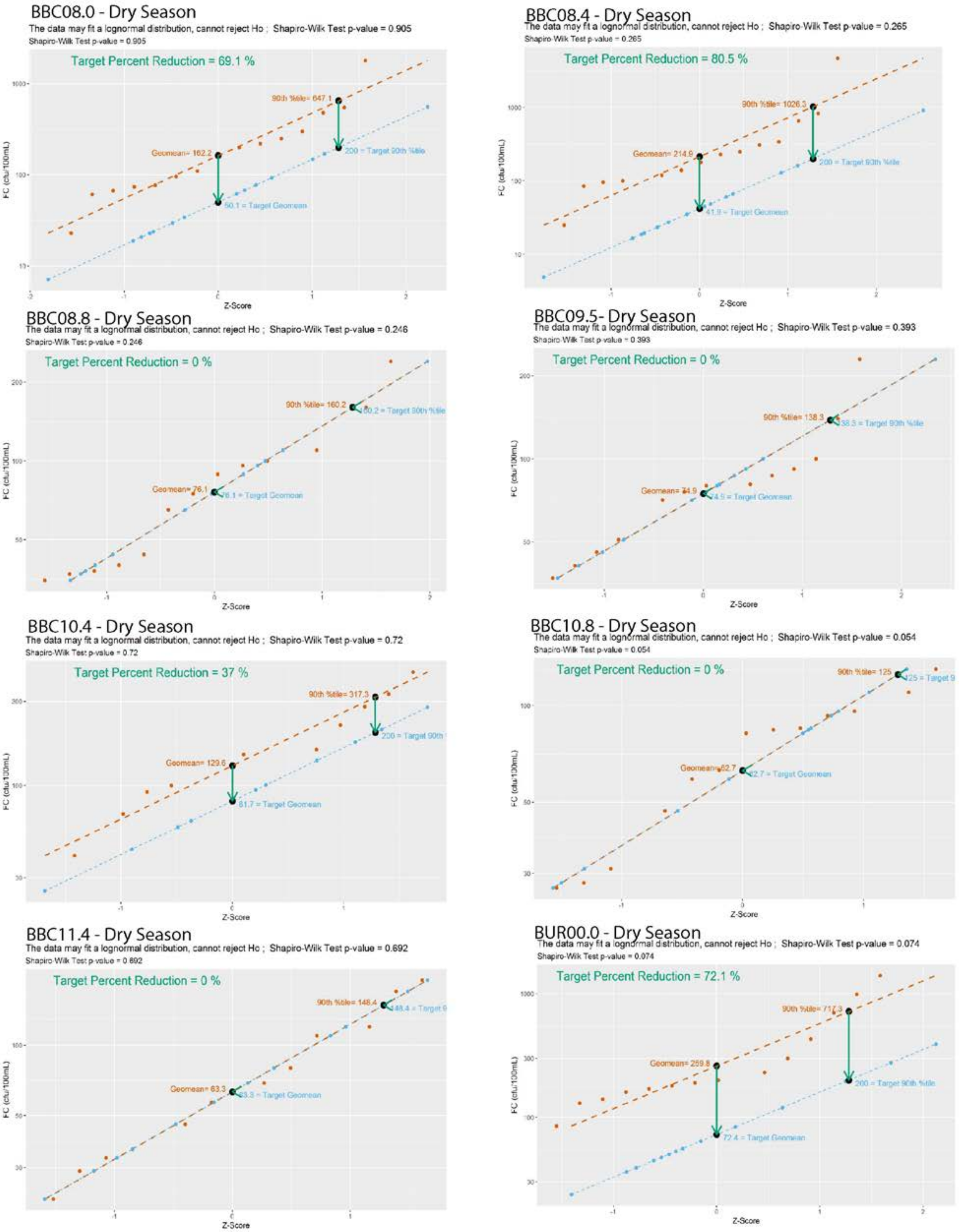

Figure D-2. Statistical rollback analysis graphical results (continued).

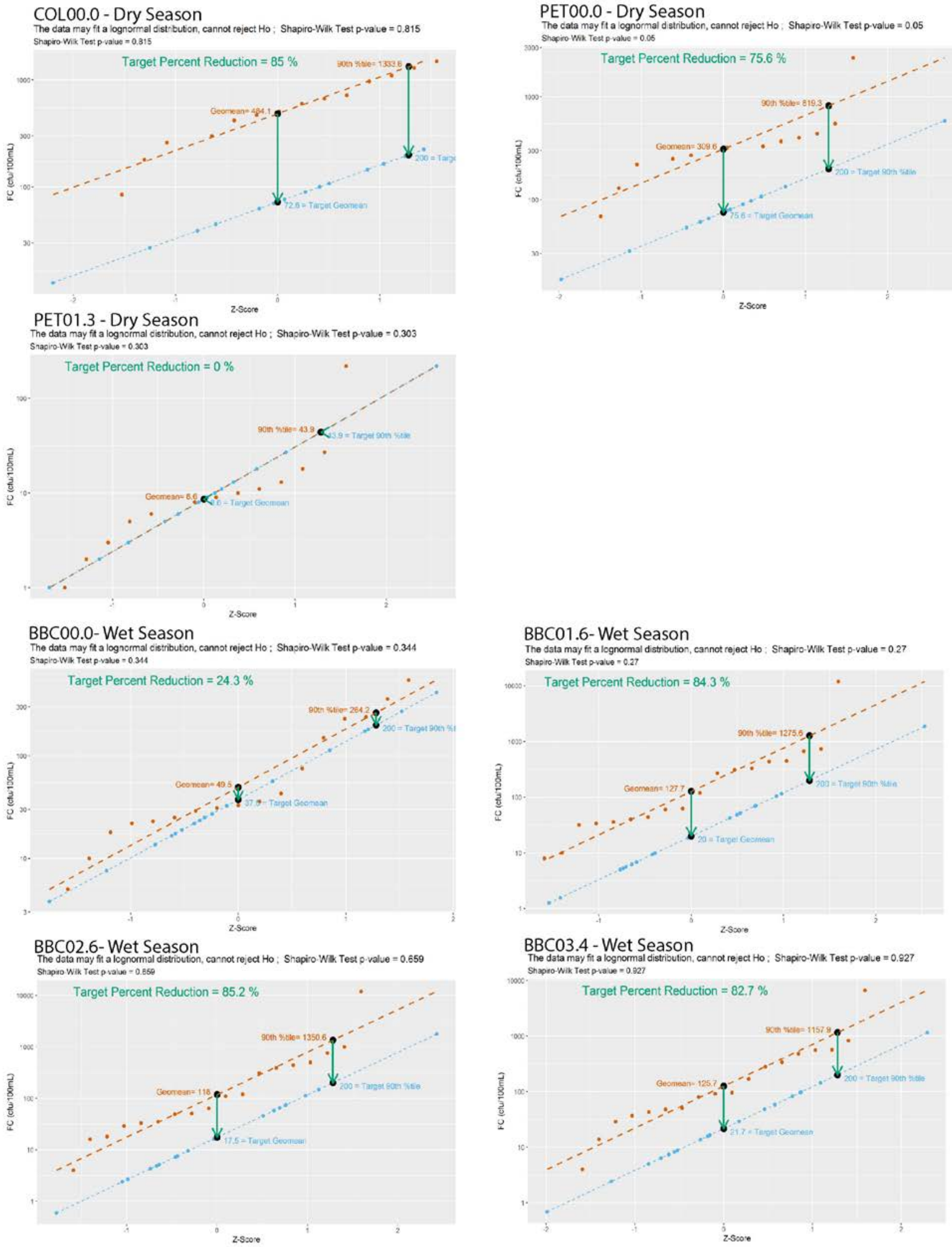

Figure D-3. Statistical rollback analysis graphical results (continued).

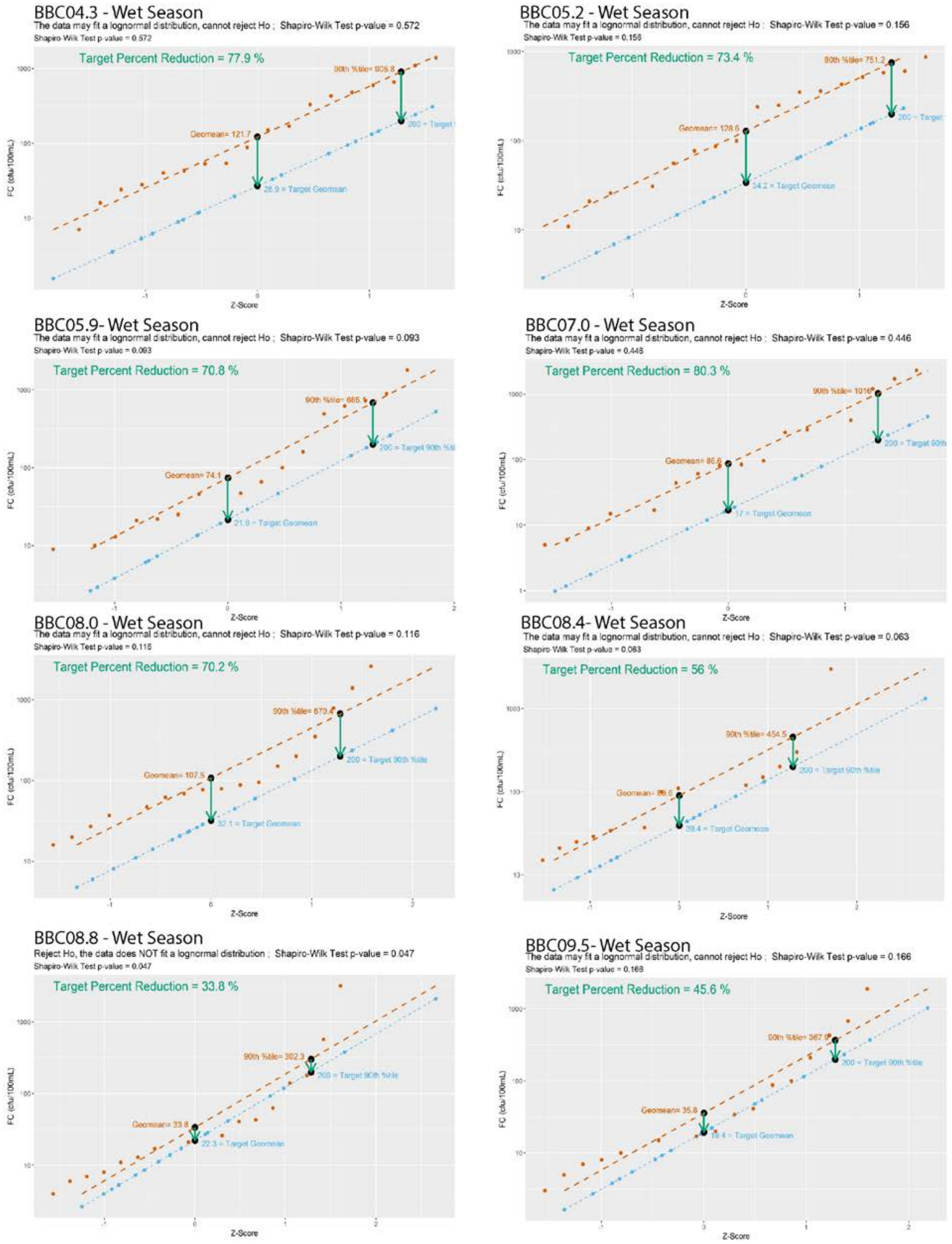

Figure D-4. Statistical rollback analysis graphical results (continued)

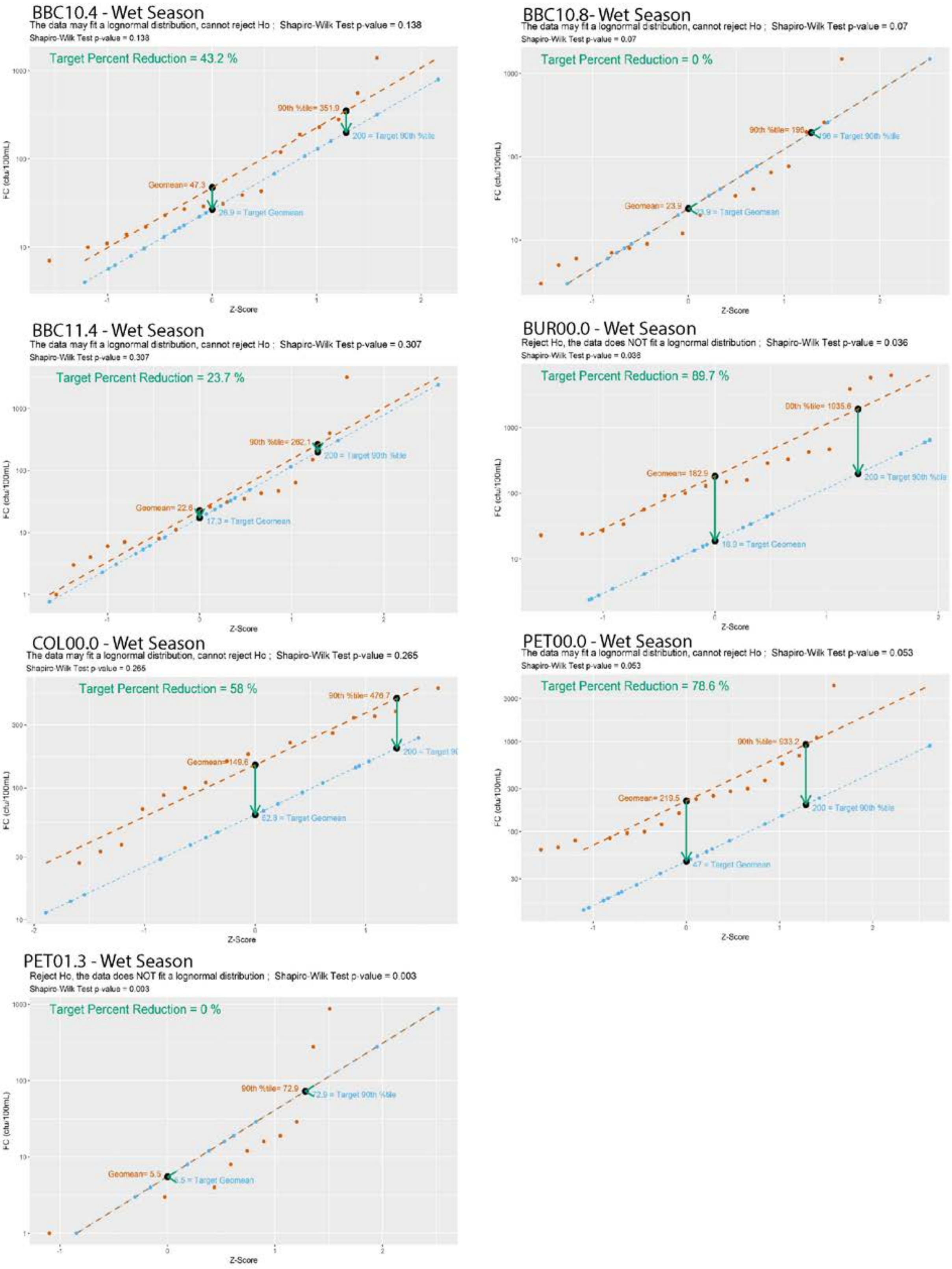

Figure D-5. Statistical rollback analysis graphical results (continued).

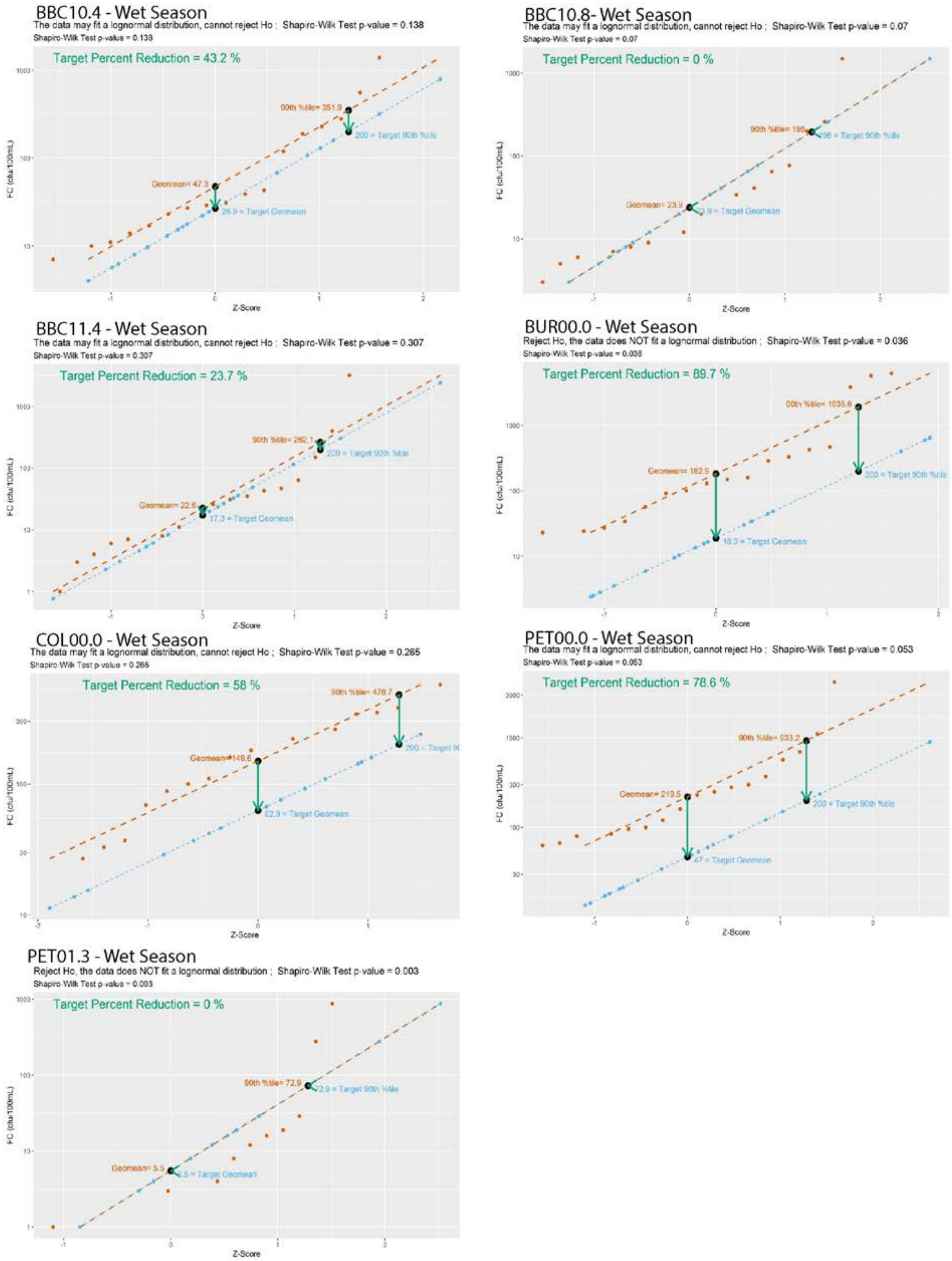

Figure D-6. Statistical rollback analysis graphical results (continued).

Appendix E. Overview of Stream Heating Processes

The temperature of a stream reflects the amount of heat energy in the water. Changes in water temperature within a particular segment of a stream are induced by the balance of the heat exchange between the water and the surrounding environment during transport through the segment. If there is more heat energy entering the water in a stream segment than there is leaving, the temperature will increase. If there is less heat energy entering the water in a stream segment than there is leaving, the temperature will decrease. The general relationships between stream parameters, thermodynamic processes (heat and mass transfer), and stream temperature change is outlined in Figure E-1.

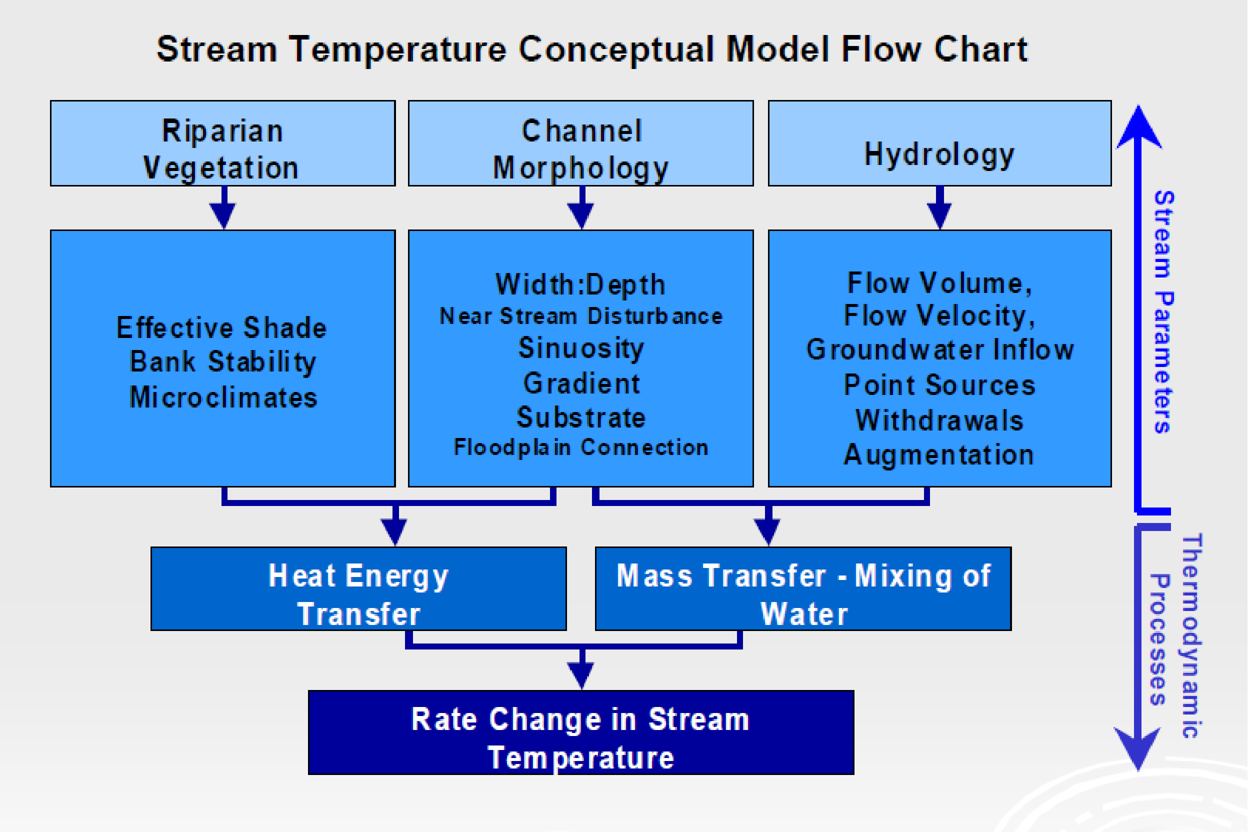

Figure E-1. Conceptual model of factors that affect stream temperature.

Adams and Sullivan (1989) reported that the following environmental variables were the most important drivers of water temperature in forested streams:

- **Stream depth.** Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.
- **Air temperature.** Daily average stream temperatures and daily average air temperatures are both highly influenced by incoming solar radiation (Johnson, 2004). When the sun is not shining, the temperature in a volume of water tends toward the dew-point temperature (Edinger et al., 1974).

- **Solar radiation and riparian vegetation.** The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily average temperatures are less affected by removal of riparian vegetation.
- **Groundwater.** Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream and the difference in temperatures between the groundwater and the stream.

Water temperature can also be strongly affected by tributaries and human discharges, depending on their temperature. In lakes and reservoirs, water temperatures can be affected by thermal stratification and wind.

Heat budgets and temperature prediction

Heat exchange processes occur between the water body and the surrounding environment, and these processes control stream temperature. Edinger et al. (1974) and Chapra (1997) provide thorough descriptions of the physical processes involved. Figure E-2 shows the major heat energy processes or fluxes across the water surface or streambed.

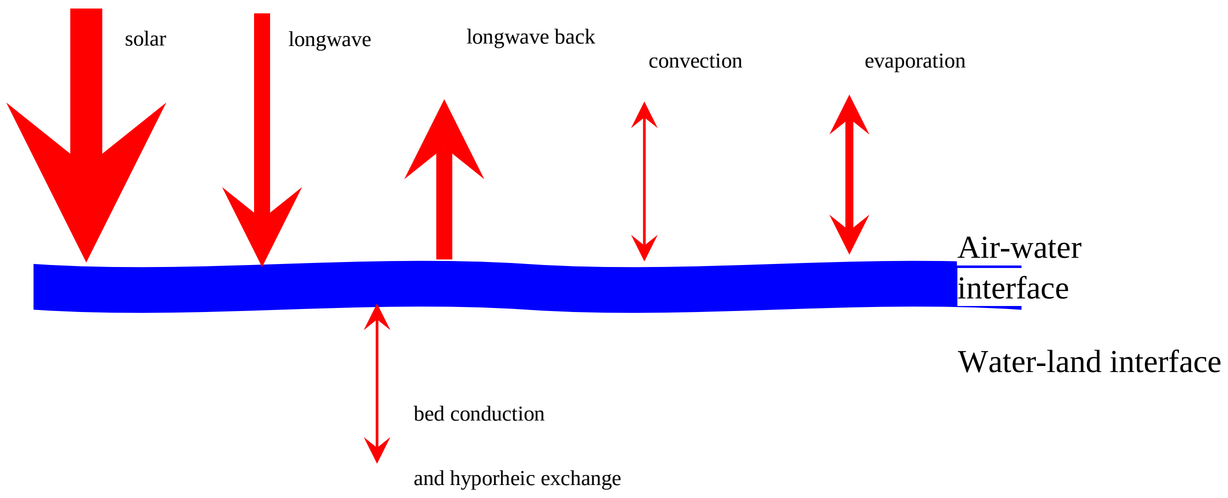

Figure E-2. Surface heat exchange processes that affect water temperature

(net heat flux = solar + longwave atmosphere + longwave back + convection + evaporation + bed). Heat flux between the water and streambed occurs through conduction and hyporheic exchange.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- **Shortwave solar radiation**. Shortwave solar radiation is the radiant energy which passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range from 0.14 to 4 um.

[Example text: At MesoWest's Liberty weather station on Swauk Creek, the daily average global shortwave solar radiation for July-August 2005 was 318 W/m^2. ***OR*** At Washington State University's (WSU) TreeForest Research and Extension Center (TFREC) station in Wenatchee, the daily average global shortwave solar radiation for August 2002 was 259 W/m2. At the University of Washington Atmospheric Sciences building roof in Seattle, the daily average global shortwave solar radiation for July-August 2001 was 240 W/m2 (NOAA, 2003).]

The peak values during daylight hours are typically about 3 times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear. Solar exposure was identified as the most influential factor in stream heating processes (Sinokrot and Stefan, 1993; Johnson and Jones; 2000; Danehy et al., 2005).

- **Longwave atmospheric radiation.** The longwave radiation from the atmosphere ranges in wavelength from about 4 to 120 um. Longwave atmospheric radiation depends primarily on air temperature and humidity, and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 W/m^2 at mid latitudes (Edinger et al., 1974).
  [Example text: NOAA's Integrated Surface Irradiance Study (ISIS) station in Seattle measures longwave radiation.]
- **Longwave back radiation from the water to the atmosphere.** Water sends heat energy back to the atmosphere in the form of longwave radiation in the wavelength range from about 4 to 120 um. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 W/m^2 (Edinger et al., 1974).

The remaining heat exchange processes generally have less magnitude and are as follows:

- **Evaporation flux at the air-water interface** is influenced mostly by wind speed and the vapor pressure gradient between the water surface and the air. When the air is saturated, the evaporation stops. When the gradient is negative (vapor pressure at the water surface is less than the vapor pressure of the air), condensation, the reversal of evaporation takes place; this term then becomes a gain component in the heat balance.
- **Convection flux at the air-water interface** is driven by the temperature difference between water and air and by wind speed. Heat is transferred in the direction of decreasing temperature.
- **Streambed conduction flux and hyporheic exchange** component of the heat budget represents the heat exchange through conduction between the bed and the water body and the

influence of hyporheic exchange. The magnitude of streambed conduction is driven by the size and conductance properties of the substrate. The heat transfer through conduction is more pronounced when thermal differences between the substrate and water column are higher. This heat transfer usually affects the temperature diel profile, rather than the magnitude of the maximum daily water temperature.

Hyporheic exchange can be an important mechanism for stream cooling in some basins (Johnson and Jones, 2000; Poole and Berman, 2000; Johnson, 2004). The hyporheic zone is defined as the region of saturated substrate located beneath the channel characterized by complex hydrodynamic processes that combine stream water and groundwater. The resulting fluxes can have significant implications for stream temperature at different spatial and temporal scales. For example, studies in the Walla Walla River in Oregon have shown water temperatures declining downstream in sections of the river as hyporheic interstitial flow cools in a riffle reach and then remixes into the stream in a pool reach.

Figures E-3 and E-4 show an example of surface heat flux in a relatively unshaded stream reach and in a more heavily shaded stream reach, respectively.

Figure E-3 shows an example of the estimated diurnal pattern of the surface heat fluxes in one of Washington’s coastal rivers for the week of August 8-14, 2001. The daily maximum temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar shortwave heat flux (Adams and Sullivan, 1989). The solar shortwave flux can be controlled by managing vegetation in the riparian areas adjacent to the stream.

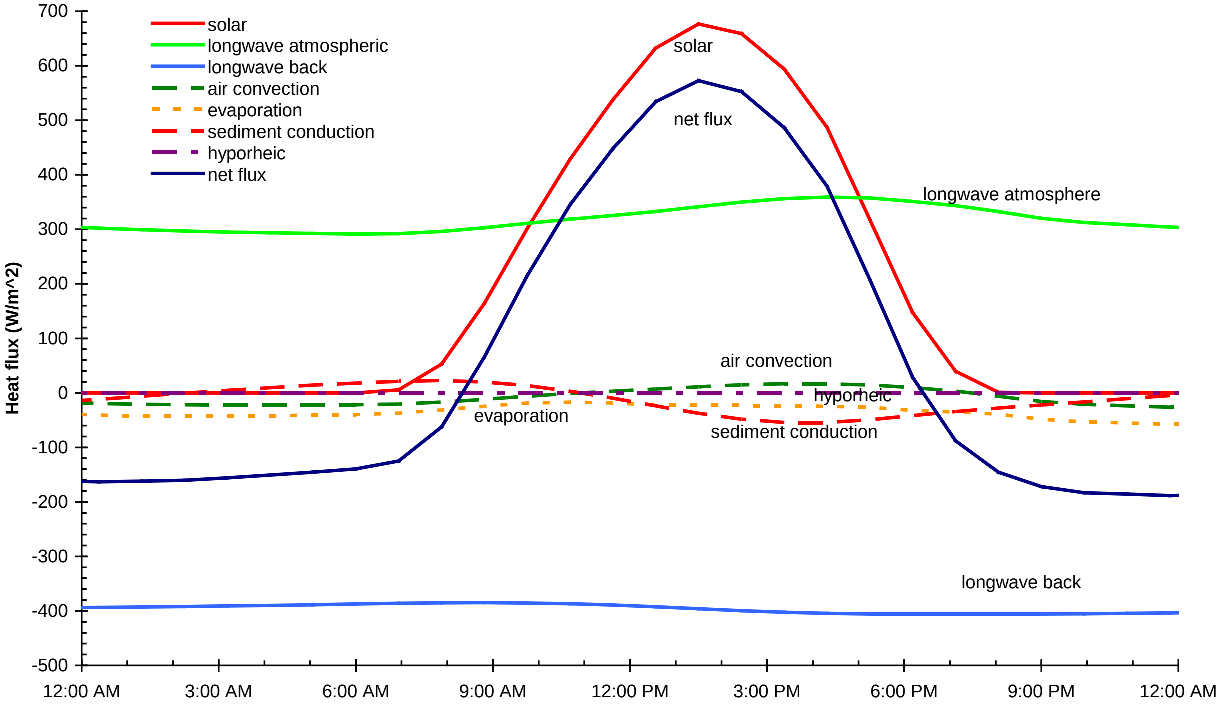

Figure E-3. Estimated heat fluxes in a river during August 8-14, 2001.

(net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Figure E-4 shows an example of the estimated diurnal pattern of the surface heat fluxes in a more heavily shaded location in the same river. Shade that is produced by riparian vegetation or topography can reduce the solar shortwave flux. Other processes – such as longwave radiation, convection, evaporation, bed conduction, or hyporheic exchange – also influence the net heat flux into or out of a stream.

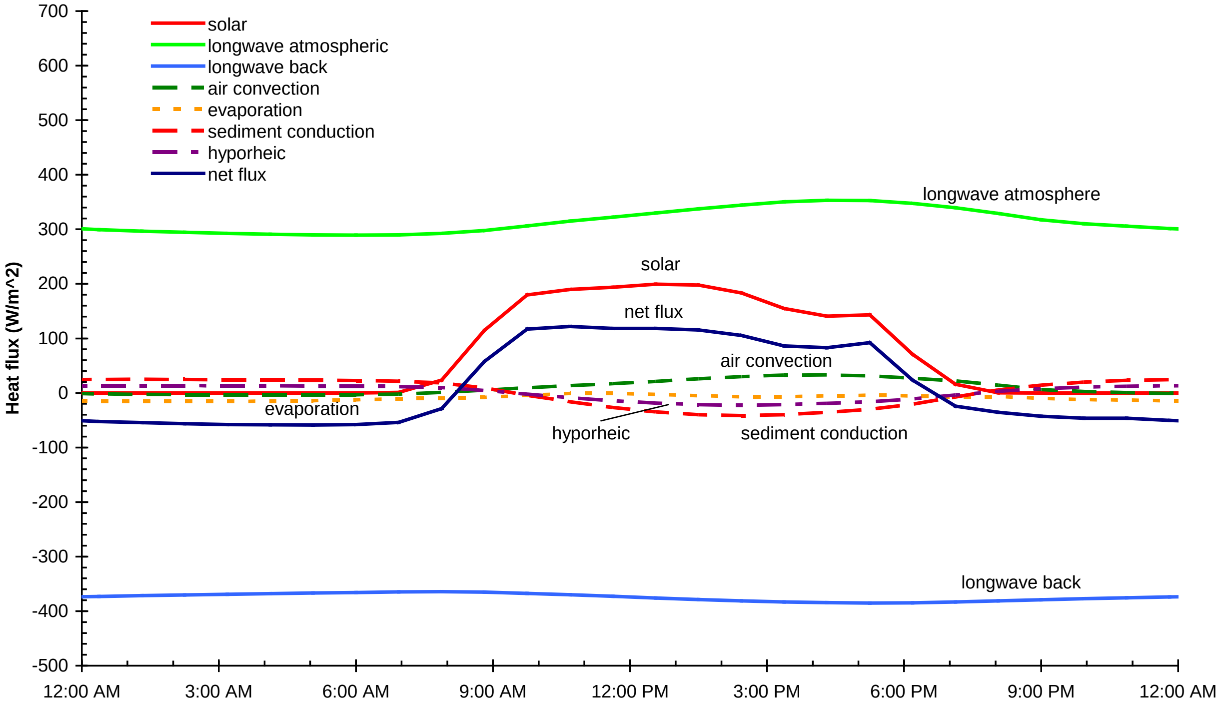

Figure E-4. Estimated heat fluxes in a more shaded section of a river during August 8-14, 2001.

(net heat flux = solar + longwave atmosphere + longwave back + air convection + evaporation + sediment conduction + hyporheic).

Heat exchange between the stream and the streambed has an important influence on water temperature. The temperature of the streambed is typically warmer than the overlying water at night and cooler than the water during the day (Figure E-5). Heat is typically transferred from the water into the streambed during the day, then back into the stream during the night (Adams and Sullivan, 1989). This has the effect of dampening the diurnal range of stream temperature variations without affecting the daily average stream temperature.

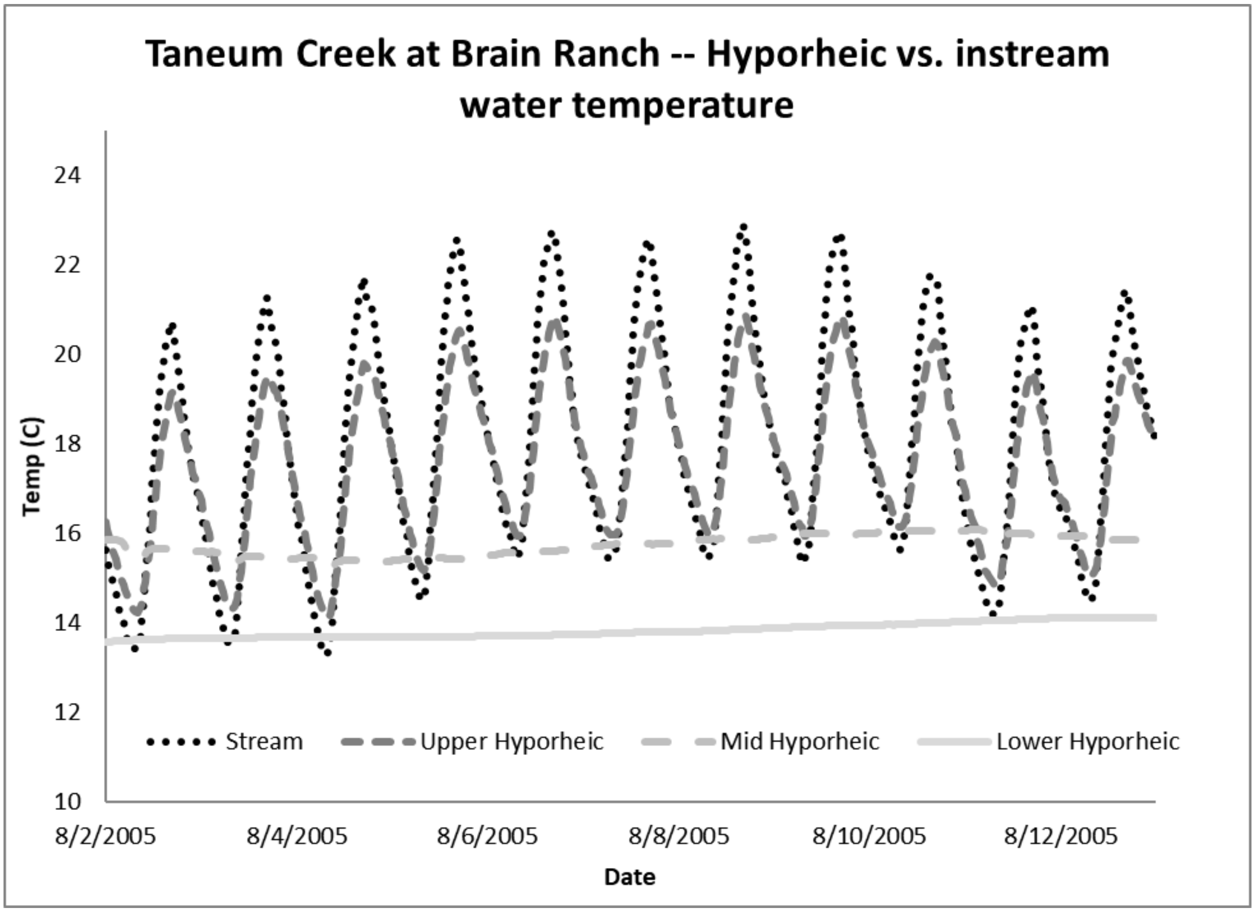

Figure E-5. Water and streambed temperatures in early August 2005 in Taneum Creek at Brain Ranch (station 39TAN-04.0).

The bulk temperature of a vertically mixed volume of water in a stream segment under natural conditions tends to increase or decrease with time during the day according to whether the net heat flux is either positive or negative. When the sun is not shining, the water temperature tends toward the dew-point temperature (Edinger et al., 1974; Brady et al., 1969). The equilibrium temperature of a natural body of water is defined as the temperature at which the water is in equilibrium with its surrounding environment and the net rate of surface heat exchange would be zero (Edinger et al., 1968; 1974).

The dominant contribution to the seasonal variations in the equilibrium temperature of water is from seasonal variations in the dew-point temperature (Edinger et al., 1974). The main source of hourly fluctuations in water temperature during the day is solar radiation. Solar radiation generally reaches a maximum during the day when the sun is highest in the sky unless cloud cover or shade from vegetation interferes.

The complete heat budget for a stream also accounts for the mass transfer processes which depend on the amount of flow and the temperature of water flowing into and out of a particular volume of water in a segment of a stream. Mass transfer processes in open channel systems can occur through advection, dispersion, and mixing with tributaries, human discharges and withdrawals, and groundwater inflows and outflows. Mass transfer relates to transport of flow volume downstream, instream mixing, and the introduction or removal of water from a stream. For instance, flow from a tributary will cause a temperature change if the temperature is different from the receiving water.

Thermal role of riparian vegetation

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (e.g., Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patrick, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in direct, unobstructed solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al., 1992; Beschta et al., 1987; Bolton and Monahan, 2001; Castelle and Johnson, 2000; CH2M Hill, 2000; GEI, 2002; Ice, 2001; and Wenger, 1999. All of these summaries recognize that the scientific literature indicates that riparian vegetation plays an important role in controlling stream temperature. Important benefits that riparian vegetation has upon the stream temperature include:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Channel morphology can be strongly affected by near-stream vegetation. Specifically, stream vegetation is often part of human impacts on land-cover type and condition, which can affect flood plain and instream roughness, the contribution of coarse woody debris, sedimentation, stream substrate composition, and stream bank stability.

Although the warming of water temperatures as a streamflows downstream can be a natural process, the rates of heating can be dramatically lower when high levels of shade exist and heat flux from solar radiation is minimized. There is a natural maximum potential level of vegetation and associated shade that a given stream is capable of attaining in an undisturbed situation. In general, the importance of shade decreases as the width of a stream increases.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Effective shade

Stream shade may be measured or calculated using a variety of methods (Chen, 1996; Chen et al., 1998; Ice, 2001; OWEB, 1999; Teti, 2001; Teti and Pike, 2005). Effective shade is defined as the fraction or percentage of the total possible solar radiation heat energy that is prevented from reaching the surface of the water:

$$\text{effective shade} = (J_1 - J_2)/J_1$$

where J_1 is the potential solar heat flux above the influence of riparian vegetation and topography, and J_2 is the solar heat flux at the stream surface.

Canopy cover is the percent of sky covered by vegetation and topography at a given point. Shade is influenced by cover but changes throughout each day, as the position of sun changes spatially and temporally with respect to the canopy cover (Kelley and Krueger, 2005).

In the Northern Hemisphere, the earth tilts on its axis toward the sun during the summer, allowing longer day length and higher solar altitude. Both are functions of solar declination, a measure of the earth’s tilt toward the sun (Figure C-6). Latitude and longitude positions fix the stream to a position on the globe, while aspect provides the direction of streamflow. Near-stream vegetation height, width, and density describe the physical barriers between the stream and sun that can attenuate and scatter incoming solar radiation, producing shade (Table C-1). The solar position has a vertical component – solar altitude – and a horizontal component – solar azimuth – that are both functions of time, date, and the earth’s rotation.

While the interaction of these shade variables may seem complex, the mathematics that describes them is relatively straightforward geometry. Using solar tables or mathematical simulations, the potential daily solar load can be quantified. The shade from riparian vegetation can be measured with a variety of methods, including (Ice, 2001; OWEB, 1999; Boyd, 1996; Teti, 2001; Teti and Pike, 2005):

- Hemispherical photography
- Angular canopy densiometer
- Solar pathfinder

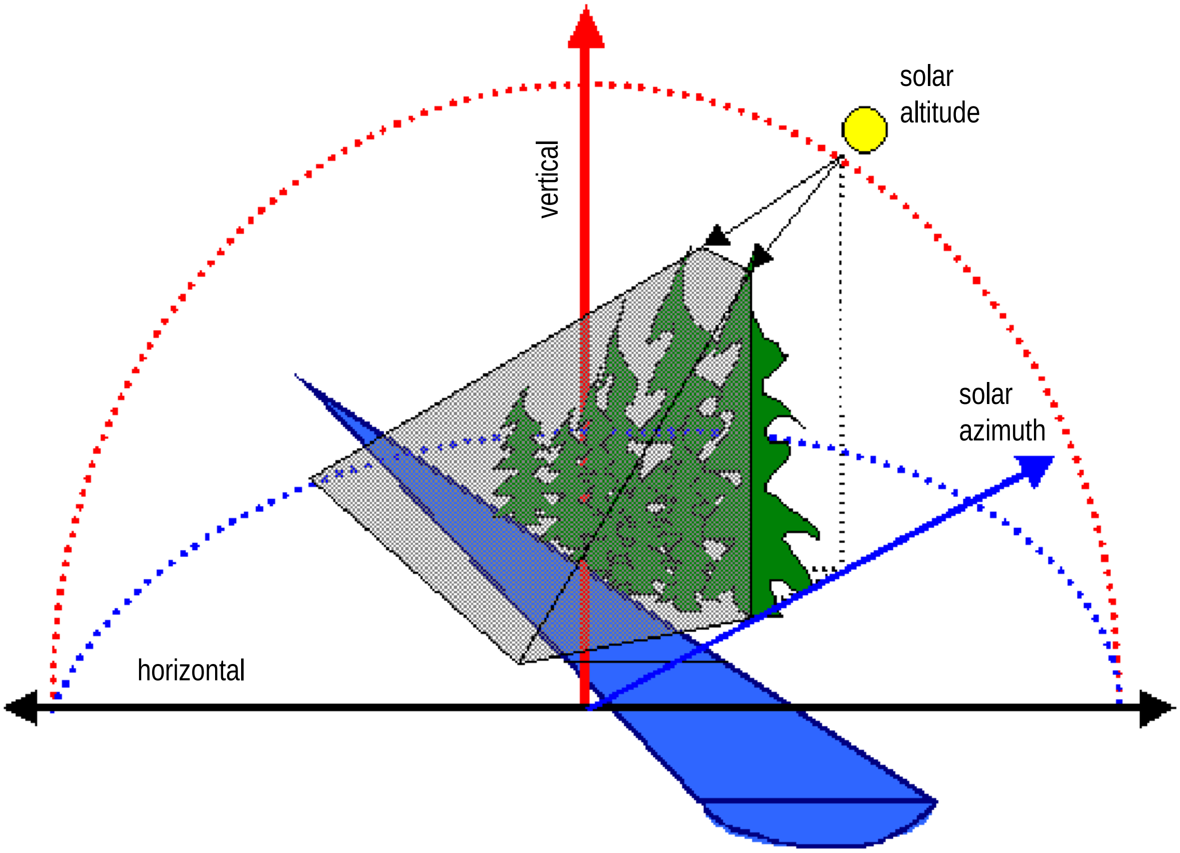

Figure E-6. Parameters that affect shade and geometric relationships.

Solar altitude **is a measure of the vertical angle of the sun's position relative to the horizon.** ***Solar azimuth*** **is a measure of the horizontal angle of the sun's position relative to north. (Boyd and Kasper, 2003.)**

Hemispherical photography is generally regarded as the most accurate method for measuring shade, although the equipment that is required is significantly more expensive compared with other methods. Angular canopy densiometers (ACD) and solar pathfinders provide a good balance of cost and accuracy for measuring the importance of riparian vegetation for preventing increases in stream temperature (Beschta et al., 1987; Teti, 2001, 2005). Whereas canopy density is usually expressed as a vertical projection of the canopy onto a horizontal surface, the ACD is a projection of the canopy measured at an angle above the horizon at which direct beam solar radiation passes through the canopy. This angle is typically determined by the position of the sun above the horizon during that portion of the day (usually between 10 AM and 2 PM in mid to late summer) when the potential solar heat flux is most significant. Typical values of the ACD for old-growth stands in western Oregon have been reported to range from 80% to 90%.(Brazier and Brown, 1973; Steinblums et al., 1984).

Computer programs for the mathematical simulation of shade may also be used to estimate shade from measurements or estimates of the key parameters listed in Table C-1 (Ecology 2003; Chen, 1996; Chen et al., 1998; Boyd, 1996; Boyd and Park, 1998).

Table E-1. Factors that influence stream shade.

Description	Parameter
Season/time	Date/time
Stream characteristics	Aspect, channel width
Geographic position	Latitude, longitude
Vegetative characteristics	Riparian vegetation height, width, and density
Solar position	Solar altitude, solar azimuth

Bold indicates influenced by human activities.

Riparian buffers and effective shade

Trees in riparian areas provide shade to streams and minimize undesirable water temperature changes (Brazier and Brown 1973; Steinblums et al., 1984). The shading effectiveness of riparian vegetation is correlated to riparian area width (Figure C-7). The shade as represented by angular canopy density (ACD) for a given riparian buffer width varies over space and time because of differences among site potential vegetation, forest development stages (e.g., height and density), and stream width. For example, a 50-foot-wide riparian area with fully developed trees could provide from 45% to 72% of the potential shade in the two studies shown in Figure E-7.

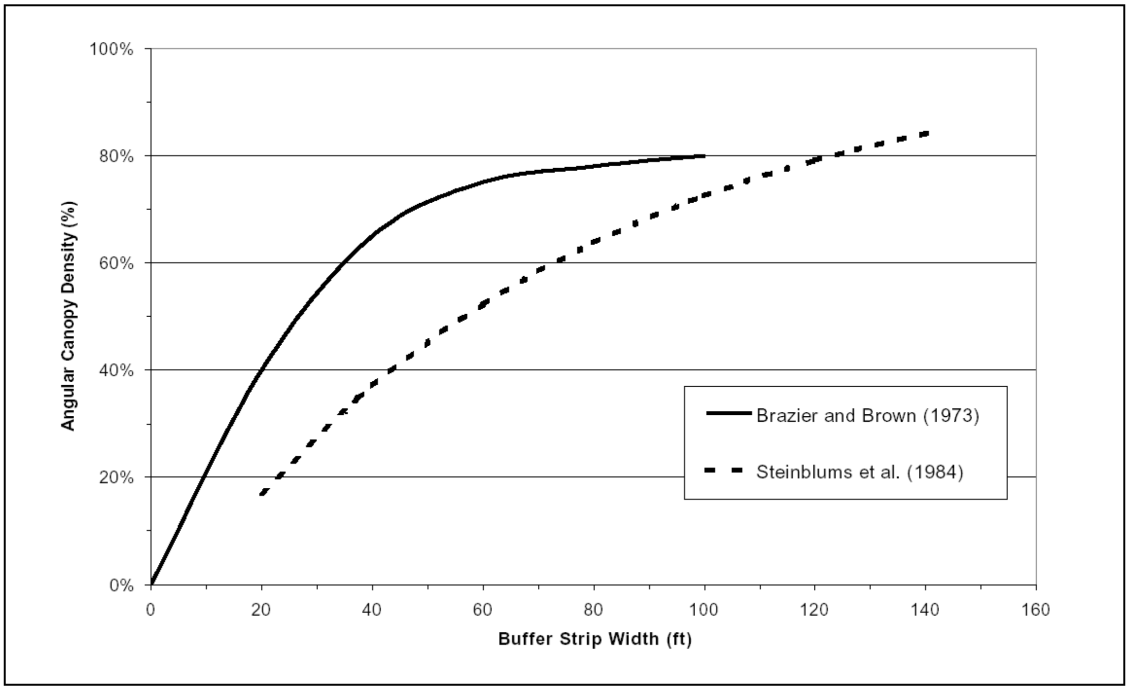

Figure E-7. Relationship between angular canopy density and riparian buffer width for small streams in old-growth riparian stands (after Beschta et al., 1987; and CH2M Hill, 2000).

The Brazier and Brown (1973) shade data show a stronger relationship between ACD and buffer strip width than the Steinblums et al. (1984) data: The r^2 correlation for ACD and buffer width was 0.87 and 0.61 in Brazier and Brown (1973) and Steinblums et al. (1984), respectively. This difference supports the use of the Brazier and Brown curve as a base for measuring shade effectiveness under various riparian buffer proposals. These results reflect the natural variation among old-growth sites studied, and show a possible range of potential shade.

Several studies of stream shading report that most of the potential shade comes from the riparian area within about 75 feet (23 m) of the channel (CH2M Hill, 2000; Castelle and Johnson, 2000):

- Beschta et al. (1987) report that a 98-foot-wide (30-m) buffer provides the same level of shading as that of an old-growth stand.
- Brazier and Brown (1973) found that a 79-foot (24-m) buffer provides maximum shade to streams.
- Steinblums et al. (1984) concluded that a 56-foot (17-m) buffer provides 90% of the maximum ACD.
- Corbett and Lynch (1985) concluded that a 39-foot (12-m) buffer should adequately protect small streams from large temperature changes following logging.
- Broderson (1973) reported that a 49-foot-wide (15-m) buffer provides 85% of the maximum shade for small streams.
- Lynch et al. (1984) found that a 98-foot-wide (30-m) buffer maintains water temperatures within 2°F (1°C) of their former average temperature in small streams (channel width less than 3 m).

GEI (2002) reviewed the scientific literature related to the effectiveness of buffers for shade protection in agricultural areas in Washington and concluded that buffer widths of 10 m (33 feet) provide nearly 80% of the maximum potential shade in agricultural areas. Wenger (1999) concluded that a minimum continuous buffer width of 10-30 m should be preserved or restored along each side of all streams on a municipal or countywide scale to provide stream temperature control and maintain aquatic habitat. GEI (2002) considered the recommendations of Wenger (1999) to be relevant for agricultural areas in Washington.

Steinblums et al. (1984) concluded that shade could be delivered to forest streams from beyond 75 feet (22 m) and potentially out to 140 feet (43 m). In some site-specific cases, forest practices between 75 and 140 feet from the channel have the potential to reduce shade delivery by up to 25% of maximum. However, any reduction in shade beyond 75 feet would probably be relatively low on the horizon, and the impact on stream heating would be relatively minimal because the potential solar radiation decreases significantly as solar elevation decreases.

Microclimate - surrounding thermal environment

A secondary consequence of near-stream vegetation is its effect on the riparian microclimate. Riparian corridors often produce a microclimate that surrounds the stream where cooler air temperatures, higher relative humidity, and lower wind speeds are characteristic. Riparian microclimates tend to moderate daily air temperatures. Evapotranspiration by riparian plant communities increases relative humidity. Physical blockage by riparian vegetation reduces wind speed.

Riparian buffers commonly occur on both sides of the stream, compounding the edge influence on the microclimate. Brosofske et al. (1997) reported that a buffer width of at least 150 feet (45 m) on each side of the stream was required to maintain a natural riparian microclimate environment in small forest streams (channel width less than 4 m) in the foothills of the western slope of the Cascade Mountains in Western Washington with predominantly Douglas-fir and western hemlock.

Bartholow (2000) provided a thorough summary of literature of documented changes to the environment of streams and watersheds associated with extensive forest clearing. Changes summarized by Bartholow (2000) are representative of hot summer days and indicate the mean daily effect unless otherwise indicated:

- **Air temperature**. Edgerton and McConnell (1976) showed that removing all or a portion of the tree canopy resulted in cooler terrestrial air temperatures at night and warmer temperatures during the day, enough to influence thermal cover sought by elk (*Cervus canadensis*) on their eastern Oregon summer range. Increases in maximum air temperature varied from 5 to 7°C for the hottest days (estimate). However, the mean daily air temperature did not appear to have changed substantially since the maximum temperatures were offset by almost equal changes to the minima.
- Similar temperatures have been commonly reported (Childs and Flint, 1987; Fowler et al., 1987), even with extensive clearcuts (Holtby, 1988). In an evaluation of buffer strip width, Brosofske et al. (1997) found that air temperatures immediately adjacent to the ground increased 4.5°C during the day and about 0.5°C at night (estimate). Fowler and Anderson (1987) measured a 0.9°C air temperature increase in clearcut areas, but temperatures were also 3°C higher in the adjacent forest. Chen et al. (1993) found similar (2.1°C) increases.
- All measurements reported here were made over land instead of water, but in aggregate support about a 2°C increase in ambient mean daily air temperature resulting from extensive clearcutting.
- **Relative humidity**. Brosofske et al. (1997) examined changes in relative humidity within 17 to 72 m buffer strips. The focus of their study was to document changes along the gradient from forested to clearcut areas, so they did not explicitly report pre- to post-harvest changes at the stream. However, there appeared to be a reduction in relative humidity at the stream, estimated at 7% during the day and 6% at night. Relative humidity at stream sites increased exponentially with buffer width. Similarly, a study by Chen et al. (1993) showed a decrease of about 11% in mean daily relative humidity on clear days at the edges of clearcuts.
- **Wind speed**. Brosofske et al. (1997) reported almost no change in wind speed at stream locations within buffer strips adjacent to clearcuts. Speeds quickly approached upland conditions toward the edges of the buffers, with an indication that wind actually increased substantially at distances of about 15 meters from the edge of the strip, and then declined farther upslope to pre-harvest conditions. Chen et al. (1993) documented increases in both peak and steady winds in clearcut areas; increments ranged from an estimated 0.7 to 1.2 meters per second.

Thermal role of channel morphology

Changes in channel morphology impact stream temperatures. As a stream widens, the surface area exposed to heat flux increases, resulting in increased energy exchange between a stream and its environment (Chapra, 1997). Further, wide channels are likely to have decreased levels of shade due to the increased distance created between vegetation and the wetted channel and the decreased fraction of the stream width that could potentially be covered by shadows from riparian vegetation. Conversely, narrow channels are more likely to experience higher levels of shade.

Channel widening is often related to degraded riparian conditions that allow increased streambank erosion and sedimentation of the streambed, both of which correlate strongly with riparian vegetation type and condition (Rosgen, 1996). Channel morphology is not solely dependent on riparian conditions. Sedimentation can deposit material in the channel, fill pools, and aggrade the streambed, reducing channel depth and increasing channel width.

Channel modification usually occurs during high-flow events. Land uses that affect the magnitude and timing of high-flow events may negatively impact channel width and depth. Channel straightening can increase flow velocities and lead to deeply incised streambanks and washout of gravel and cobble substrate. Riparian vegetation conditions will affect the resilience of the streambanks/flood plain during periods of sediment introduction and high flow. Disturbance processes may have differing results depending on the ability of riparian vegetation to shape and protect channels.

Channel morphology can also be the result of upland land practices or disconnection of the flood plain. Erosion in watershed can result in high bed load and shallower, wider channels downstream. The separation of the flood plain from the main channel of a river can result in sediment being carried in the channel that would otherwise be deposited in the flood plain. It can also increase velocities and bank erosion.

Channel morphology is related to riparian vegetation composition and condition by:

- **Building streambanks**. Traps suspended sediments, encourages deposition of sediment in the flood plain, and reduces incoming sources of sediment.
- **Maintaining stable streambanks**. High rooting strength and high streambank and flood plain roughness prevent streambank erosion.
- **Reducing flow velocity** (erosive kinetic energy). Supplies large woody debris to the active channel, provides a high pool to riffle ratio, and adds channel complexity that reduces shear stress exposure to streambank soil particles.

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Appendix F. SEH America Data

Table F-1. Provisional flow data at SEH America end-of-pipe, Peterson Channel outlet flow (PET00.0), gain/loss between SEH America end-of-pipe and PET00.0, and percentage of flow at PET00.0 from SEH America (SEH % Flow).

Date	SEH (cfs)	PET00.0 (cfs)	Gain/Loss (cfs)	SEH % Flow
6/3/2008	3.8	6.9	3.08	45%
6/17/2008	1.5	2.9	1.45	49%
6/30/2008	1.5	2.6	1.07	42%
7/15/2008	1.1	2.4	1.36	56%
8/12/2008	1.2	2.1	0.90	43%
8/26/2008	1.3	2.5	1.24	50%
9/9/2008	1.1	2.6	1.48	57%
10/6/2008	1.3	2.0	0.65	33%
10/20/2008	1.0	1.8	0.85	46%
11/3/2008	1.2	2.1	0.88	42%
11/17/2008	1.3	2.5	1.17	47%
12/1/2008	1.2	1.9	0.76	40%
12/15/2008	1.5	2.3	0.87	37%
12/28/2008	3.4	3.8	0.43	11%
1/12/2009	2.3	5.1	2.82	55%
1/26/2009	1.6	3.2	1.59	50%
2/9/2009	1.5	2.5	0.94	38%
2/23/2009	1.2	2.4	1.19	50%
3/10/2009	1.0	1.9	0.88	46%
3/23/2009	1.0	2.3	1.27	56%
4/6/2009	1.1	2.5	1.39	56%
4/20/2009	1.2	2.3	1.08	47%
5/4/2009	2.1	4.7	2.59	56%
5/18/2009	1.4	2.4	1.05	43%
6/1/2009	2.9	2.4	-0.57	-24%
6/15/2009	0.9	1.9	0.96	52%
6/28/2009	0.9	1.5	0.63	41%
7/13/2009	1.7	2.2	0.49	23%
7/27/2009	2.5	1.1	-1.45	-137%
8/10/2009	1.1	2.2	1.13	51%
8/24/2009	1.1	2.0	0.93	46%

Table F-2. PET01.3 (near SEH America outfall 001) temperature summary and exceedances above SEH America criteria (21°C).

Date	Max Temp (°C)	Exceedance	Comments
6/28/08	21.01	yes	Within thermistor accuracy ±0.2°C
7/8/08	21.03	no	Valve closed during time of max
7/9/08	21.27	no	Valve closed during time of max
8/5/08	21.08	no	Valve closed during time of max
8/7/08	21.01	yes	Within thermistor accuracy ±0.2°C
8/14/08	21.70	no	Valve closed during time of max
8/15/08	22.54	no	Valve closed during time of max
8/16/08	25.52	no	Valve closed during time of max
8/17/08	24.51	yes	Outside thermistor accuracy ±0.2°C
8/18/08	23.35	yes	Outside thermistor accuracy ±0.2°C
7/17/09	21.08	no	Valve closed during time of max
7/18/09	21.03	no	Valve closed during time of max
7/21/09	21.06	no	Valve closed during time of max
7/27/09	23.71	no	Valve closed during time of max
7/28/09	23.98	no	Valve closed during time of max
7/29/09	26.01	no	Valve closed during time of max
7/30/09	26.01	no	Valve closed during time of max
7/31/09	21.72	no	Valve closed during time of max
8/1/09	21.68	no	Valve closed during time of max
8/2/09	23.91	no	Valve closed during time of max
8/3/09	21.70	no	Valve closed during time of max