Water Year 2024 Trend Analysis Report

Burnt Bridge Creek Water Quality Monitoring Program

Prepared for
City of Vancouver Surface Water Management

Prepared by
Herrera Environmental Consultants, Inc.

Water Year 2024 Trend Analysis Report

Burnt Bridge Creek
Water Quality Monitoring Program

Prepared for
City of Vancouver Surface Water Management
4500 Southeast Columbia Way
P.O. Box 1995
Vancouver, Washington 98668-1995

Prepared by
Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206-441-9080

April 9, 2025

Contents

Appendices

Tables

Figures

EXECUTIVE SUMMARY

Since 2004, the City of Vancouver, Washington (the City) has conducted water quality monitoring in Burnt Bridge Creek (BBC) as part of a long-term monitoring program. Key objectives of the program include collecting credible water quality data and assessing compliance with state regulations. The main goal of the program is to support adaptive and effective surface water management practices throughout the watershed to protect and improve water quality for recreational uses, public health, and salmonid spawning and rearing habitat. The program also supports the City's goals related to sustainability and resiliency with strategies and actions to protect natural systems and water resources impacted by climate change. The City's Climate Action Framework (Vancouver 2022) outlines actions to restore and protect wetlands, rivers, and natural habitats to support biodiversity and water quality, integrate green infrastructure for sustainable stormwater management, and expand urban tree canopies to mitigate heat islands. Monitoring water quality in BBC is critical for assessing the City's progress towards these goals. As an urban stream with a robust water quality dataset and monitoring program, analyzing trends in water quality helps evaluate and guide strategies to achieve watershed improvement and protection goals.

This report presents methods and results of trend analyses of long-term monitoring data collected from 2011 through WY2024 (WY2024; defined as the hydrologic water year (WY) from October 1, 2023 through September 30, 2024). It also serves as an annual report for monitoring conducted during WY2024 in accordance with procedures in the Quality Assurance Project Plan (QAPP; Herrera 2023).

In WY2024, stream samples were collected at 11 stations in the BBC watershed, including stations in three tributaries, during seven base flow events (with little or no precipitation in the previous 24 hours) and five storm flow events (during periods of substantial precipitation). Monitoring both base and storm flow events allows for a more holistic understanding of the factors influencing water quality in the stream, including groundwater and stormwater runoff inputs. This context for how certain pollutants of concern enter surface waters provides the foundation necessary to prioritize water quality improvements that target specific contaminant pathways.

Key Findings

In accordance with the QAPP, a quality assurance review was performed to ensure that all data collected under this monitoring program were valid and useable for analysis. Key findings from WY2024 monitoring and trend analyses include:

- WY2024 Water Quality Criteria Comparison: Water quality criteria were frequently exceeded for several parameters including temperature, dissolved oxygen, and nutrients but generally met criteria for other parameters including pH, metals, and turbidity. *Escherichia coli* (*E. coli*) concentrations during storm flow events exceeded the applicable criteria for bacteria at all stations, but did not exceed the criteria during base flow events at five of eleven stations. The 7-day average daily maximum (7-DADMax) criterion for temperature was exceeded at all stations with continuous temperature probes for 25 to 59 percent of the monitoring period. Metals criteria were exceeded on one occasion for copper at tributary stations for Burton Channel and Cold Creek; on one occasion for zinc at three upper to midstream BBC stations; and on three occasions for zinc at the Burton Channel station.

- Spatial Trends: Statistically significant spatial trends were identified across BBC monitoring stations. Field pH and dissolved oxygen measurements, for example, followed an increasing pattern from upstream stations to downstream stations, with some variability throughout the midstream stations including station BBC5.9 (River Mile 5.9 where the creek crosses under East 18th Street) which had significantly lower dissolved oxygen than several other BBC stations. Other patterns, such as turbidity and metals concentrations, appeared to be driven by influence from tributaries with their unique water quality characteristics. Copper concentrations during storm flow were significantly higher at tributary stations for Peterson Channel and Cold Creek, likely impacting downstream BBC stations BBC8.4 (Burton Road) and BBC1.6 (Alki Road) which exhibited significantly higher copper concentrations compared to other mainstem stations. Relatively few significant differences were identified for *E. coli*, with tributary stations for Burton Channel (during base flow) and Cold Creek (during storm events) having significantly higher concentrations than other stations.
- Temporal Trends: Significant temporal trends were identified for several parameters at most stations. These trends represented a mix of improving and decreasing water quality with some broader patterns. Select base flow trends that indicate improving water quality include decreasing nitrate + nitrite at most stations and decreasing fecal coliform at three mid to downstream stations. For storm flow, a decreasing trend in total phosphorus was detected at three mainstem stations. Select base flow trends that indicate decreasing water quality include increasing turbidity at ten of 11 stations, increasing 7-DADMax temperatures at three upstream stations, and increasing chloride (storm and base flow) at the majority of stations.
- Water Quality Index: The water quality index (WQI) was developed by Washington State Department of Ecology (2002) as a numeric indicator of water quality. Few significant trends were detected for overall water quality index scores across mainstem BBC stations. Across most stations, overall WQI scores were driven by relatively poor total nitrogen, nutrient, and total phosphorus individual group scores and relatively good sediment, turbidity, pH, and TSS individual group scores.

While the City has implemented a variety of water quality improvement activities, analysis of monitoring data has not yet shown significant improvement in overall water quality at monitoring locations throughout the watershed with a few exceptions. Although undetected, improvements may be occurring but offset by changes in other variables that influence water quality. Not all impacts can be easily quantified; factors such as climate change and increasing pressure on riparian areas from unauthorized camping near waterbodies can counter other water quality improvements. Continued implementation of best management practices in the watershed and long-term water quality monitoring will be necessary to determine effectiveness and guide adaptive strategies. Current efforts to decrease temperatures through riparian planting for shade as well as reduced sources of nutrient pollution through the elimination of septic systems in the watershed are expected to improve water quality over time.

Key Influences

Trends and patterns in individual parameters can be explained by certain basin-wide or local sources including:

- Decreasing nitrate + nitrogen concentrations throughout BBC may be related to the decommissioning of 165 septic systems within the watershed over the past five years.
- Unique natural conditions present in wetlands and groundwater where the creek originates are likely contributing to relatively low pH, dissolved oxygen, and temperatures at the upstream station BBC10.4.
- Gaps in riparian cover in the developed area immediately upstream of station BBC8.8 is likely contributing to an increase in 7-DADMax water temperature exceedances from BBC10.4 to BBC8.8.
- Riparian plantings associated with greenway improvement projects may be buffering against climate change related temperature increases. Significant increasing stream temperatures were detected in the upper stream reaches (BBC8.4 and above), but no significant temporal trends were detected in the more heavily planted mid and lower reaches.
- Increases in turbidity from BBC5.2 to BBC2.6 and from BBC2.6 to BBC1.6 appear to be driven by different sources including road and highway runoff and erosion accelerated by human impacts in the Cold Creek tributary watershed.
- Increasing trends in chloride and conductivity may be associated with each other and driven by widespread use of magnesium chloride deicer in the BBC basin. While chloride concentrations are low relative to water quality criteria, additional consideration and monitoring related to deicer applications may be necessary to protect vegetation and infrastructure.
- Water quality in tributaries, particularly Peterson Channel and Cold Creek, are driven by unique conditions that appear to be impacting water quality in BBC. Priorities for management activities within tributary basins may be different than for basins contributing directly to the mainstem but are an important component of addressing water quality concerns in the watershed.
- Compared to other Western Washington creeks, BBC had comparable concentrations of TSS and total zinc but tended to have higher concentrations of nutrients (total phosphorus and nitrate + nitrite). Water Quality Index (WQI) scores at BBC stations were lower than most King County creeks monitored in 2015 for the Stormwater Action Monitoring program (King County 2018).

Key Recommendations

No changes to monitoring locations or sampling frequency are recommended, as a consistent dataset will facilitate future statistical analyses to quantify changes in water quality, environmental impacts of climate change, and in stream response to management activities. Slight changes to sampling methods to address potential quality assurance issues of soluble reactive phosphorus (SRP) samples have already been implemented. In addition, microbial source tracking to further identify sources of bacterial contamination in BBC in WY2025 is underway. Future beneficial studies and analyses to support water quality improvements and general watershed and public health include stream flow monitoring, select source tracking sampling, high-level survey of encampment distribution along BBC, and climate modeling to identify potential impacts to environmental and public health. These additional studies should be revisited upon the finalization of Washington State Department of Ecology's Total Maximum Daily Load (TMDL) Advance Restoration Plan to ensure priorities are aligned.

Consistent with previous reports, we recommend that the City continue its existing and planned water quality management activities including:

- **Septic system disconnects**. Continued prioritization of the Sewer Connection Incentive Program and other means to facilitate elimination of septic systems within the BBC watershed, prioritizing the approximately 530 systems within 1,500 feet of the creek. Additional funding mechanisms to encourage connection to the city sewer system may need to be explored to ensure long-term support for the program.
- **Expanded stormwater treatment**. For subbasins impacted by highway runoff, we recommend using WSDOT stormwater funds to implement additional stormwater BMPs, particularly in basins like BBC2.6 where several highway outfalls discharge to BBC and storm flow turbidity levels are elevated. In the BBC2.6 subbasin, roadways that contribute substantial runoff to the creek should be evaluated for stormwater retrofit opportunities. The contributing area draining to Burton Channel is also a good candidate for a retrofit study to address metals exceedances observed at BUR0.0.
- **Riparian cover and stream restoration**. To address relatively widespread water temperature criteria exceedances, continued emphasis on restoring riparian cover is recommended. This may include protection for pre-existing mature riparian cover and increased plantings in stream reaches with limited riparian cover including the reach of BBC upstream of BBC8.8. Continue to collaborate with community and private partners to maximize restoration in priority areas. Instream restoration in other basins, such as the Cold Creek drainage, could be used to address streambank erosion that is likely contributing to increased turbidity.
- **Illicit dumping and human impacts**. Direct human impacts on the stream and riparian zones are visible along several reaches of BBC. The City has implemented enforcement mechanisms to minimize the presence of human encampments and illicit dumping or discharges to the creek, but the tremendous extent of this issue has impacted areas of this watershed. Additional support, safety, and sanitation services, along with increased capacity in housing alternatives can reduce encampments near streams by people experiencing homelessness. Continued collaboration and coordination with community groups may also be beneficial in supporting homelessness response and waste removal in environmentally sensitive areas.

1. INTRODUCTION

Since 2004, the City of Vancouver, Washington (the City) has conducted water quality monitoring in Burnt Bridge Creek (BBC). The primary goal of the long-term monitoring program is to collect credible water quality data and identify spatial and temporal trends in water quality. This ongoing monitoring program provides a robust dataset that the City can use to assess the effectiveness of existing programs and to implement adaptive management strategies to protect water resources. BBC remains on the state 303(d) list of impaired waterbodies for not meeting water quality standards for temperature, dissolved oxygen, bacteria and pH. The City is anticipating the completion of a Total Maximum Daily Load (TMDL) Advance Restoration Plan by Washington State Department of Ecology (Ecology) that will identify activities and strategies needed to bring the creek into compliance with state criteria. This long-term monitoring program aids the City in fulfilling its regulatory requirements and supports its goals in protecting water quality and public health within the BBC watershed.

Data collected between June 2011 through October 2018 consisted primarily of summer and early base flow monitoring (six events per year during the critical temperature season), with the addition of storm monitoring in the winter of 2012-2013. Previous monitoring was summarized in separate annual monitoring reports (Herrera 2012a, 2013a, 2014a, 2015a, 2016a, 2017a, 2018a, and 2019a), using procedures detailed in the 2011 Quality Assurance Project Plan (QAPP) (Herrera 2011a) and subsequent QAPP addendums (Herrera 2012b, 2013b, 2014b, 2015b, 2016b, 2017b, and 2018b).

In 2019 the program transitioned to year-round monitoring (12 events per year), following a hydrologic water year (WY) period of October 1, 2019, to September 30, 2020 (WY2020). Data collected in WY2020 to WY2023 followed procedures outlined in the Monitoring Program 2019-2021 QAPP (Herrera 2019a) and its subsequent addenda, extending coverage to WY2021-2023 (Herrera 2022a). Storm and base flow monitoring conducted from 2019 to 2023 are summarized in separate monitoring reports (Herrera 2022b, 2022c, 2024a). To maintain consistency and comparability, monitoring procedures were generally consistent with those in previous QAPPs. One exception is that additional parameters were introduced for WY2020–WY2021 monitoring: hardness, chloride, dissolved organic carbon (DOC), as well as total and dissolved metals (cadmium, copper, lead and zinc).

Trend analysis reports were prepared in 2013 and 2017 and evaluated data collected from 2011–2013 (Herrera 2014a) and 2011–2017 (Herrera 2018a). This report includes an annual summary for recent monitoring conducted in WY2024 and a temporal and spatial trend analysis of data collected from 2011 to 2024.

1.1. Overview

The City continues its long-term monitoring activities for BBC under the Ambient Water Quality Monitoring Program (the Project). The purpose of the Project is to collect credible water quality data that supports and informs City and State efforts to improve and protect water quality in BBC. Data collected under the Project is used to assess the effectiveness of water quality improvement activities throughout the watershed.

State water quality standards have been established to restore and maintain beneficial uses in Washington's waters as required by the federal Clean Water Act (WAC 173 201A). These standards are specifically designed to protect public health, public recreation in the waters, and the propagation of fish, shellfish, and wildlife. Beneficial uses of BBC as defined by the Washington State Department of Ecology (Ecology) are primary contact recreation and salmonid spawning, rearing, and migration (Ecology 2008).

Water quality in BBC has been monitored extensively for more than 40 years, including a TMDL study by Ecology, with 19 monitoring stations along the stream and its tributaries in 2008 through 2009 (Ecology 2008). Monitoring data have shown that segments of BBC do not meet state water quality standards for temperature, dissolved oxygen, pH and bacteria (fecal coliform and *E. coli*) at varying times of the year. A state Source Assessment study conducted by McCarthy (2020) analyzed impairments to the watershed, including a shade analysis in relation to temperature impairments. An Advance Restoration Plan (pre-TMDL) is in the final stages of development by Ecology identifying necessary actions to improve water quality and meet state standards, preempting a full TMDL plan (Vancouver 2023). Temperature, dissolved oxygen, pH and fecal coliform bacteria are parameters of primary focus. Other parameters of concern include nutrients and contaminants associated with stormwater runoff.

It is the City's intent to bring BBC into compliance with state water quality standards. To meet this goal, the following objectives have been defined for this project:

- Accurately characterize specific water quality parameters within the creek
- Maintain consistency with past monitoring efforts
- Monitor water temperature continuously at select monitoring locations during the critical season (June – October) for elevated temperature
- Provide high quality data for the City and other users
- Determine whether trends or correlations are present in the water quality data
- Identify stream reaches or tributaries that show improvement in water quality related to the application of best management practices in the watershed
- Provide feedback for adaptive strategies in stormwater management programs

1.2. Study Area

BBC is a highly modified urban stream that flows westward 12.6 miles, from the eastern edge of Vancouver's city limits to the western boundary, where it discharges into Vancouver Lake (Figure 1). The oversized valley that BBC now occupies was created when the Missoula floods swept down the Columbia River 15,000 to 13,000 years ago, repeatedly emptying a massive lake created by ice dams formed in the last ice age. Historically the upper portion of BBC, between Northeast 162nd Avenue to East 18th Street, carried groundwater and precipitation from the marshlands that were dispersed through the broad plains of the basin.

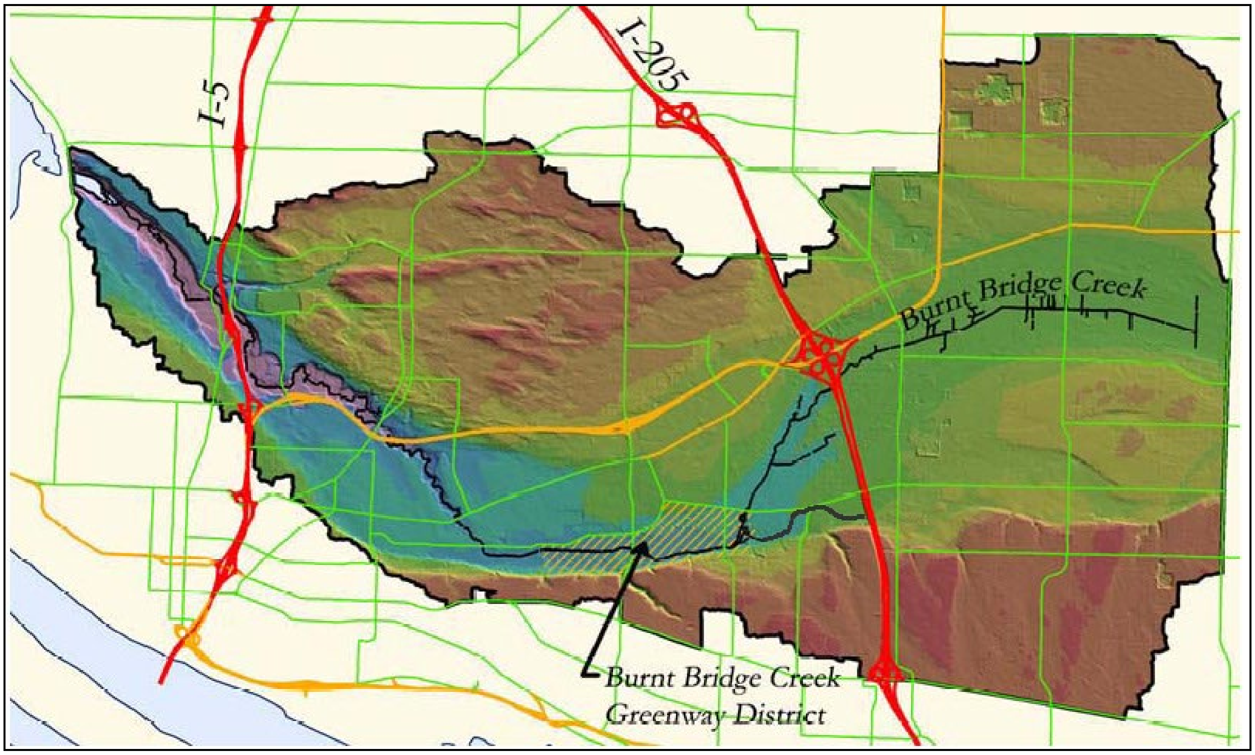


Figure 1. Burnt Bridge Creek Watershed.

What is now referred to as the city of Vancouver is within unceded territory of the Chinookan peoples who lived in the area from 4000 BCE or earlier until displacement by European colonizers in the 1800s. As settlement expanded, the marshlands became valuable for agricultural use and the wetlands and prairies were ditched and connected to drain the marshes. Today, wetland and upland prairie areas remain evident in the topography and vegetation (Figure 2).

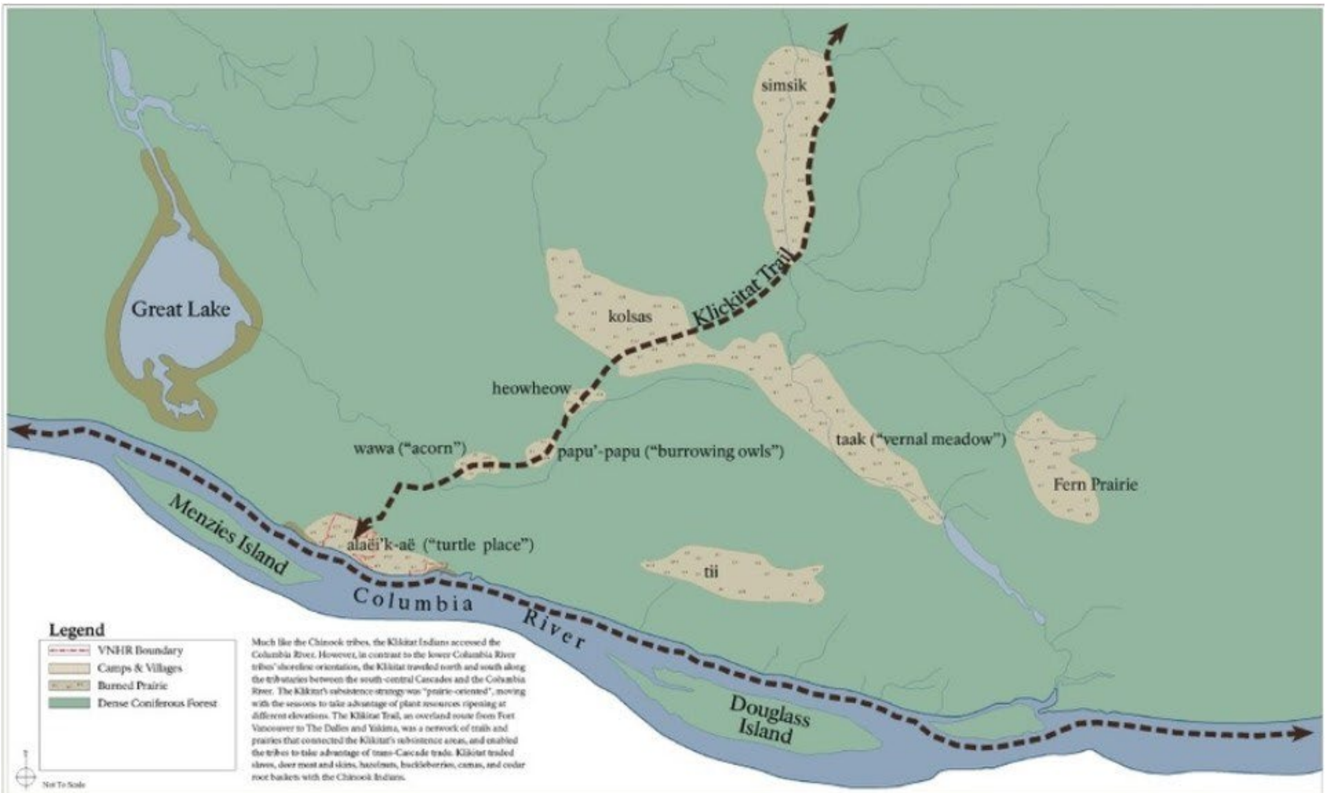


Figure 2. The Area of the City of Vancouver, As It Appeared Prior to 1824.

Image Credit – National Park Service (NPS 2018).

On average, the gradient of the stream is less than 1 percent (Tetra Tech 2015). Stream flow from late fall through spring is driven by precipitation, while summer flow is maintained by natural groundwater inflow coupled with non-contact cooling water from a silicone water manufacturing facility located east of Interstate 205 (I-205). The manufacturing facility extracts groundwater for cooling operations and contributes a significant amount of discharge water, which helps sustain summer base flow in the creek.

Peterson Channel and Burton Channel are two minor tributaries that flow into BBC east of Northeast 86th Avenue. Peterson Channel begins east of I-205 and conveys industrial discharge and urban stormwater runoff to BBC near the southern end of Royal Oaks Country Club and golf course. Burton Channel also initiates east of I-205 and joins BBC south of Burton Road, near the southern end of Meadowbrook Marsh. A third tributary, Cold Creek, flows west through unincorporated Clark County and joins BBC just west of Interstate 5 (I-5) approximately two miles upstream of Vancouver Lake. Monitoring stations are identified by their River Mile (RM) location along the 12.6 mile stream, from the mouth at BBC0.0 (RM 0.0) where the stream enters Vancouver Lake to current station BBC10.4 (RM10.4) at NE 110th Avenue.

1.3. Background Review

Monitoring in BBC has been ongoing for decades. The following sections summarize pertinent current and previous studies in the watershed related to water quality and biological health.

1.3.1. Surface Water Quality

1.3.1.1. Long-Term Monitoring Program

In 2004, the City's Surface Water Management Program launched a long-term ambient monitoring program to collect credible water quality data and provide periodic data analysis reports. This work supports City and state programs and activities designed to improve water quality and protect the environment throughout the watershed. The program initially started with monitoring at six sites in the central corridor (2004–2007) and expanded to 14 locations in 2011 following a state TMDL monitoring study in the watershed. Eleven key monitoring locations were selected for ongoing monitoring under base flow conditions in 2012 and 2013. Herrera conducted annual summer base flow monitoring of BBC and its tributaries as well as storm event monitoring during the winter 2012–2013 season. Monitoring conducted from 2014 to 2023 has targeted the same 11 monitoring locations (Figure 3). In addition to collecting water quality data during base flow events, monitoring under storm flow conditions resumed in 2020.

Data collected in 2011–2021 were summarized in separate annual monitoring reports (Herrera 2012a–Herrera 2018a; Herrera 2019b; and Herrera 2022b). The 2013 and 2017 monitoring reports included evaluation of water quality trends for data collected from 2011–2013 (Herrera 2014a) and 2011–2017 (Herrera 2018a).

Monitoring methods have been selected to be consistent with previous efforts and are described in applicable QAPPs and subsequent QAPP addenda for the following monitoring periods:

- 2011–2013: 2011 QAPP and addenda (Herrera 2011a; Herrera 2012b; Herrera 2013b)
- 2014–2018: 2014 QAPP and addenda (Herrera 2014b; Herrera 2015b; Herrera 2016b; Herrera 2017b; Herrera 2018b)
- 2019–2023: 2019 QAPP and addenda (Herrera 2019a; Herrera 2022a)
- 2024: 2024-2027 QAPP (Herrera 2023)

1.3.1.2. Total Maximum Daily Load and Water Quality Assessment

In 2008, the state initiated a multiple parameter TMDL study and collected water quality data throughout the BBC watershed over a 2-year period. Stakeholders participating in Ecology's Burnt Bridge Creek Partnership are anticipating the completion of an Advance Restoration Plan based on recommendations from the Burnt Bridge Creek Source Assessment Report (McCarthy 2020). The Advance Restoration Plan is a near-term plan that includes a schedule of actions that will be taken to achieve water quality standards and is intended for faster implementation of strategies to benefit water quality than waiting for the completion of a full TMDL Plan. It will focus on temperature, dissolved oxygen, pH, and fecal coliform bacteria, establishing targets and timelines to meet state water quality standards.

Ecology is required to periodically assess the status of water quality in state waterbodies and submit an updated 303(d) list of impairments to the Environmental Protection Agency (EPA) using all existing, readily available and credible data. Waterbodies included in the assessment are assigned to specific categories based on data evaluated for each parameter (Water Quality Program Policy 1-11; Ecology 2018).

- Category 1: Meets tested standards for clean water. Although the water body meets state water quality standards, it does not necessarily imply the absence of all pollutants.
- Category 2: Shows evidence of a water quality problem but data is insufficient to demonstrate persistent impairment and continued monitoring is required.
- Category 3: Lacks sufficient data to categorize definitively into other categories.
- Category 4: Doesn't meet water quality standards but has a TMDL or alternative Pollution Control Program being implemented.
- Category 5: List of impaired water bodies traditionally known as the 303(d) list. TMDLs or other approved water quality improvement projects are required for water bodies in this category

During each water quality assessment cycle, updates to state water quality criteria and new data submittals are incorporated. Ecology recently completed the 2022 Water Quality Assessment and will submit it to the EPA for approval. Recent changes include the transition from fecal coliform to *E. coli* to determine compliance with bacteria standards. Monitoring project plans for BBC have also evolved to remain in alignment with state requirements to best protect water resources and aquatic life.

Table 1 summarizes existing and new assessment recommendations for water quality category assignments for BBC and its tributaries below. The 2022 assessment includes new impairment (Category 5) listings for copper and zinc in Burton Channel. Another recent addition to the impairment list for BBC was based on pesticide data collected by the Washington State Department of Agriculture (WSDA) in 2020 (WSDA 2022). Dichlorodiphenyltrichloroethane (DDT) was found to exceed criteria and the lower reach of the stream assigned to Category 5 303(d) in 2022 for DDT and its metabolites. When enough monitoring data have been submitted to demonstrate compliance with a specific criterion, the waterbody segment is placed in Category 1 for that parameter.

Table 1. Water Quality Assessment Listings for Burnt Bridge Creek and Tributaries.

Name and Relevant Monitoring Stations	Assessment Unit ID	Assessment Category	Existing Listing	2022 Listing
Burnt Bridge Creek (upper and middle) (BBC10.4, BBC8.8, BBC8.4, BBC7.0, BBC5.9, BBC5.2, BBC2.6)	17080003038767	Cat 5 – 303(d) list	Bacteria – Fecal Coliform pH Temperature Dissolved Oxygen	**Bacteria – *E. Coli*** pH Temperature Dissolved Oxygen
		Cat 1		**Cadmium** **Copper** **Lead** **Zinc**
Burnt Bridge Creek (lower) (BBC1.6)	17080003039082	Cat 5 – 303(d) list	Bacteria – Fecal Coliform Temperature Dissolved Oxygen	**Bacteria – *E. Coli*** Temperature Dissolved Oxygen **DDT (and metabolites)**
		Cat 2	Benzo(a)pyrene	Benzo(a)pyrene **Zinc**
		Cat 1	pH Metals[a] Ammonia-N	pH Metals[a] Ammonia-N **Chloropyrifos** **Pentachlorophenol** **4,4′-DDD** **4,4′-DDE** **4,4′-DDT**
Burnt Bridge Creek (lower, just before discharge to Vancouver Lake)	17080003038585	Cat 5 – 303(d) list	pH Bacteria – Fecal Coliform Temperature Total Phosphorus	pH **Bacteria – *E. Coli*** Temperature Total Phosphorus
Peterson Ditch (PET0.0)	17080003039841	Cat 5 – 303(d) list	Bacteria – Fecal Coliform Temperature	Bacteria – *E. Coli* Temperature
		Cat 2		**Dissolved Oxygen** **pH**
		Cat 1		**Cadmium** **Copper** **Lead** **Zinc**
Burton Channel (BUR0.0)	17080003039842	Cat 5 – 303(d) list	Bacteria – Fecal Coliform Temperature Dissolved Oxygen	Bacteria – *E. Coli* Temperature Dissolved Oxygen **Copper** **Zinc**
		Cat 2	pH	pH
		Cat 1		**Cadmium** **Lead**
Cold Creek (COL0.0)	17080003038368	Cat 5 – 303(d) list	Bacteria – Fecal Coliform	Bacteria – *E. Coli* Copper
		Cat 2	pH Dissolved Oxygen	pH Dissolved Oxygen **Zinc**
		Cat 1	Temperature	Temperature **Cadmium** **Lead**

New listings or changes to existing listings are proposed in the2022 Water Quality Assessment are **bolded.**

DDT = dichlorodiphenyltrichloroethane

[a] Metals include arsenic, lead, cadmium, chromium, copper, nickel, silver, zinc

1.3.2. Groundwater Influence

1.3.2.1. Vancouver Watershed Health Assessment

The results of the Vancouver watershed health assessment conducted by Herrera and Pacific Groundwater Group (PGG) are described in the *Integrated Scientific Assessment Report* (Herrera and PGG 2019). Key findings of the study include:

- While groundwater quality is generally very good within the watershed, it is vulnerable to contaminants introduced from the land surface as well as pollutants from septic systems and stormwater infiltration facilities. Pharmaceuticals have been detected in a number of groundwater sampling locations and elevated nitrate concentrations, particularly within the shallow groundwater system, indicate likely contamination from septic systems. The city relies solely on groundwater from deeper aquifers for all drinking water.
- The results of a GIS-based statistical analysis identified statistically significant correlations indicating that septic systems are increasing nitrogen and fecal bacteria concentrations, and that urban development is likely increasing phosphorus concentrations in BBC. The analysis also found statistically significant correlations between increasing riparian canopy cover and increasing dissolved oxygen and pH.

Recommendations of the study include:

- Collect additional data during storm flow conditions to allow for future analysis of stormwater management on water quality during storm events.
- Expand the Sewer Connection Incentive Program (SCIP) to incentivize septic disconnects.
- Continue efforts to improve and retrofit wells subject to underground injection control requirements.

This Project will assist the City with its continued efforts to assess the effectiveness of existing programs and to implement adaptive management strategies to protect water resources.

1.3.3. Stormwater Management

The City developed a Stormwater Management Action Plan (SMAP; Vancouver 2023) as a condition of their National Pollutant Discharge Elimination System (NPDES) permit. Through a Receiving Water Prioritization process, the middle BBC basin was identified as the area that would benefit most from stormwater management planning. The middle basin contains the greatest concentration of high traffic corridors, including sections of I-205 and SR500.

The SMAP identified the following most feasible best management practices (BMPs):

- Replacement of existing catch basins with treatment catch basins to provide basic treatment
- Retrofit of existing treatment facilities to provide enhanced treatment where possible

- Priority tree planting through City of Vancouver Urban Forestry
- Increased street sweeping in high traffic corridors and areas of high sediment loading
- Focused community outreach and education events

The City has completed an outfall impact assessment to further help prioritize outfalls and catchment areas for water quality improvement projects. Grant funds have been awarded for specific retrofit projects throughout the watershed, including locations along East Mill Plain Boulevard and Fourth Plain Boulevard that feed into the creek and shallow groundwater. In addition, the City has identified surface water projects in its 2025-2030 Public Works Capital Improvement Program (CIP) including a system basin study in the Peterson Channel basin to identify alternatives to address localized flooding and capacity constraints with expected start of construction in 2027. The CIP also identifies basin studies within the Burton Channel basin including Northeast 112th Avenue and Northeast 18th Street to Northeast 26th (active study), Northeast Cranbrook Drive (future study) and Northeast 98th Avenue by Marrion Elementary School (future study).

1.3.4. Urban Forestry & Sensitive Lands Management

The City manages stormwater from a comprehensive watershed approach to improve watershed health. The City completes grey infrastructure projects and actively invests in green infrastructure throughout the watershed. A thriving tree canopy is part of that comprehensive approach, providing a clean and sustainable environment that assists in improving water quality wherever trees are located. Based on recent tree canopy data, Vancouver's tree canopy has grown from 16 percent in 2011 to 21 percent in 2021. The City's goal is to improve and increase tree canopy throughout the watershed as part of a comprehensive watershed approach which includes both the lowland riparian zone and the upland areas of the watershed (Vancouver 2024). The City's Greenway Sensitive Lands Team manages the riparian areas, and the Urban Forestry Team manages the upland areas.

1.3.4.1. Greenway Restoration Improvements

In 2005, a three-mile stretch in the central riparian corridor of BBC was transformed through the Burnt Bridge Creek Greenway Improvement Project (see Figure 1). The eleven-million-dollar investment added water quality treatment through stormwater ponds and restored wetlands. The City's Greenway and Sensitive Lands program continues to increase riparian shade and expand natural habitat through the ongoing planting of hundreds of thousands of trees and shrubs. An eight-mile trail follows BBC's path as it winds through neighborhoods, forested riparian areas, open meadows and past wetlands, water quality treatment ponds, and enhanced upland and riparian habitats. Stream ambient water quality monitoring, initiated by the City in 2004, focused on the central greenway project area and expanded over time to include other sites along the mainstem and tributaries.

Grant funding has supported the purchase of six parcels up- and downstream of monitoring station BBC10.4 on Northeast 51st Circle and Northeast 112th Ave. Additional properties in the lower reach of the creek are under consideration currently to help expand protection and restoration projects. The Greenway/Sensitive Lands program will be managing these riparian properties.

1.3.5. Climate Action

The City's Climate Action Framework outlines strategies to enhance natural systems and increase climate resilience. Key actions pertaining to the Project include NS-1, which prioritizes expanding and maintaining urban tree canopies to mitigate heat islands and improve air quality; NS-2, which focuses on restoring and protecting wetlands, rivers, and natural habitats to support biodiversity and water quality; and NS-3, which emphasizes integrating green infrastructure, such as rain gardens and permeable surfaces, to manage stormwater sustainably. Together, these actions aim to leverage natural systems to enhance climate resilience and improve natural systems (Vancouver 2022).

1.3.6. Biological Health

1.3.6.1. Biologic Condition Assessment

A biological condition assessment was conducted in 2015 at four stations along BBC (BBC10.4, BBC8.4, BBC7.0, and BBC1.6) previously assessed in 2001. The study evaluated substrate, pools, large woody debris, stream morphology, channel slope, erosion, riparian vegetation, stream shading, fish cover and benthic macroinvertebrates.

The habitat types in the study reaches varied dramatically, and the authors recommend assessing each site over time, rather than comparing them to each other. Low gradient surface water slopes were observed along the stream segments, with the reach between BBC10.4 and BBC7.0 having the lowest gradient slopes. The highest percentage of bank erosion was observed at BBC8.4. Vegetative cover for fish ranged from 10 percent (BBC1.6) to 60 percent (BBC7.0). Salmonid species were observed at BBC 1.6 during sampling, and other species of fish were observed at BBC7.0. Channel shading was high at all four of the sites, with mid channel shading ranging from 74 to 80 percent, and bank shading ranging from 80 to 96 percent. Benthic index of biotic integrity (B-IBI) scores ranged from very poor to poor. BBC7.0 had the highest B-IBI score but was dominated by the nonnative New Zealand mud snail (Tetra Tech 2015).

1.3.6.2. Lower Columbia Urban Streams Monitoring

The City, in collaboration with other southwest Washington agencies operating under state NPDES Municipal Stormwater Permits, contributes funds for a regional receiving water monitoring program. Clark County is performing this long-term study under an Interagency Agreement with Ecology and conducts annual stream health monitoring at small urban streams throughout the Lower Columbia River region. Data collected in this study supports the Status and Trends Monitoring for Watershed Health and Salmon Recovery component of the statewide Stormwater Action Monitoring program. Annual monitoring is conducted at 22 sites. Five trend sites are monitored each year, and 17 status sites are sampled at intervals on a five-year rotation basis (Clark County 2020).

One location on BBC (Clark County ID: BBC050) met the study selection criteria and has been included as a trend site for annual monitoring. This site is located where the creek flows under East 18th Street and is also a current and historical monitoring location in the City's long-term monitoring program (station BBC5.9). The regional stream monitoring program assesses land cover, flow metrics, total impervious area, daily traffic intensity, B-IBI, stream temperature, sediment, and habitat. In WY2021, total impervious area in the subbasin contributing to BBC050 was 86 percent. BBC had the lowest B-IBI score of the eight streams monitored and qualified as “Very Poor.” BBC050 also had the highest 7-DADMax at 80.1 degrees Fahrenheit, and the 7-DADMax exceeded the criteria for core summer salmonid habitat (60.8 degrees Fahrenheit) over the entire monitoring period, June 15 to September 15, 2021 (Clark County 2023).

2. METHODS

The field monitoring, laboratory analysis, and data management and analysis methods are described below.

2.1. Field Monitoring Methods

Methods for collection of continuous temperature logging data, field water quality data, and grab samples are described in the following subsections.

The WY2024 monitoring program methods, in accordance with the 2024-2027 QAPP (Herrera 2023), are generally aligned with earlier monitoring periods (2011-2023) with some changes pertaining to parameters as well as number and type (i.e., the addition of storm events) of monitoring events within a given water year.

2.1.1. Monitoring Stations

Water quality sampling and field measurements were conducted at 11 stations along BBC and its tributaries, as shown in Figure 3. Continuous temperature monitoring data was collected seasonally at eight of the 11 stations. The same 11 monitoring stations and eight continuous temperature monitoring stations have been monitored by Herrera since 2011 and are listed below from upstream to downstream and identified by stream and river mile location:

Station BBC10.4: Burnt Bridge Creek at Northeast 110th Avenue near Northeast 51st Circle

Station BBC8.8: Burnt Bridge Creek immediately upstream of the Peterson Channel confluence near Northeast 93rd Avenue

Station PET0.0: Peterson Channel near the mouth at the northern end of Northeast 93rd Avenue

Station BBC8.4: Burnt Bridge Creek south of Northeast Burton Road just west of Northeast 90th Avenue

Station BUR0.0: Burton Channel 0.3 mile upstream of the mouth at Northeast 92nd Avenue and 19th Circle (no continuous temperature monitoring)

Station BBC7.0: Burnt Bridge Creek at the southern end of Northeast 65th Avenue

Station BBC5.9: Burnt Bridge Creek at East 18th Street east of Bryant Street

Station BBC5.2: Burnt Bridge Creek at Algona Drive (no continuous temperature monitoring)

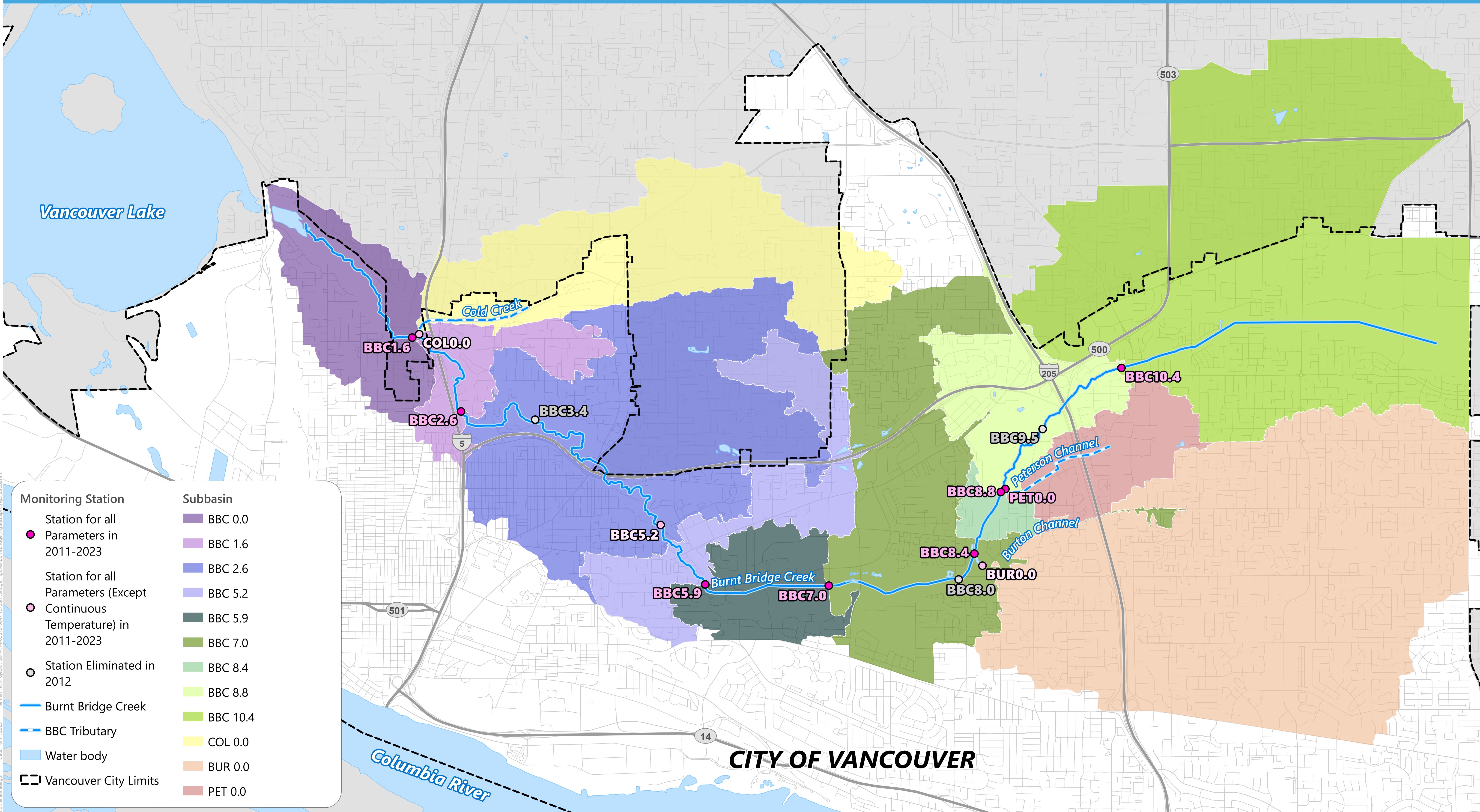
Station BBC2.6: Burnt Bridge Creek in Leverich Park near lower parking lot

Station COL0.0: Cold Creek near the mouth at Hazel Dell Road (no continuous temperature monitoring)

Station BBC1.6: Burnt Bridge Creek at Alki Road and below the Cold Creek confluence

Monitoring station subbasin attributes including land cover, septic system density and information about stormwater treatment facilities are provided in the *Integrated Scientific Assessment Report* (Herrera and PGG 2019). All the subbasin statistics are cumulative (including total upstream area). The subbasins consist of primarily residential land use (at least 80 percent), approximately half of impervious surface cover, and less than 20 percent tree canopy cover. Riparian canopy cover in the 100-foot-wide riparian buffer within 0.5 mile upstream of monitoring stations range from 25 to 56 percent. Septic systems are present in all subbasins with the greatest septic system densities in the BUR0.0, BBC10.4 and BBC8.4 subbasins.

Figure 3.
Burnt Bridge Creek Monitoring Stations and Subbasins.



Produced by Herrera Environmental Consultants (herrerainc.com) | Sources: City of Vancouver, Clark County, WSDOT.

2.1.2. Parameters of Concern

Parameters monitored from 2011 through WY2024 are summarized in Table 2 below, and the significance of individual parameters to water quality and BBC are discussed in the following subsections.

Table 2. Parameters of Concern for 2011-2019 and WY2020-2024.

Parameter	Monitoring Period				
	2011 – 2016	2017 – 2019	WY2020 – WY2022	WY2023	WY2024
In Situ measurements[a]	X	X	X	X	X
Total suspended solids	X	X	X	X	X
Turbidity	X	X	X	X	X
Hardness as $CaCO_3$			X	X	S
Chloride			X	X	
Dissolved organic carbon			X	X	
Nutrients[b]	X	X	X	X	X
Cadmium, total & dissolved			X		
Copper, total & dissolved			X	X	S
Lead, total & dissolved			X		
Zinc, total & dissolved			X	X	S
Fecal coliform bacteria	X	X	X		
E. coli bacteria		X	X	X	X
Optical brighteners			X		

[a] *In situ* measurements include instantaneous water temperature, pH, conductivity, dissolved oxygen concentration, and dissolved oxygen saturation.

[b] Individual nutrient parameters include total phosphorus, orthophosphate (or soluble reactive phosphorus), nitrate + nitrite, and total Kjeldahl nitrogen.

WY = Water year, the hydrologic period from October 1 through September 30.

X = Collected during both storm and base flow monitoring events.

S = Collected during storm flow monitoring events only.

2.1.2.1. Temperature

Water temperature is critical to the health and survival of fish and other aquatic species in many life stages including embryonic development, juvenile growth, and adult migration. The composition, metabolism, and reproductive effectiveness of cold-blooded aquatic species are also regulated by the water temperature. An increase in water temperature accelerates the biodegradation of organic matter, increases the DO demand, and decreases the solubility of oxygen. The state water quality standards for temperature are based on a 7-day average daily maximum (7-DADMax). The maximum allowable 7-DADMax is 17.5 degrees Celsius (°C) in waters designated for salmon and trout spawning, noncore rearing, and migration. BBC, Peterson Channel, Burton Channel and Cold Creek are Category 5 listed (requiring an improvement project) for water temperature due to state criteria exceedances.

2.1.2.2. pH

pH is a measure of the hydrogen ion activity in water, which can have a direct effect on aquatic organisms or an indirect effect since the toxicity of various common pollutants are markedly affected by changes in pH. Waters that have pH levels ranging from 0 to 7 are considered acidic, while waters with pH levels ranging from 7 to 14 are considered alkaline. Waters that have a pH of approximately 7 are considered neutral. Washington State surface water quality standards for noncore salmonid rearing require pH to be within the range of 6.5 to 8.5 (WAC 173-201A). Some wetlands such as peat bogs are naturally acidic with a pH between 5 and 6. BBC is Category 5 listed (requiring an improvement project) for pH.

2.1.2.3. Dissolved Oxygen

Dissolved oxygen is another important water quality parameter for salmonids and other aquatic organisms. Low dissolved oxygen levels can be harmful to larval life stages and respiration of juveniles and adults, directly affecting the survival of aquatic organisms. Depletion of oxygen in waterbodies can also lead to a shift in the composition of the aquatic community. Washington State surface water quality standards require that dissolved oxygen concentrations exceed 10 mg/L in fresh waters designated for noncore salmonid rearing (WAC 173-201A). Dissolved oxygen is affected by temperature; oxygen concentrations decrease as water temperatures increase. Higher nutrient concentrations are often found in warmer waters, so low dissolved oxygen is also associated with high nutrient concentrations. BBC and Burton Channel are Category 5 listed (requiring an improvement project) for dissolved oxygen.

2.1.2.4. Conductivity

Conductivity is a measure of the ability of water to conduct an electrical current, which is directly related to the content of dissolved ions in the water. Conductivity varies with temperature and is typically measured as specific conductance, which is normalized to a temperature of 25 °C. Although there is no state surface water quality standard established for conductivity, this measurement is useful for identifying sources of dissolved solids (primarily salts). It is also useful for determining the relative flow contributions attributed to groundwater, since conductivity is typically higher in groundwater than in surface water.

2.1.2.5. Turbidity

Turbidity is a measure of water clarity that is determined by how the transmission of light is scattered as it passes through water. An increase in the amount of particulate matter in water reduces clarity (or transparency) by increasing the scattering of light. Measurements of turbidity are expressed in nephelometric turbidity units (NTU). Washington State surface water quality standards restrict turbidity increases to a maximum of 5 NTU more than background when background turbidity is 50 NTU or less, and to no more than a 10 percent increase in turbidity when the background turbidity is greater than 50 NTU (WAC 173-201A). Typically, background turbidity is measured at an upstream location and turbidity criteria are applied to downstream location.

2.1.2.6. Total Suspended Solids

Total suspended solids (TSS) are the most widespread pollutants entering surface waters. Solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish spawning and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds. These pollutants tend to adsorb to the solids particles and are transported in surface runoff to receiving waters if onsite controls are not implemented for solids removal. Thus, the presence of suspended solids is used to evaluate the overall pollutant loading within a basin. No state surface water quality standards have been established for TSS.

2.1.2.7. Nitrate + nitrite Nitrogen

Washington State does not have a surface water quality standard for nitrate + nitrite nitrogen; however, it is a regulated parameter in state groundwater and drinking water (WAC 173-200-040 and WAC 246-290-310, respectively) for the protection of human health. To prevent a potentially fatal blood disorder in infants called "blue baby syndrome" as well as other human health problems, both standards specify that nitrate + nitrite nitrogen concentrations shall not exceed 10 mg/L. Nitrate + nitrite nitrogen is also a concern in freshwaters because it may contribute to an overabundant growth of algae and aquatic plants and to a decline in diversity of the biological community. EPA (2001) recommended a nutrient criterion of 0.15 mg/L for nitrate nitrogen in rivers and streams in the Willamette Valley ecoregion. This criterion was used for comparison to sampling results.

2.1.2.8. Total Nitrogen

Currently, Washington State has not established surface water quality criteria for total nitrogen. However, the EPA (2001) has established a nutrient criterion of 0.31 mg/L for total nitrogen in streams located in the Willamette Valley Ecoregion. This criterion was used for comparison to these sampling results. Nitrogen can come from natural or anthropogenic sources including atmospheric deposition, wastewater treatment plants or septic system failures, animal manure storage, and fertilizer runoff. Total nitrogen concentrations for each sample were calculated by the analytical laboratory using results from nitrate + nitrite and total Kjeldahl nitrogen analyses.

2.1.2.9. Soluble Reactive Phosphorus

SRP, also known as orthophosphate, is the dissolved inorganic fraction of phosphorus that is produced by natural processes and from sources similar to those for total phosphorus such as septic system failure, animal waste, decaying vegetation and animals, resuspension from the bottom of a lake, and fertilizer runoff. It is a very unstable form of phosphate that is directly absorbed by aquatic vegetation and microbes such as algae. Neither Washington State nor the EPA have established surface water quality criteria for SRP.

2.1.2.10. Total Phosphorus

Total phosphorus is a combination of inorganic and organic forms of phosphorus, which can come from natural sources or anthropogenic sources (e.g., wastewater treatment plants, septic system failures, animal manure storage, and fertilizer runoff). Phosphorus is a concern in fresh water because high levels can lead to accelerated plant growth, algal blooms, low dissolved oxygen, decreases in aquatic diversity, and eutrophication. Currently, Washington State does not have surface water quality standards for total phosphorus in rivers and streams. The EPA recommended a nutrient criterion of 0.040 mg/L for total phosphorus in streams located in the Willamette Valley ecoregion (EPA 2001).

2.1.2.11. Dissolved Organic Carbon

DOC was introduced during the WY2020 monitoring period to support calculation of acute and chronic aquatic toxicity of dissolved copper and to correct optical brightener measurements which were introduced during the same period. DOC analysis was discontinued in WY2024 after conclusion of the temporary optical brighteners study and because Washington State surface water quality criteria do not use DOC in toxicity calculations.

DOC is a measure of the amount of dissolved organic matter in water. Surface water sources of DOC include precipitation, leaching, and organic decomposition. DOC is a key driver in stream metabolism and can reduce acute toxicity of many contaminants to aquatic organisms through removal of free metal ions or sorption of chemicals to DOC. DOC can vary greatly among water body type and region; in Washington state, DOC in surface water samples vary from approximately 0.2 to 81 mg/L, with a mean of 2.1 mg/L according to Ecology's Environmental Information Management database.

2.1.2.12. Hardness as CaCO3

Hardness is a measurement of the dissolved mineral content (primarily calcium and, to a lesser extent, magnesium) of water. Hard water contains a high mineral content and soft water contains a low mineral content. High hardness values can increase or decrease the toxicity of metals in runoff, depending on the aquatic species that is exposed. Hardness values are therefore used to calculate dissolved metals toxicity criteria. Natural sources of hardness include limestone (which introduces calcium into groundwater), dolomite (which introduces magnesium), or any other calcium- or magnesium-bearing minerals and soils. No state surface water quality standards have been established for hardness. Hardness as calcium carbonate was introduced during the WY2020 monitoring period along with select dissolved metals to calculate dissolved metals toxicity criteria.

2.1.2.13. Chloride

Chloride is a measurement of dissolved chloride in association with sodium, potassium, calcium, and magnesium as salts. Chlorides are present in a variety of products, such as water and wastewater treatment products (i.e., chlorine, iron chloride), roadway deicing salts including magnesium chloride which the City utilizes, and fertilizers (e.g., potassium chloride). Thus, anthropogenic sources of chloride may include road deicer, landfill leachate, septic tank or industrial effluent, and irrigation drainage. Chlorides may also occur naturally in surface and groundwater, originating from natural sources like seawater intrusion in coastal areas and weathering of various rocks. Chloride was introduced during the WY2020 monitoring period as a septic indicator parameter. It was discontinued in the WY2024 monitoring program because sufficient data had been collected, and base flow concentrations were generally consistent from station to station.

Chloride can increase the corrosivity of water, so it may react with metal ions in pipes and increase the concentration of metals in drinking water or waterways. Measuring chloride in freshwater systems is an important indicator of impairment and is often used specifically to evaluate potential inputs from septic systems. According to the World Health Organization (WHO), chloride levels in unpolluted waterways are often below 10 mg/L, and sometimes below 1 mg/L. There are no Washington State human health criteria for chloride. Healthy individuals can tolerate large quantities of chloride as long as it is accompanied by an intake of fresh water (WHO 2003). However, Washington State does maintain a criterion for aquatic life uses, which restricts chloride concentrations to less than 860 mg/L for acute exposure and 230 mg/L for chronic exposure (WAC 173-201A-240).

2.1.2.14. Total and Dissolved Metals

Select total and dissolved metals were added to the monitoring program starting in WY2020. Of these, copper and zinc are two of the most common heavy metals observed in urban streams. The dissolved fractions of these heavy metals were included in the storm flow monitoring program to evaluate acute aquatic toxicity within the project area. Potential sources of these heavy metals within the BBC watershed include vehicle components, petroleum-based fuels and oil, electronics waste, metal roofs, and eroding soils. Washington State surface water quality standards (WAC 173-201A) for these two heavy metals are based on the dissolved fraction and vary directly with hardness concentrations such that toxicity decreases with increasing hardness.

Cadmium and lead were included as target parameters from WY2020 through WY2022 and were discontinued because the parameters were either consistently undetected or were well below water quality criteria. The remaining metals, copper and zinc, were changed to storm flow events only starting in WY2024 due to infrequent chronic water quality criteria exceedances during base flow events.

2.1.2.15. Bacteria

Urban and agricultural runoff typically contain elevated levels of fecal coliform bacteria. These organisms are used as indicators of fecal contamination from humans and other warm-blooded animals. Human sources include failing septic systems, waste from unhoused encampments, leaking wastewater conveyance systems or side sewers, and cross-connections with municipal wastewater systems. Animal sources include pets, livestock, and wildlife (e.g., birds and mammals). Fecal coliform bacteria are also present in the natural environment from decaying vegetation and other organic matter. The simple presence of these bacteria does not necessarily indicate a threat to public health because only a small portion is likely to be pathogenic to humans. However, their use as an indicator is considered important in the early detection of problems that could lead to public health concerns.

Washington State surface water quality standards (WAC 173-201A) for fecal coliform bacteria are presented in Table 7 in Section 2.2.5, Comparison to Water Quality Criteria. In July 2018, Ecology proposed a transition from fecal coliform to the use of *E. coli* criteria for freshwater bodies due to the more robust correlation of gastrointestinal illness with these bacteria parameters and in conformance with EPA recommendations (Finch 2018). In January 2019, Ecology adopted the *E. coli* water quality standard (WAC 173-201A; Ecology 2019). Fecal coliform and *E. coli* bacteria were both analyzed over several years starting in 2017 to determine the relationship between the two indicator parameters. Fecal coliform was ultimately removed as a parameter for the WY2024 monitoring program.

BBC, Peterson Channel, Burton Channel and Cold Creek are currently Category 5 listed (requiring an improvement project) for fecal coliform bacteria. Ecology has proposed updating the listing to *E. coli* bacteria to reflect adoption of *E. coli* instead of fecal coliform state criteria.

2.1.3. Monitoring Events

Data collection methods followed the protocols outlined in the 2024-2027 QAPP (Herrera 2023) and are summarized in the following sections. Table 3 presents the dates and details of each sampling event for the WY2024 monitoring program.

Table 3. WY2024 Sampling Events for the Burnt Bridge Creek Water Quality Monitoring Project.

Event ID	Sample Date	Sample Event Type	Weather Season[a]	Sample Duplicate Station	Antecedent Dry Period (days)[b]	Storm Depth at Start of Sampling (inches)	Total Storm Depth (inches)[c]
1	11/27/2023	Base	Wet	BBC10.4	5.0	0	0.01
2	12/5/2023	Storm	Wet	PET0.0	1.1	0.72	1.38
3	1/8/2024	Storm	Wet	BBC5.2	1.1	0.22	0.71
4	2/13/2024	Base	Wet	BBC8.8	1.9	0	0
5	2/28/2024	Base	Wet	BBC7.0	1.8	0.03	0.04
6	3/12/2024	Storm	Wet	BBC2.6	0.8	0.09	0.10[d]
7	3/27/2024	Storm	Wet	COL0.0	0.9	0.46	0.51
8	4/25/2024	Storm	Wet	BBC5.9	17.5	0.27	0.39
9	6/24/2024	Base	Dry	BBC8.8	6.8	0	0
10	7/15/2024	Base	Dry	BUR0.0	26.8	0	0
11	8/13/2024	Base	Dry	BBC8.4	55.8	0	0
12	9/3/2024	Base	Dry	BBC1.6	0.9	0	0

[a] Dry and wet weather season are defined as June through September and October through May, respectively.

[b] Antecedent dry period was defined as the number of days with less than 0.04 inch of rain in a 6-hour period (storm events) or 24-hour period (base flow events) that preceded the event date (Portland BES 2023).

[c] Storm depth was determined as the total precipitation amount measured for the full duration of the targeted storm event (as defined by storm criteria) or base flow event (as determined by base flow sampling criteria) (Portland BES 2023).

[d] A storm event was targeted for March 12, 2024, but the event resulted in less rainfall than was predicted. A total of 0.10 inch was observed on the sampling day. The antecedent dry period was calculated from the start of the previous day's rainfall.

2.1.4. Continuous Temperature Logging Data

One HOBO Pro v2 water temperature data logger was installed at each of eight monitoring stations. Additional probes were installed at stations BBC8.8, PET0.0, BBC8.4, BBC2.6, and BBC1.6 for backup because of vandalism and challenges locating them. For WY2024, the loggers were deployed from April 23 to November 8, 2024.

The data loggers were installed and operated according to the Washington State Department of Ecology's protocols for continuous temperature sampling as described in the QAPP (Herrera 2023). Temperature loggers were installed inside a shade device consisting of a perforated PVC pipe that was attached to rebar set in the stream bed. Due to concerns of vandalism, the PVC pipe was painted brown to camouflage the loggers. Temperature loggers were placed in well-mixed locations that were shaded from direct sunlight (wherever possible) to minimize influence from direct solar radiation. All temperature loggers were programmed to record temperature at an interval of 15 minutes.

Continuous temperature data were downloaded from all temperature data loggers during each base flow monitoring event using the Onset HOBOware® software. Missing and qualified continuous temperature data are identified in the Data Quality Review in Appendix A. Temperature probe calibration check results are presented in Appendix B.

2.1.5. Field Water Quality Data

In situ water quality measurements were made at each of the 11 monitoring stations by submerging the probe of a calibrated water quality multimeter into the water column. Herrera's YSI Pro DSS multimeter was used for all events. To ensure accuracy and minimize variability across different multimeters standardized field calibration procedures, including post-event calibration checks, were followed (Herrera 2023).

Upon arrival at a monitoring station, the probe was submerged in the stream where the current was estimated to be at least 1 foot per second to avoid false low readings and was left to stabilize for several minutes. The probe was placed upstream of all instream activity. When the meter's readings were stabilized, measurements were recorded for each water quality parameter on standardized field forms. Field duplicate measurements were collected once during each sampling event by re-submerging the multi-probe meter in the stream during the sampling event.

2.1.6. Grab Sample Collection

Water samples were collected by hand from each of the 11 monitoring stations using precleaned bottles supplied by ALS Environmental. Samples were collected from the center of the stream by wading into the channel and using an aseptic technique. Water samples were collected after the *in situ* measurements were recorded in order to ensure that both the *in situ* measurements and water sampling would occur upstream of all channel disturbance from monitoring activities. One field duplicate sample was collected from a different station during each sampling event by consecutively filling each pair of sample bottles and differentiating the duplicate sample bottles with a blind sample number. The collected water samples were immediately stored in a cooler with ice at a temperature less than 6 degrees Celsius (°C). All other samples were picked up by the ALS laboratory courier the morning after the sampling event. Chain-of-custody forms were completed and included with each batch of samples sent to the laboratory.

2.1.7. Laboratory Analysis Methods

Table 4 presents the required analytical methods and the total number of samples analyzed in WY2024. These methods are consistent with the methods outlined in the 2024-2027 QAPP (Herrera 2023).

Table 4. Methods and Number of Samples for Water Quality Analyses for WY2024.

Parameter	Analytical Method	Method Number[a]	Number of Samples[b]
Base and Storm Flow			
Turbidity	Nephelometric	EPA 180.1	144
Total suspended solids	Weighed filter	SM 18 2540D	144
Total phosphorus	Persulfate digestion, ascorbic acid	EPA 365.3	144
Soluble reactive (orthophosphate) phosphorus	Ascorbic acid	EPA 365.3	144
Total nitrogen	Kjeldahl digestion, ammonia-selective electrode with known addition, adding to nitrate nitrite	EPA 351.4; SM 4500-NH3 G LL	144
Nitrate + nitrite nitrogen	Automated cadmium reduction	EPA 353.2	144
E. coli bacteria	Colilert® Quanti-Tray/2000®	SM 9223B	144
Storm Flow Only			
Hardness as CaCO3	Titrimetric	SM 2340C	60
Metals, total and dissolved	Inductively Coupled Plasma-Mass Spectrometry	EPA 200.8	60

[a] SM = APHA Standard Methods (APHA et al. 1998), EPA = U.S. Environmental Protection Agency Method Code

[b] Number of samples based on 12 samples for each of the 11 locations plus 12 field duplicates for quality control for base and storm flow parameters. For storm flow only parameters, the number of samples is based on 5 samples for each of the 11 locations plus 5 field duplicates.

Sample preservation, maximum holding times, and analytical methods met federal requirements for the Clean Water Act (Federal Register 40 CFR Part 136; EPA 2011) and recommendations by Standard Methods (APHA et al. 1998) with the following exceptions specified in the QAPP:

- *E. coli* bacteria was analyzed within 30 hours of sample collection, exceeding the EPA recommended maximum holding time of 8 hours for source water compliance samples. However, EPA guidance allows for up to 30-hour holding times for other types of samples including drinking water samples and up to 48 hours if the State determines, on a case-by-case basis, that analyzing the sample within 30 hours is not feasible (EPA 2008). A review of nine studies on holding time exceedances for *E. coli* samples found that most samples can be analyzed by common methods (e.g., membrane filtration, multiple tube fermentation, Quanti-Tray) up to 48 hours after collection if they are stored below 10°C (Thapa et al. 2020). The holding time of 30 hours used for this study was appropriate and allowed for samples that are not source water compliance samples.
- Orthophosphate phosphorus and dissolved metals samples were filtered at the laboratory within 30 hours of sample collection, exceeding the recommended maximum filtration time of 15 minutes. Field filtration is recommended primarily for ground water and wastewater samples with a low

dissolved oxygen concentration to prevent oxidation and precipitation of orthophosphate and dissolved metals. The maximum filtration time of 30 hours was used because the collected surface water samples are not expected to be in a reduced (low oxygen) state or contain high biochemical oxygen demand.

2.2. Data Analysis Methods

This section includes a subsection for each of the following procedures: data sources, data management, computation of summary statistics, temporal and spatial patterns, comparison of results to the applicable water quality criteria, Water Quality Index (WQI) scores, and comparison of results to other streams. Summary statistics and comparisons to water quality criteria were made with data collected in WY2024. All other analyses used available data from 2011–WY2024 monitoring results, this data is further detailed in the following section. The results from these analyses are summarized in Section 3, Results.

2.2.1. Data Sources

Table 5 presents the number of events and time periods for data collected prior to WY2024 and used for temporal and spatial analyses.

Table 5. Sampling Events for the Burnt Bridge Creek Ambient Water Quality Monitoring Program, 2011-2017 and Burnt Bridge Creek Water Quality Monitoring Project, WY2020– 2023.

Monitoring Program Year[a]	Number of Events	Storm Events	Base Events	Time Period	Date Range
2011-2018 Monitoring					
2011	6	NS	6	June – October	6/21/11 – 10/18/11
2012				June – November	6/11/12 – 11/7/12
2013				June – October	6/11/13 – 10/15/13
2014				June – November	6/19/14 – 11/11/14
2015				June – October	6/16/15 – 10/14/15
2016				June – October	6/21/16 – 10/12/16
2017				June – October	6/19/17 – 10/10/17
2018				June – October	6/26/18 – 10/16/18
WY2020-2023 Monitoring					
WY2020	10	5	5	November 2019 – November 2020	11/11/19 – 11/5/20
WY2021	12	5	7	November 2020 – September 2021	11/18/20 – 9/27/21
WY2022				November 2021 – September 2022	11/11/21 – 9/21/22
WY2023				November 2022 – October 2023	11/1/22 – 10/4/23

[a] Number of events are associated with program year and occasionally extend into the following water year.

NS = Not sampled. Storm event monitoring data was collected in 2013 but were omitted from the analyses due to limited sample size.

Monitoring conducted from 2011 through 2018 included six base flow sampling events each year, occurring approximately once every 3 to 4 weeks from June to October, with one sampling event in early November in 2012 and 2014. Twelve samples were collected for each event, including one duplicate, for a total of 72 samples per year. All monitoring events occurred during dry weather and base flow conditions and met the antecedent dry period criteria of less than 0.04 inches of rain in the previous 24 hours.

Monitoring conducted from WY2020 through WY2023 was described in the 2019–2021 QAPP (Herrera 2019a) and an addendum for WY2022–WY2023 (Herrera 2022a). Five storm and seven base flow events were conducted annually, with one exception. Interruptions in the sampling program due to the coronavirus (COVID-19) pandemic resulted in cancellation of two of the seven planned base flow events in WY2020. Sampling resumed in August 2020, with health and safety precautions in place. Additionally, some planned storm events in WY2020 were delayed until WY2021 due to COVID-19 restrictions and insufficient precipitation (Herrera 2022b). Approximately half of base flow events occurred during the dry-weather season (June through September), and half occurred during the wet-weather season (October through April). Most storms occurred during the wet season. Two storm events, February 7, 2023, and March 23, 2023, were targeted for monitoring but resulted in less rainfall than anticipated (Herrera 2024a).

2.2.2. Data Management

Field measurements were entered into a Microsoft Excel spreadsheet along with the laboratory analytical results. Data flags representing estimated values were also entered in the spreadsheet database based on results of the data quality review. Database input was checked after entry to ensure that any transcription errors were corrected.

Continuous temperature data were transferred from the manufacturer's software system (HOBOware®) to a Microsoft Excel spreadsheet. The data were visually reviewed, spikes and drops representing times when the probes were taken out of the stream for downloading were removed. The raw data were preserved for each station, while the corrected data were used for further analysis and graphical presentations.

2.2.3. Computation of Summary Statistics

In order to assess water quality conditions at each of the sample locations, R software packages were used to calculate the following summary statistics from the WY2024 compiled data:

- Minimum
- Mean
- Geometric mean (*E. coli* only)
- Median
- 25th percentile
- 75th percentile
- 90th percentile
- Maximum

When undetected values were present in the data, the reporting limit was used in all calculations. Use of the reporting limit for undetected values is consistent with historical data management practices but may result in a slightly higher bias than other estimating methods, such as using one-half of the reporting limit or zero for undetected values. The summary statistics were then compiled in individual summary tables for each of the monitoring parameters. Summary statistics are presented in Appendix D-1.

In addition to the tabular data summaries, graphical data summaries consisting of "box and whisker" plots (boxplots) were produced for the WY2024 monitoring program. The boxplots present the following information for each station: the minimum and maximum values as the lower and upper whiskers, respectively; the median and mean as the line and point in the box, respectively; and the 25th and 75th percentiles of the data as the lower and upper boundaries of the box, respectively. For *E. coli*, the 90th percentile of the data is also shown on the plot as a brown triangle and the geometric mean is presented rather than the arithmetic mean for comparison to water quality criteria. Base and storm flow (green and blue boxes respectively) data are plotted together for comparison.

The boxplots are presented in Appendix D-2.

2.2.4. Temporal and Spatial Patterns

Statistical analyses of temporal and spatial patterns were performed to meet the following study objectives:

1. Detect significant temporal trends in water quality from 2011 to WY2024.
2. Determine whether there are significant differences in water quality among monitoring stations using data from WY2022 to WY2024 to identify spatial patterns.

2.2.4.1. Temporal Trend Analyses

To meet the first study objective, Kendall's Tau correlation analyses were performed on the 2011–2024 data to evaluate significant continuous increasing or decreasing trends in water quality at each station. Statistical significance in these analyses was assessed at an alpha level of 0.05. Temporal analysis results are provided in Appendix E and methodology is described below.

Base flow. A seasonal Kendall's Tau correlation analysis was performed based on sample date for base flow data. The data was classified based on two seasons: a wet season (from November through May) and a dry season (from June through September). A separate Kendall's Tau correlation coefficient was calculated for each season, then combined to determine overall trend across both seasons. This analysis was selected to account for seasonal differences in base flow water quality.

Storm flow. A Kendall's Tau correlation analysis was performed based on sample date for storm flow data. The analysis was applied to all 24 parameters described above. Seasons were not considered in the analysis of storm events because seasonality is expected to have less of an impact on water quality during storm events when compared with base events.

Continuous temperature analysis: Available continuous temperature data from 2011–2024 was used to calculate the 7-day average of the daily maximum temperature (7-DADMax). The 7-DADMax for any individual day was 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 in accordance with the methodology specified in WAC 173-201A-020. The 7-DADMax was only calculated if all 7 days in the averaging range had continuous temperature data available. For some stations, missing 7-DADMax values were calculated using a linear regression based on 7-DADMax values for stations with complete data for the calendar year. The data gaps were typically due to lost or stolen temperature probes. Regression results are shown graphically in Appendix B. For each station, an average monthly 7-DADMax and percent exceedance of the temperature criterion (DADMax greater than 17.5°C) was calculated for all months with a 7-DADMax value available for at least 75 percent of the days in the month. A seasonal Kendall's Tau correlation analysis was performed for these two values. A separate Kendall's Tau correlation coefficient was calculated for each month, then combined to determine overall trend. This analysis was selected to account for seasonal differences in temperature and changing sampling duration over time.

Water Quality Index: A Kendall's Tau correlation was used to identify temporal trends in annual Water Quality Index scores (WQI). For monthly WQI scores, a seasonal Kendall's Tau correlation analysis was performed based on month. As discussed in Section 2.2.6, a single monthly WQI score was determined for each month with at least one sampled base flow event. WQI constituent scores for events occurring in the same month were averaged to determine monthly constituent scores. The data was classified based on two seasons: a wet season (from November through May) and a dry season (from June through September). A separate Kendall's Tau correlation coefficient was calculated for each season, then combined to determine overall trend across both seasons. This analysis was selected to account for seasonal differences in base flow water quality.

2.2.4.2. Spatial Analysis

Spatial patterns were evaluated using the Friedman Test along with pairwise comparison using R for the WY2020–2024 data. This timeframe was selected to provide a large sample size but include enough recent data to evaluate spatial patterns relevant to existing water quality conditions and management activities. The following parameters were excluded from the analysis because they were only sampled for a portion of the date range: fecal coliform, lead, and cadmium. The Friedman test is a nonparametric analogue to a blocked analysis of variance (ANOVA) test that was used to determine if there were significant differences in water quality among stations (Helsel and Hirsch 2002). Using a blocked test, differences in water quality among the stations could be assessed with more statistical power because the noise (or variance) associated with sampling over a range of climatic and hydrologic conditions can be controlled for in the analysis. If a significant difference was detected, the nonparametric Nemenyi post- hoc test was conducted to determine which monitoring sites were significantly different from the others (Helsel and Hirsch 2002). The pairwise comparison results are shown as letters below each station boxplot, where stations without common letters are significantly different and stations with common letters are not significantly different. Statistical significance for this test was assessed at an alpha level of 0.05. The pairwise comparison results are also summarized as a heat map, where numbers indicate how frequently a particular station was significantly greater than or less than the other stations for a given parameter. While the heat map is helpful for summarizing general spatial patterns, it's interpretation should consider that the numbers are the result of summation of any positive and negative values (e.g., if a station is significantly greater than four stations and significantly less than three stations the number reported would be the same as a station that is significantly greater than one station).

Because the Friedman Test is a blocked test, complete data is required for analysis. Some sample date-parameter pairs were dropped from the analysis because not all stations were sampled for that parameter, or data were rejected during the quality assurance review. These dropped date-parameter pairs are shown in Table 6.

Spatial analysis results are provided graphically in Appendix F.

Table 6. Date-Parameter Pairs Excluded from the Friedman Analysis due to Incomplete Data.

Parameter	Date
pH	3/13/2023
E. coli	4/6/2023
	12/5/2023
	7/26/2023

2.2.5. Comparison to Water Quality Criteria

To identify water quality impairment at the BBC sampling stations, monitoring data were compared to regulatory criteria from the following sources:

- Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A, updated November 2024)
- Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion I (EPA 2001).

Water quality standards for surface waters in the state of Washington are based on specific designated uses that have been identified for each waterbody (WAC 173-201A-602). Water quality criteria associated with designated uses for BBC are summarized in Table 7. BBC is designated for salmonid spawning, rearing, and migration with associated aquatic life criteria for temperature, dissolved oxygen, pH, turbidity, and dissolved metals. BBC is also designated for primary contact recreation with specific recreational use criteria for *E. coli* and fecal coliform bacteria. Because the state surface water standards do not include nutrient criteria for streams, criteria recommended by the U.S. Environmental Protection Agency (EPA 2001) for total phosphorus, total nitrogen, and nitrate + nitrite nitrogen in streams located in the Willamette Valley Ecoregion are also presented in Table 7 or comparison to monitoring data.

Washington State fecal coliform and *E. coli* water quality criteria are based on a 90-day averaging period with at least three measurements per period. Frequency of sampling events, particularly during the dry season, during the WY2024 monitoring period did not meet the required sampling frequency used to evaluate compliance with state water quality criteria. The geometric mean and 90th percentile were calculated for each site using the combined dataset and are intended to provide a general overview of site conditions compared to water quality criteria. Exceedance of the geometric mean or 90th percentile criteria does not necessarily mean that the monitoring station was in exceedance for the entire monitoring period.

Table 7. Water Quality Criteria Used for Comparison to Data Collected for the Burnt Bridge Creek Water Quality Monitoring Project.

Parameter	Criteria
Aquatic Life Use Criteria for Salmonid Spawning, Rearing, and Migration[a]	
Temperature	The 7-day average of the daily maximum temperature (7-DADMax) shall not exceed **17.5°C**. When a water body's temperature is warmer or within 0.3°C of 17.5°C and that condition is due to natural conditions, then human actions considered cumulatively may not cause the 7-DADMax temperature of that water body to increase more than 0.3°C.
Dissolved Oxygen	The lowest 1-day minimum shall exceed **10 mg/L**. When a water body's dissolved oxygen concentration is lower than or within 0.2 mg/L of 10 mg/L and that condition is due to natural conditions, then human actions considered cumulatively may not cause the dissolved oxygen concentration of that water body to decrease more than 0.2 mg/L.
pH	Shall be within the range of **6.5 to 8.5**, with a human-caused variation within this range of less than 0.5 units.
Turbidity	Shall not exceed 5 NTU over background when the background turbidity is 50 NTU or less; or a 10 percent increase in turbidity when the background turbidity exceeds 50 NTU.
Copper, dissolved	Metals criteria are calculated using hardness and vary
Zinc, dissolved	Metals criteria are calculated using hardness and vary
Nutrient Criteria from Reference Conditions for the Willamette Valley Ecoregion[b]	
Total phosphorus	Shall not exceed 0.040 mg/L
Total nitrogen	Shall not exceed 0.36 mg/L
Nitrate + nitrite nitrogen	Shall not exceed 0.15 mg/L
Total Kjeldahl nitrogen	Shall not exceed 0.21 mg/L
Recreational Use Criteria for Primary Contact Recreation[a]	
Fecal coliform bacteria	Geometric mean of at least 3 samples shall not exceed 100 CFU or MPN per 100 mL**,** with no more than 10 percent of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean values exceeding 200 CFU or MPN per 100 mL. Use of fecal coliform to determine compliance expired on December 31, 2020.
Updated Recreational Use Criteria for Primary Contact Recreation[a]	
Escherichia coli	Geometric mean of at least 3 samples shall not exceed 100 CFU or MPN per 100 mL, with no more than 10 percent of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean values exceeding 320 CFU or MPN per 100 mL.

C = Celsius mg/L = milligram/L mL = milliliter NTU = nephelometric turbidity units CFU = Colony forming units MPN = Most probable number

[a] Source: Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A).

[b] Source: EPA (2001); 25th percentile of medians for 171 streams for all seasons from 1990–1999 in the Willamette Valley Ecoregion (Table 3a).

2.2.6. Water Quality Index

To summarize water quality patterns in BBC, and to facilitate comparisons between the sampling sites, the water quality index (WQI) was calculated for each station on a monthly and water year basis using protocols developed by Ecology (2002). The WQI is a unitless number ranging from 1 to 100, with higher numbers indicating better water quality. The WQI is calculated using base flow data from the following suite of parameters: temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended solids, total phosphorus, total nitrogen, and turbidity. WQI constituent scores for events occurring in the same month are averaged to determine monthly constituent scores. Constituent scores from each parameter are aggregated to produce an overall score for each station on a monthly and water year basis.

For sample dates when fecal coliform data was unavailable, fecal coliform concentrations were approximated using a linear regression relationship, developed for *E. coli* and fecal coliform concentrations collected during base flow events from June 2018 through November 2023, when both parameters were sampled. The resulting regression equation is shown below:

$$y = 1.1 * x + 15$$

Where: y = fecal coliform concentration (CFU/100mL)
x = E. coli concentration (CFU/100mL)

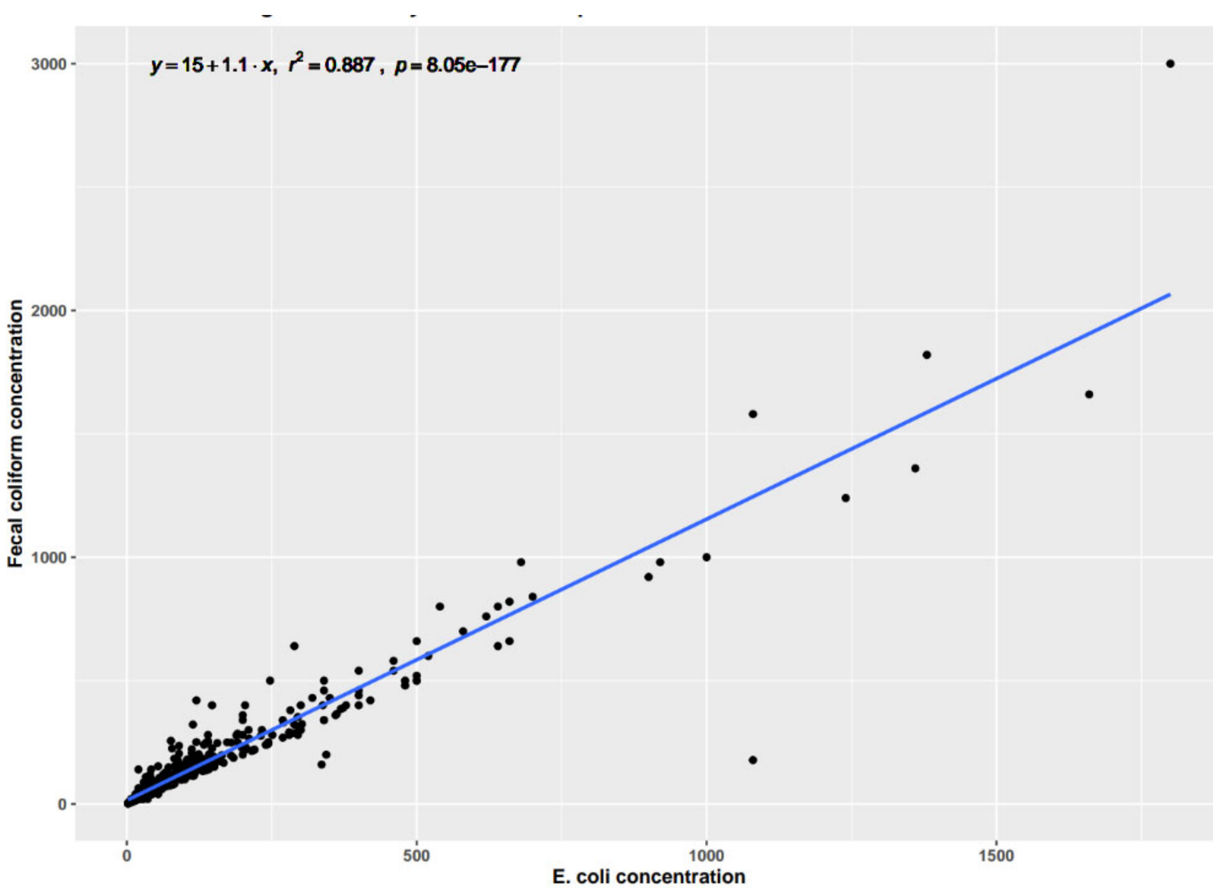


Figure 4. Fecal Coliform versus *E. coli* Concentrations during Base Flow Events.

In general, the WQI provides an indication of the adequacy of water quality for supporting the beneficial uses of a given water body as defined in the Washington State Surface Water Quality Standards (WAC 173-201A). For temperature, pH, fecal coliform bacteria, and dissolved oxygen, the WQI expresses results relative to applicable water quality standards that have been promulgated to maintain beneficial uses (see Table 7). For nutrients without state criteria, the results are expressed relative to the distribution of data from Ecology's long-term monitoring stations located in the ecoregion. Sites scoring 80 and above likely meet expectations for water quality supporting beneficial uses and are of "lowest concern." Scores ranging from 40 to 80 indicate water quality of "marginal concern," and sites with scores less than 40 likely are not able to support diverse populations of aquatic life and are of "highest concern" (Ecology 2002).

It should be noted that the WQI conveys less information by design than the raw data summarized by the index. Therefore, it is most useful for making broad comparisons between sites and answering general questions about the relative water quality in each stream (Ecology 2002). The WQI is less suited to answering site-specific questions where detailed analyses of the water quality data are needed. There are at least two reasons that the WQI may fail to accurately communicate water quality information. First, this index, like most indices, is based on a pre-identified suite of water quality parameters. A particular site may receive a good WQI score and yet have water quality that is impaired in terms of parameters that are not included in the index. Second, aggregation of data may mask short term water quality problems. It follows that a satisfactory WQI at a particular site does not necessarily mean that water quality was always satisfactory. A good score indicates only that poor water quality was not a chronic problem. Due to these considerations, the WQI was used in this analysis only to summarize broad patterns in the data.

The Ecology WQI scores were calculated using R software, the protocols developed by Ecology (2002), and the latest curves from the Ecology WQI Index spreadsheet (Ecology 2014). The following inputs were selected:

- Recreation use: Primary
- Aquatic Life (Temperature): Spawn (17.5)
- Aquatic Life (Oxygen): Spawning
- Supplemental Spawning: None
- Ecoregion: 3 (Willamette Valley)
- Small Puget Sound Stream: Yes

The Small Puget Sound Stream input was selected as recommended by Ecology (2002) to better align with naturally high nutrient concentrations in the stream (Herrera 2016).

2.2.7. Comparison to Other Streams

BBC monitoring data for all stations was aggregated across stations for select parameters and plotted alongside data from similar monitoring studies in different watersheds in Western Washington for comparison (Appendix G). Storm and base flow data were separated, and the comparison is shown in boxplots. The studies used for comparison are:

- Redmond Paired Watershed Study (RPWS; Ecology 2024) – An ongoing monitoring program in seven creeks in Redmond, Washington. Raw data used for comparison are from March 2016 through January 2023.
- Toxics in the Surface Runoff to Puget Sound (Herrera 2011b) – Monitoring was conducted in 2009-2010 in creeks in the Puyallup and Snohomish watersheds to estimate toxic chemical loading to Puget Sound. Summary statistics from this study were used to create boxplots.

Because these projects were not intended as inter-watershed comparisons, only select parameters overlapped between the various monitoring efforts. Parameters evaluated include total zinc, total suspended solids, nitrate + nitrite, and total phosphorus. Comparison data are intended to provide points of reference for comparing water quality in the BBC watershed to that of other watersheds, but do not necessarily represent typical concentrations in urban runoff and other Pacific Northwest streams. Watersheds with primarily residential land use were selected for comparison to most closely match land use in the BBC watershed.

3. RESULTS

Results are summarized in the following subsections: data quality review, hydrology, and water quality. Full results can be viewed in the following appendices:

- Appendix A: Data Quality Assurance Review
- Appendix B: Water Temperature Probe Calibration Checks and 7-DADMax Regression Results
- Appendix C: Water Quality Results by Station
- Appendix D: WY2024 Summary Statistics Tables and Water Quality Figures
- Appendix E: Temporal Trends Tables
- Appendix F: Spatial Trend Figures
- Appendix G: Comparison to Other Studies

3.1. Data Quality Review

A quality assurance review was performed for all field and laboratory data collected in WY2024, as specified in the QAPP (Herrera 2023). The quality assurance review findings were presented in an interim update report for each sampling event and are summarized in Appendix A. In general, the data quality for all parameters was considered acceptable based on holding time, reporting limit, method blank, control standard, laboratory duplicate, and field duplicate criteria specified in the QAPP. However, as summarized below, some quality control issues were identified in the data. Results that did not meet QA criteria specified in the QAPP were qualified as estimates or rejected. Conductivity data were rejected for one storm flow event. SRP data were rejected for one station at one event.

Data quality review findings are summarized below for field and laboratory data collected in WY2024.

3.1.1. Field Data

The water quality meter was calibrated and then checked before and after each event as documented in the calibration logs provided as an attachment to the Interim Reports. The accuracy of the continuous temperature loggers was checked prior to their installation and upon their removal using a thermometer certified by National Institute of Standards and Technology (see Appendix B). In general, *in situ* measurements and continuous temperature logging met all data measurement quality objectives, with one exception on April 25, 2024, where all conductivity results were rejected due to a water quality meter calibration issue as described in Appendix A.

Continuous temperature logging met all data measurement quality objectives, with the following corrections:

- Erroneous logged temperature spikes and drops from probes being out of the water during data download were removed. The temperature probes include timestamps and log entries each time the probe is connected to or disconnected from a compatible download shuttle. Deletion of out of water temperature spikes was limited to the two entries immediately before and after the probe logged connection with the download shuttle.

3.1.2. Laboratory Data

All scheduled samples were collected, and the laboratory reported all parameters with few exceptions. Laboratory methods were consistent with those specified in the QAPP (Herrera 2019a). Method- and QAPP-specified analytical and filtration holding times were generally met with a few exceptions where data was flagged as estimated. No method blanks analyzed contained levels of target parameters above the reporting limit, and all laboratory control standard samples met the established control limits. No data were flagged due to matrix spike samples or laboratory duplicate samples. Field duplicate samples generally met the established control limits except for qualification as estimated of three results for *E. coli* and eight results for parameters including total suspended solids, total nitrogen, SRP, and turbidity. The dissolved fraction of target parameters was generally less than the total fraction, with some exceptions in which SRP was at least 20 percent greater than total phosphorus and flagged as estimated.

Exceptions to QAPP specified data quality criteria and resulting data qualifiers, if applicable, are detailed in Appendix A.

3.1.3. Data Quality Summary

In general, data quality criteria were met with relatively few exceptions (Appendix A).

The percentage of estimated (J flag) and rejected (R flag) values are summarized by parameter (excluding field duplicate samples) in Table 8. In addition to the reasons discussed in the above subsections, some results were flagged as estimated due to detections below the reporting limit.

Table 8. Percentage of Data Qualified as Estimated (J) and Rejected (R) Values for WY2024.

	Water Year 2024[a]			
	Base Flow		Storm Flow	
Parameter	J	R	J	R
Temperature	0	0	0	0
Dissolved Oxygen	0	0	0	0
pH	0	0	0	0
Conductivity	0	0	0	20
Turbidity	1	0	2	0
Total Suspended Solids	1	0	2	0
Hardness as CaCO3	NS	NS	0	0
Total Phosphorus	14	0	0	0
Soluble Reactive Phosphorus	5	0	15	2
Total Nitrogen	3	0	2	0

Table 8 (continued). Percentage of Data Qualified as Estimated (J) and Rejected (R) Values for WY2024.				
	Water Year 2024[a]			
	Base Flow		Storm Flow	
Parameter	**J**	**R**	**J**	**R**
Nitrate +Nitrite Nitrogen	0	0	0	0
Total Copper	NS	NS	0	0
Dissolved Copper	NS	NS	0	0
Total Zinc	NS	NS	0	0
Dissolved Zinc	NS	NS	0	0
E. coli	10	0	24	0

[a] Percentages do not include duplicate samples.

NS = Not Sampled

3.2. Hydrology

Precipitation data collected by others are presented in Figure 5 and for each monitoring event. Rainfall data were collected in 1-hour intervals by Portland Bureau of Environmental Services (BES) at Hayden Island Rain Gage (Portland BES 2025), which is located 7.5 miles southwest of station BBC2.6. In WY2024, the gage recorded 43.54 inches of rain with a maximum daily precipitation value of 2.03 inches.

One sampled storm event (March 12, 2024) did not meet the storm depth criterion of at least 0.3 inch of rain with less rainfall than predicted at 0.10 inch of rain. All sampled base flow events met the criterion of less than 0.04 inch of rain in the previous 24 hours.

In WY2024, there was substantially less precipitation in September compared to 2011–WY2023. Precipitation amounts in WY2024 were substantially higher in December, January, February, and August compared to 2011–WY2023. All other months in WY2024 were comparable to historical ranges (Figure 6).

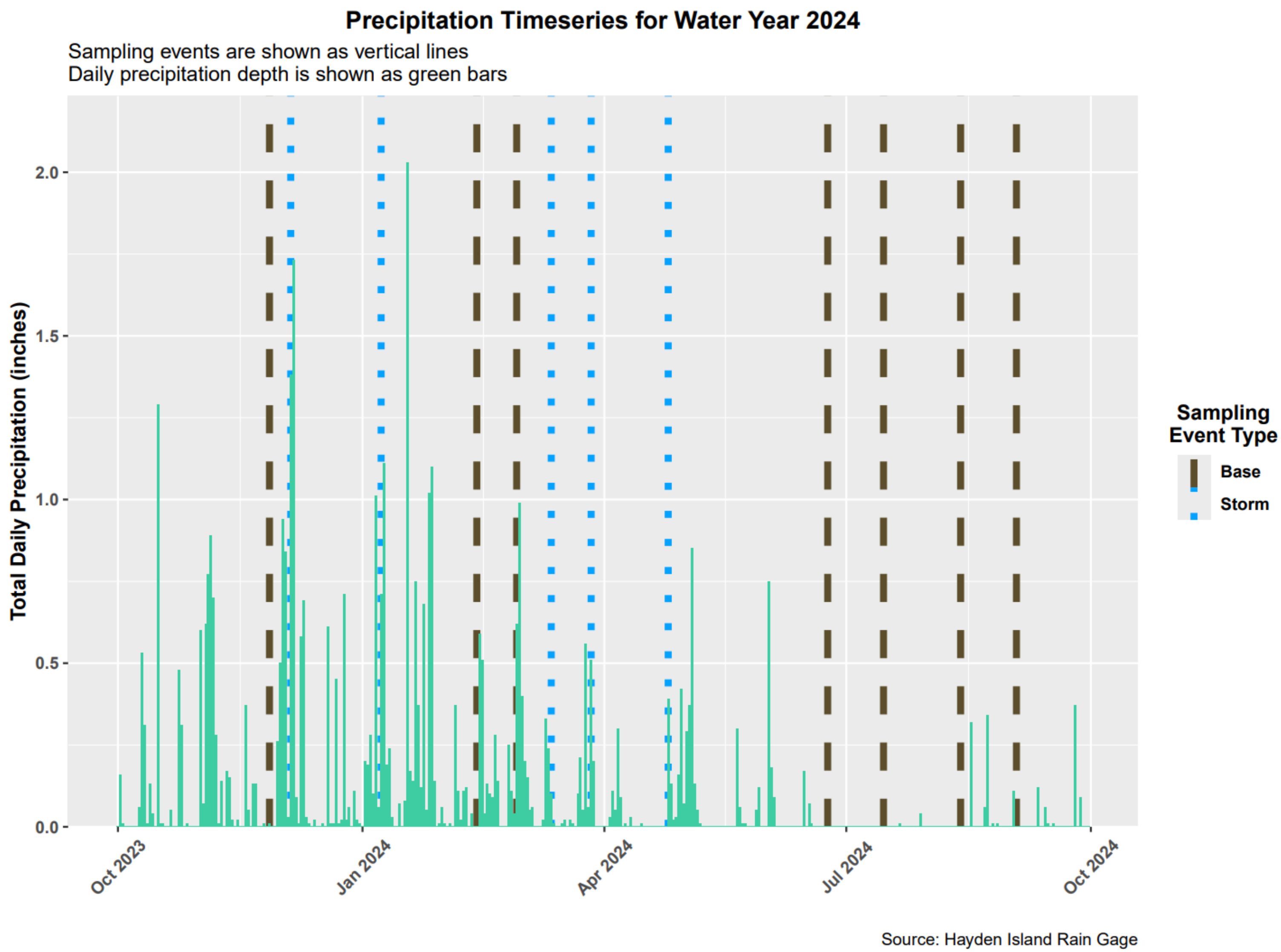


Figure 5. Burnt Bridge Creek Precipitation 7.5 Miles Southwest of BBC2.6 During Water Years 2024 (Portland BES 2025).

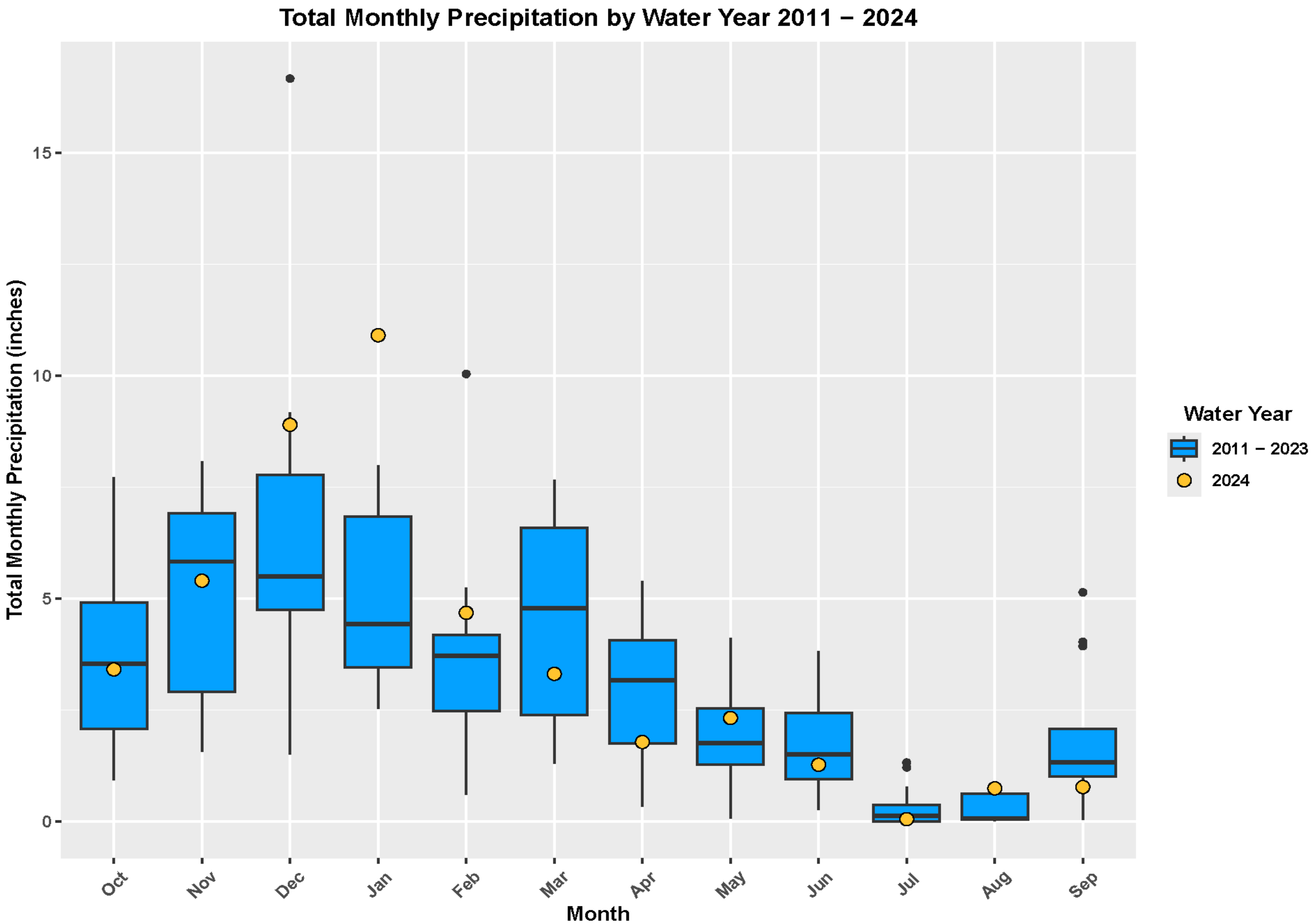


Figure 6. Total Monthly Precipitation at Burnt Bridge Creek for 2011 to 2024 (Portland BES 2025).

3.3. Water Quality

The sections below provide a summary of key water quality and trend analysis results, including:

- Water quality criteria comparison for data collected during the WY2024 monitoring period
- Spatial trends (Friedman) in water quality within the WY2020 to WY2024 period
- Temporal trends (Kendall's Tau) in water quality within the 2011 to 2024 period

A detailed description of results for each station can be found in Appendix C. Data visualization and statistical summary tables are provided in appendices D through E, including:

- Appendix D-1: Summary statistics tables for the WY2024 monitoring period
- Appendix D-2: Boxplots for the WY2024 monitoring period
- Appendix E: Temporal trend analysis tables
- Appendix F: Spatial analysis Friedman test boxplots for the WY2020 to WY2024 period

In the following discussion of results, use of "significant" indicates statistically significant results.

3.3.1. Water Quality Criteria Comparison

Water quality in BBC exceeded applicable criteria for several parameters during WY2024. Results of the water quality criteria comparison are described below with the exception of nutrients, which exceeded levels based on EPA's recommendation for the Willamette Valley in the majority of samples at all stations.

- Temperature: The temperature criterion (17.5°C) was exceeded at all stations during continuous temperature monitoring in WY2024 ranging from 25 percent of days exceeding the criteria at BBC10.4 to 59 percent at BBC8.8. Table 9 summarizes 7-day average daily maximum (7-DADMax) temperature exceedances between April 26 and November 5, 2024.

Table 9. Total Number of Days the 7-DADMax Temperature Exceeds the Temperature Criterion of 17.5°C in from April 26 through November 5, 2024.

Station	Water Year 2024	
	Total Days 7-DADMax Exceeds 17.5°C	Percent of Days Exceeding Criterion
BBC10.4	49	25
BBC8.8	114	59
PET0.0	76	39
BBC8.4	61	31
BBC7.0	82	42
BBC5.9	92	47
BBC2.6	75	39
BBC1.6	63	32

- **Dissolved Oxygen:** The dissolved oxygen criterion specifies that the lowest 1-day minimum value shall exceed 10.0 mg/L. Dissolved oxygen would need to be monitored continuously to know the daily minimum; however, the discrete dissolved oxygen measurements taken during sampling events frequently did not meet the criterion. Median dissolved oxygen concentrations for WY2024 were below 10 mg/L at eight stations during base flow and six stations during storm flow, indicating that more than half of the events at these stations did not meet the criterion. The dissolved oxygen criterion was met during all sampling events at COL0.0 but was not met during any event at BBC10.4 and PET0.0.
- **pH:** The pH criterion (6.5 to 8.5) was not met at BBC10.4 during one base flow and four storm flow events in which the pH was below the range. The median pH during storms at BBC10.4 was also below the criterion. However, BBC10.4 is located downstream of wetlands with peat soils which can naturally lower pH. All other stations met the criterion during storm and base flow events, except for BBC8.8 and BUR0.0, which were below the range during one storm event.
- **Turbidity:** Using an upstream station as background, the turbidity standard of a greater than 5 NTU increase was not met during the events listed below. Exceedances only occurred during storm events at BBC2.6 and BBC1.6. Exceedances at BBC1.6 always corresponded with high turbidity at COL0.0.
    - December 5, 2023 storm event: increase from 7 NTU at BBC5.2 to 12.5 NTU at BBC2.6, then to 18.1 NTU at BBC1.6. High turbidity in Cold Creek (35.2 NTU at COL0.0) likely contributed to the increase at BBC1.6.
    - January 8, 2024 storm event: increase from 7.5 NTU at BBC5.2 to 14.5 NTU at BBC2.6.
    - March 27, 2024 storm event: increase from 6.2 NTU at BBC5.2 to 26.2 NTU at BBC2.6, then to 35.2 NTU at BBC1.6. High turbidity in Cold Creek (70.5 NTU at COL0.0) likely contributed to the increase at BBC1.6.
    - April 25, 2024 storm event: increase from 9.9 NTU at BBC5.2 to 21.3 NTU at BBC2.6, then to 29.9 NTU at BBC1.6. High turbidity in Cold Creek (74.6 NTU at COL0.0) likely contributed to the increase at BBC1.6.
- **Metals:** Table 10 summarizes all metals exceedances from WY2024. Metals were only analyzed during storm events during WY2024 due to lack of chronic criteria exceedances during base flow events in previous water years. Only acute exceedances are listed because acute criteria are the most appropriate measure during high flows with storm events. COL0.0 and BUR0.0 exceeded the acute criterion for copper during one event each. BBC7.0, BBC8.4, and BBC8.8 exceeded the zinc acute criterion during one event each, and BUR0.0 exceeded the criterion during three events. The only exceedances at BBC8.8, BBC8.4, and BBC7.0 all occurred on April 25, 2024, indicating a major input of zinc upstream of BBC8.8, which also affected the downstream stations. BUR0.0 had the most metals exceedances of any station, which supports Ecology's 2022 Category 5 listing of Burton Channel for copper and zinc.

Table 10. WY2024 Metals Results that Exceeded Acute and Chronic Water Quality Criteria.							
Station	Date	Type	Parameter	Result (µg/L)	Hardness (mg/L)	Criteria Type	Criteria Value (µg/L)
COL0.0	12/5/2023	Storm	Copper, Dissolved	5.73	26.5	Acute	4.87
BUR0.0	4/25/2024	Storm	Copper, Dissolved	9.56	30.2	Acute	5.51
BUR0.0	12/5/2023	Storm	Zinc, Dissolved	38.1	23.7	Acute	33.8
BUR0.0	1/8/2024	Storm	Zinc, Dissolved	41.7	22.6	Acute	32.5
BUR0.0	4/25/2024	Storm	Zinc, Dissolved	80.5	30.2	Acute	41.5
BBC8.8	4/25/2024	Storm	Zinc, Dissolved	926	73.9	Acute	88.6
BBC8.4	4/25/2024	Storm	Zinc, Dissolved	676	74.3	Acute	89.0
BBC7.0	4/25/2024	Storm	Zinc, Dissolved	148	63.7	Acute	78.1

- Bacteria: No stations met *E. coli* criteria during storm events. BBC8.8, PET0.0, BBC8.4, BBC7.0, and BBC5.2 met the criteria during base flow events. BBC10.4 and BBC5.9 met the geometric mean criterion but exceeded the 90th percentile criterion during base flow events. BUR0.0, BBC2.6, COL0.0, and BBC1.6 exceeded both criterion during base flow events. Because the state *E. coli* criteria specify a 90-day averaging period, these exceedances do not necessarily mean that the relevant monitoring stations were in exceedance of state water quality criteria during the entire monitoring period.

3.3.2. Overall Trends

3.3.2.1. Spatial Trends

The concentrations of many water quality parameters measured in BBC varied spatially over WY2022 through WY2024. Statistically significant differences between stations were assessed using the Friedman Test and presented in Appendix F as individual boxplots and in a summary heat map (Figure 7). In addition to general changes in concentrations from upstream to downstream, water quality at multiple stations appeared to be affected by contributions from nearby tributaries for some parameters. Key conclusions related to spatial patterns include:

- pH: During both base and storm flow events, pH values were significantly lower at the most upstream station, BBC10.4, compared to most other stations. This is likely due to wetland areas, which naturally have lower pH, and low pH groundwater source at BBC's headwaters upstream of BBC10.4's location. pH increased at BBC8.8 and remained stable across midstream stations until increasing again at BBC2.6. Storm and base flow pH at downstream stations (BBC2.6, COL0.0, and BBC1.6) was significantly greater than most other stations.
- Dissolved Oxygen: Dissolved oxygen concentrations followed a similar spatial pattern to pH. During both base and storm flow events, dissolved oxygen concentrations were significantly lower at the most upstream station, BBC10.4, compared to most other stations, which may also be associated with the wetland conditions and groundwater source upstream of this station. Dissolved oxygen increased at BBC8.8 and remained stable across midstream stations, with the exception of PET0.0 and BBC5.9, which were significantly lower than many other stations. Storm and base flow dissolved oxygen

concentrations at downstream stations (BBC2.6, COL0.0, and BBC1.6) were greater than upstream stations, with more significant differences during storm flow.

- **Conductivity:** Base flow conductivity was significantly lower at upstream stations BBC10.4 and BBC8.8 than most other stations, and significantly higher in tributaries PET0.0 and COL0.0. Storm flow conductivity was similar across mainstem stations. Storm flow conductivity at BUR0.0 and COL0.0 was significantly lower than several other stations.
- **Turbidity:** Median base flow turbidity at all tributary stations was lower than all mainstem stations, with more significant differences at PET0.0 and BUR0.0. Median storm flow turbidity was greatest at COL0.0 and was significantly higher than all stations except BBC10.4, BUR0.0, BBC2.6, and BBC1.6. High turbidity in Cold Creek may have contributed to higher turbidity at BBC1.6 compared to other mainstem stations. BBC1.6 had the greatest storm flow median of all mainstem stations, and was significantly greater than BBC8.4, BBC7.0, BBC5.9, and BBC5.2.
- **Nitrogen:** Base and storm flow total nitrogen and nitrate + nitrite concentrations at mainstem BBC stations generally decreased from the high at BBC10.4 to lows at BBC5.9 through BBC1.6. Upstream mainstem stations BBC10.4 and BBC8.8 were significantly higher than most midstream and downstream BBC stations. Total Kjeldahl nitrogen was similar across all stations during both types of events.
- **Phosphorus.** Base flow total phosphorus and SRP concentrations generally increased from lows at BBC10.4 and BBC8.8 to highs from BBC7.0 through BBC1.6. Storm flow total phosphorus and SRP concentrations were relatively stable within mainstem stations with few significant differences. Base flow total phosphorus and SRP concentrations at BBC10.4, BBC8.8, and BUR0.0 were significantly lower than several other stations. Storm flow SRP concentrations were significantly lower at BUR0.0 and COL0.0.
- **Copper:** Spatial patterns in copper concentrations were consistent for both total and dissolved forms. Base flow copper concentrations were significantly lower at the upstream stations BBC10.4 and BBC8.8 and tributary station BUR0.0. PET0.0 had significantly higher copper concentrations than most other stations during base flow events. Most stations had similar copper concentrations during storm flow, except PET0.0 and COL0.0, which were significantly higher than most other stations.
- **Zinc:** Fewer significant differences were identified in zinc concentrations than copper concentrations across mainstem BBC stations. BUR0.0 had the highest median concentration of dissolved zinc and was significantly higher than half of the stations. However, total zinc at BUR0.0 was not significantly different than other midstream and downstream stations. During storms, BUR0.0 and COL0.0 had the highest median total and dissolved zinc concentrations and were significantly higher than several other stations. BUR0.0 and COL0.0 hardness concentrations during storm events were also significantly lower than several other stations, which increases the toxicity of metals including zinc.

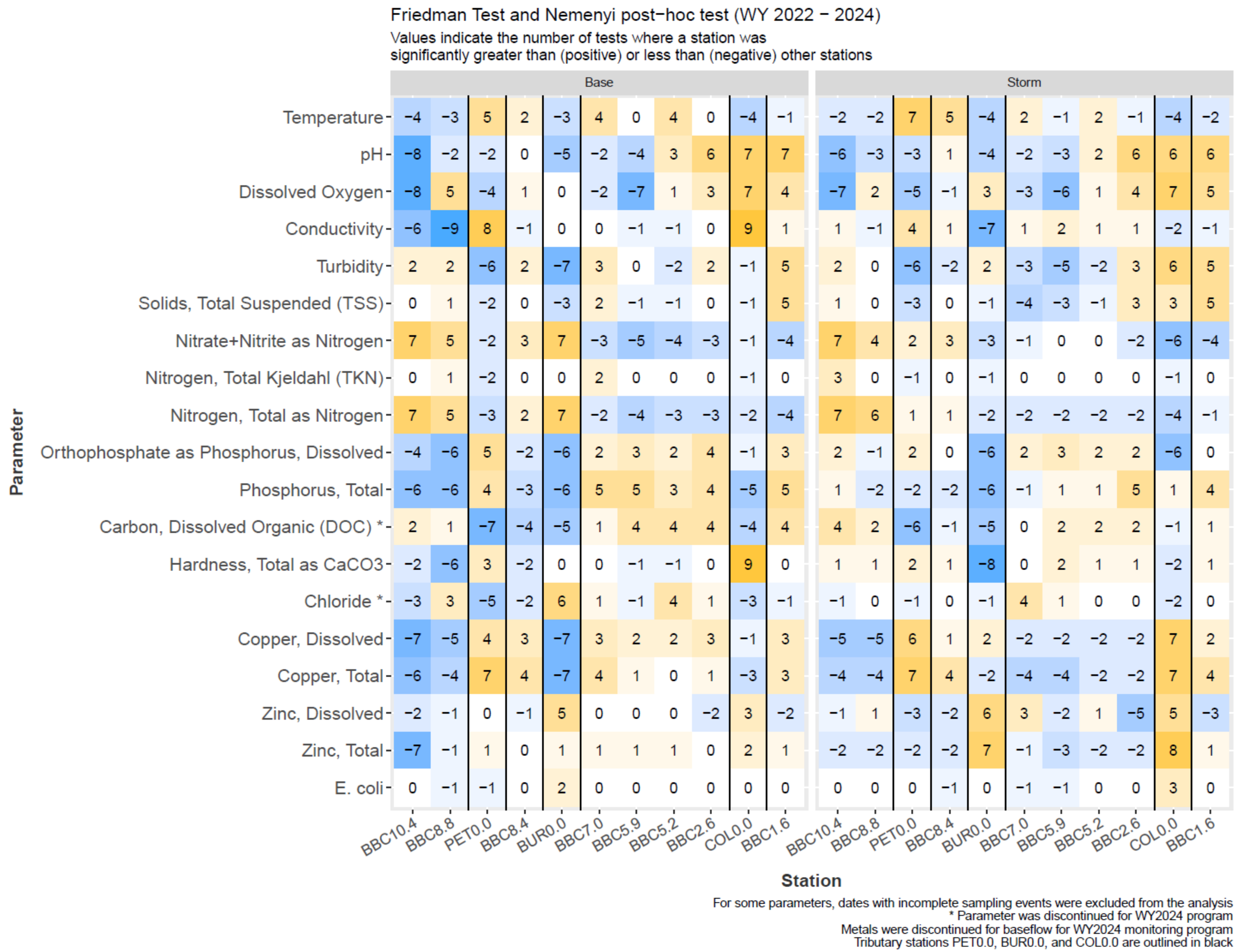


Figure 7. Spatial Analysis Heat Map (WY2022-2024).

3.3.2.2. Temporal Trends

The Kendall's Tau correlation analysis was used to determine statistically significant trends in storm and base flow events separately and showed a mix of both improving and decreasing water quality trends. Over this period, significant trends in turbidity, nitrogen, and phosphorus were most common and present at most stations. Turbidity had a significant increasing trend at all stations except BBC5.2, which corresponded with a decreasing trend in turbidity WQI score (parameter-specific water quality declined) at all stations except BUR0.0 and BBC5.2. Nitrate + nitrite had a significant decreasing trend at every mainstem station as well as BUR0.0 but increased at PET0.0 and COL0.0. The corresponding total nitrogen WQI score had a significant increasing trend (water quality improved) at BBC10.4, BBC8.8, BUR0.0, and decreasing score at PET0.0 and COL0.0. SRP increased at every station except the two most upstream, BBC10.4 and BBC8.8. However, PET0.0 was the only station where the total phosphorus WQI score decreased.

Fecal coliform and *E. coli* bacteria were analyzed from 2012 through WY2023 and WY2020 through WY2024, respectively. Despite the correlation between these two parameters, more significant temporal trends were identified for fecal coliform. As additional *E. coli* data is collected in future years, similar trends to fecal coliform may appear. Significant increasing fecal coliform trends were identified in base flow at upstream stations BBC10.4 and BBC8.8 and midstream station BBC7.0, while decreasing trends were identified at midstream stations BBC5.9 and BBC5.2 and downstream station BBC1.6.

Statistically significant trends for individual parameters and WQI are discussed in detail in the following subsections.

Storm Events

Storm flow event data from WY2020 through WY2024 were used to analyze long-term trends in storm flow event water quality. Total phosphorus, chloride, and dissolved zinc were the only three parameters with significant trends at multiple stations during storm events (Table 11).

- Phosphorus: Total phosphorus concentrations have been decreasing since WY2020 at three stations, BBC7.0, BBC5.9, and BBC5.2 indicating a positive trend in water quality.
- Chloride: Chloride was monitored in WY2020 through WY2023. Over this period, chloride concentrations increased at six stations: BBC8.8, BBC8.4, BBC7.0, BBC5.9, BBC5.2, and BBC2.6.
- Dissolved Zinc: Dissolved zinc has been monitored during storm flow events since WY2020. Concentrations during this period significantly increased at monitoring stations PET0.0 and BBC7.0.

Table 11. Temporal Trend Analysis Summary for Storm Events WY2020-WY2024.											
Parameter	**BBC10.4**	**BBC8.8**	**PET0.0**	**BBC8.4**	**BUR0.0**	**BBC7.0**	**BBC5.9**	**BBC5.2**	**BBC2.6**	**COL0.0**	**BBC1.6**
Temperature											
pH			↓								
Dissolved Oxygen		↑									
Conductivity											
Turbidity			↑								
Solids, Total Suspended (TSS)											
Nitrate + nitrite as Nitrogen											↑
Nitrogen, Total Kjeldahl (TKN)									↑		
Nitrogen, Total as Nitrogen											
Orthophosphate as Phosphorus											
Phosphorus, Total						↓	↓	↓			
Carbon, Dissolved Organic (DOC)											
Hardness, Total as CaCO3											
Chloride		↑		↑		↑	↑	↑	↑		
Cadmium, Dissolved											
Cadmium, Total											
Copper, Dissolved											
Copper, Total											
Lead, Dissolved											
Lead, Total											
Zinc, Dissolved			↑			↑					
Zinc, Total											
E. coli											
Fecal Coliform											

↑ = statistically significant increasing trend ↓ = statistically significant decreasing trend

Green shading indicates a water quality improvement

Red shading indicates a decline in water quality

Yellow shading indicates a neutral trend

Seasonal Base Flow Events

Base flow event data were analyzed for trends in the wet season (November-May), the dry season (June-September), and the combined seasons (the full year overall) and results are provided in Table 12. Trends in WQI were analyzed by the same methods (Table 13). Years of available data varied by parameter. In general, more statistically significant trends were identified in the dry and combined seasons than in the wet season which may in part be due to the larger sample size available for dry season data. Trend analysis results for continuous temperature data are provided in Table 14.

Significant trends were detected for the following parameters using data from 2011 through WY2024:

- Overall WQI: Decreased at BBC10.4 and PET0.0 during the dry and combined seasons, indicating declining water quality. The overall WQI score at BBC7.0 increased during the wet season, indicating improving water quality, with no significant trend during the dry or combined seasons.
- Temperature: Continuous temperature was only monitored during the dry season. Statistically significant trends were identified at three of the continuous temperature monitoring stations. BBC10.4 and BBC8.8 increased for both the average monthly 7-DADMax and the average monthly percent exceedance of the criterion. The average monthly 7-DADMax also increased at BBC8.4, but the average monthly percent exceedance did not increase significantly. Slight decreasing, but not statistically significant, trends were identified for several midstream and downstream stations including BBC7.0, BBC5.9, BBC2.6, and BBC1.6.
- Conductivity: Increased at all stations except the two most upstream, BBC10.4 and BBC8.8, which did not have significant trends. The increases were measured during the dry and combined seasons at the stations downstream of BBC8.8. No trends were identified during the wet season.
- Turbidity: Increased at all stations except BBC5.2. This trend occurred during the dry and combined seasons at the rest of the stations. Additionally, turbidity increased during the wet season at BBC2.6. These trends corresponded with a lower turbidity WQI score at all stations except BUR0.0 and BBC2.6.
- TSS: Decreased at three stations, BBC8.4, BBC5.9, and BBC5.2, and increased at BBC10.4. These trends occurred during the dry and combined seasons. No TSS trends were identified during the wet season. The stations with decreased TSS had improved TSS WQI scores while the TSS WQI score at BBC10.4 decreased.
- Nitrogen: Trends were identified for nitrate + nitrite at every station. Nitrate + nitrite decreased at every mainstem station and BUR0.0, while concentrations increased at PET0.0 and COL0.0. These trends occurred during the dry and combined seasons at all stations. PET0.0 also increased during the wet season. Total nitrogen trends mirrored nitrate + nitrite at BBC10.4, BBC8.8, BUR0.0, PET0.0 and COL0.0. The only total Kjeldahl nitrogen trend identified was an increase during the dry season at PET0.0. The total nitrogen WQI scores increased at BBC10.4, BBC8.8, BUR0.0, and decreased at PET0.0 and COL0.0.
- Phosphorus: SRP increased at every station except the two most upstream, BBC10.4 and BBC8.8. These trends occurred during the dry and combined seasons at the downstream stations. PET0.0 was the

only station with significant total phosphorus trends, which decreased in the wet, dry, and combined seasons. The total phosphorus WQI score increased at PET0.0.

Significant trends were detected for the following parameters monitored during base flow events in WY2020 through WY2023:

- **Chloride**: Significantly increased at every site except BUR0.0, which had no significant trends. The trend was identified in the wet, dry, and combined seasons at BBC10.4, BBC8.8, PET0.0, BBC8.4 and BBC5.9. The trend was not identified in the wet season at BBC7.0, BBC5.2, BBC2.6 and BBC1.6. Chloride decreased only in the dry season at COL0.0.
- **Metals (Copper and Zinc)**: There were few significant temporal trends for total metals. Total copper increased at BBC5.2 during the dry season and at COL0.0 in the combined seasons. Total zinc increased at BBC5.9 over the combined seasons. There were no significant trends in dissolved copper or zinc at any station.

Several significant trends were also detected for fecal coliform, which was monitored from 2011 through WY2023:

Fecal coliform: Increased at BBC10.4 and BBC7.0 during the dry and combined seasons. Fecal coliform also increased at BBC8.8 during the dry season only. Fecal coliform decreased at BBC5.9 and BBC1.6 in the wet, dry, and combined seasons, and decreased at BBC5.2 during the dry and combined seasons. The fecal coliform WQI score decreased at BBC10.4 and BBC7.0 and increased at BBC5.9 and BBC5.2.

E. coli bacteria concentrations were analyzed using data from 2018 through WY2024. Possibly due to the limited dataset compared to fecal coliform, *E. coli* trends did not mirror fecal coliform. One significant trend was identified at BBC8.8 for decreasing concentrations during the combined season. Fecal coliform and *E. coli* concentrations have generally been correlated in BBC, so the difference in significant trends may be driven by the different monitoring periods rather than differences in concentrations.

Table 12. Temporal Trend Analysis Summary for Base Flow Events.

		BBC10.4			BBC8.8			PET0.0			BBC8.4			BUR0.0			BBC7.0			BBC5.9			BBC5.2			BBC2.6			COL0.0			BBC1.6		
Parameter	**Years**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**D**	**B**	**W**	**Dry**	**B**	**W**	**D**	**B**
Temperature	2011-2024		↑	↑																														
pH	2011-2024				↓			↓				↑	↑	↓	↓	↓	↓			↓		↓												
Dissolved Oxygen	2011-2024					↓												↓	↓											↓				
Conductivity	2011-2024								↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑
Turbidity	2011-2024		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑				↑	↑	↑		↑	↑		↑	↑
TSS	2011-2024		↑	↑								↓	↓								↓	↓		↓	↓									
Nitrate + nitrite	2011-2024		↓	↓		↓	↓	↑	↑	↑		↓	↓		↓	↓		↓	↓		↓	↓		↓	↓		↓	↓		↑	↑		↓	↓
TKN	2021-2024								↑																									
Nitrogen, Total	2011-2024		↓	↓		↓	↓		↑	↑					↓	↓														↑	↑			
SRP	2011-2024								↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑		↑	↑
Phosphorus, Total	2011-2024							↓	↓	↓																								
DOC	2019-2023																																	
Hardness	2019-2023																↑												↓	↓	↓			↓
Chloride	2019-2023	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑					↑	↑	↑	↑	↑		↑	↑		↑	↑		↑			↑	↑
Cadmium, Dissolved	2019-2021												NA												NA			NA						
Cadmium, Total	2019-2021																																	
Copper, Dissolved	2019-2023																																	
Copper, Total	2019-2023																							↑							↑			
Lead, Dissolved	2019-2023							↓				↑																						
Lead, Total	2019-2023					↑																												
Zinc, Dissolved	2019-2023																																	
Zinc, Total	2019-2023																					↑												
E. coli	2018-2024						↓																											
Fecal Coliform	2011-2023		↑	↑		↑												↑	↑	↓	↓	↓		↓	↓							↓	↓	↓

↑ = statistically significant increasing trend   ↓ = statistically significant decreasing trend   NA = Trend not analyzed; standard deviation of the data = 0

Green shading indicates a water quality improvement

Red shading indicates a decline in water quality

Yellow shading indicates a neutral trend

W = Wet Season, November through May

D = Dry Season, June through October

B = Both, combined dry and wet season data set

DOC = Dissolved organic carbon

SRP = Soluble reactive phosphorus

TKN = Total Kjeldahl nitrogen

TSS = Total suspended solids

Table 13. Seasonal Water Quality Index (WQI) Scores.

Station	BBC10.4			BBC8.8			PET0.0			BBC8.4			BUR0.0			BBC7.0			BBC5.9			BBC5.2			BBC2.6			COL0.0			BBC1.6		
Season	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both	Wet	Dry	Both
Overall		↓	↓					↓	↓							↑																	
Temperature		↓	↓																										↓	↓			
pH							↓				↑	↑	↓	↓	↓				↓														
Dissolved Oxygen		↓	↓											↓																			
Turbidity		↓	↓		↓	↓		↓	↓		↓	↓					↓	↓		↓	↓					↓	↓		↓	↓		↓	↓
TSS		↓	↓								↑	↑								↑	↑		↑	↑									
Sediment Score		↓	↓																				↑	↑									
Nitrogen, Total		↑	↑		↑	↑		↓	↓					↑	↑														↓	↓			
Phosphorus, Total							↑	↑	↑																								
Nutrient Score								↓	↓																								
Fecal Coliform		↓	↓														↓	↓	↑		↑		↑	↑									

↑ = statistically significant increasing trend ↓ = statistically significant decreasing trend

Green shading indicates a water quality improvement

Red shading indicates a decline in water quality

Wet Season = November through May

Dry Season = June through October

Both = Combined dry and wet season data set

WQI scores for samples within the same month were average (Ecology 2002).

TSS = total suspended solids

Station	Average Monthly 7-DADMax	Average Monthly Percent Exceedance
BBC10.4	↑	↑
BBC8.8	↑	↑
PET0.0		
BBC8.4	↑	
BBC7.0		
BBC5.9		
BBC2.6		
BBC1.6		
BBC1.6		

Table 14. Temporal Trend Analysis for Continuous Temperature.

↑ = statistically significant increasing trend

Red shading indicates a decline in water quality

3.3.3. Comparison to Other Streams

BBC data from all stations for all available years was compared to data from other Western Washington streams in eight watersheds for select parameters: total zinc, TSS, nitrate + nitrite, and total phosphorus. Comparison boxplots are provided in Appendix G, and key observations are summarized below:

- Zinc: The BBC median zinc concentration was comparable to most of the other streams for both base flow and storm events. However, the BBC median was substantially higher than Evans Creek and the Snohomish and Puyallup watersheds during both types of events. BBC was also substantially lower than Tosh Creek during storm events.
- TSS: The BBC median TSS concentration was comparable to most of the other streams for both base flow and storm events. However, BBC was substantially lower than Tosh Creek during storm events and substantially higher than Snohomish during base flow.
- Nitrate + Nitrite: The BBC median nitrate + nitrite concentration was substantially greater than half of the other creeks (four of the Redmond creeks) for both types of events. The BBC base flow median was also substantially greater than Snohomish.
- Phosphorus: BBC has the highest base flow median phosphorus concentration and was substantially greater than five of the other creeks (four Redmond creeks and the Snohomish watershed). The BBC median storm concentration was not substantially different from other creeks.

The most notable differences are higher nutrients in BBC than in many of the other creeks in the comparison. Concentrations of all four parameters at BBC stations were comparable to Columbia Slope creeks (also located in the City of Vancouver) for all types of events. This could be due to similar geographic or environmental factors related to proximity, or it could be related to the City's management practices.

The 2015 SAM Status and Trends Study assessed stream health across 105 sites in the Puget Lowland Ecoregion by focusing on indicators such as water quality, habitat condition, and biological communities (King County 2018). The study found that many streams in the Puget Lowland are impacted by urbanization with degraded habitat conditions, increased pollutants in the stream, and altered flow regimes. The results indicate a need for enhanced stormwater management practices and habitat restoration to improve stream health and support aquatic ecosystems in the region. The 2015 study also compared its findings with other Puget Lowland stream monitoring programs. Although the methods used between studies vary, the comparison highlighted similar challenges across urbanized areas, such as habitat degradation, water quality impairments, and reduced biological diversity. The 2015 SAM study provided more regional insights due to the scope of the program, whereas localized studies had a limited scope due to geographic limitations (King County 2018).

The 2015 SAM study used specific criteria to determine if streams were in poor, fair, or good condition. WY2024 results from BBC were compared to the criteria and results from this study for select parameters.

- WQI: For the 2015 SAM study, a WQI score less than 40 was considered poor condition and a score greater than or equal to 80 was good condition. None of the 28 stream sites within urban growth areas or 24 stream sites outside urban growth areas in the 2015 study were found to be in poor condition. For BBC in 2024, annual WQI scores at BBC stations ranged from 25 at BBC10.4 to 59 at BBC8.8. Based on the 2015 SAM WQI criteria, three of eight mainstem BBC stations and two of three tributary stations were in poor condition in 2024.
- Fecal bacteria: The SAM criterion for fecal coliform was a geometric mean greater than 100 CFU/100mL was an indicator of poor condition, and less than 100 CFU/mL was not rated as poor. The study found 32 percent of stream miles within urban growth areas (UGAs) were in poor condition based on fecal coliform concentrations. Sixty-nine percent of all sites in the study (within and outside UGAs) satisfied criteria for safe human contact. At BBC in WY2024, the geometric mean of *E. coli* concentrations at two tributary stations and one mainstem station exceeded the 100 CFU/100mL criterion. These three stations exceeded the human contact criteria, in addition two mainstem stations exceeded the 90th percentile criterion.
- Total phosphorus: The SAM criterion for total phosphorus was a summer mean (August through October) of greater than 0.050 mg/L indicating poor condition. Based on this criterion, the study found 46 percent of stream miles within UGAs were in poor condition. In WY2024, the annual mean total phosphorus concentrations at all BBC stations were greater than or equal to 0.070 mg/L.
- Total nitrogen: A summer mean of greater than 0.862 mg/L indicated a poor reading according to the SAM criterion for total nitrogen. Based on this criterion, the study found 43 percent of stream miles within UGAs were in poor condition. In WY2024, the annual mean total nitrogen concentrations at all BBC stations were greater than or equal to 2.0 mg/L.

In WY2024, much of BBC was in poor condition based on the criteria used in the 2015 SAM study, particularly for nutrients. A greater percentage of BBC stream length is in poor condition as compared to the various Puget Sound streams monitored in 2015, both within and outside of UGAs.

4. DISCUSSION

This section discusses the most impactful water quality trends throughout BBC and its tributaries, the potential causes and mitigation strategies. Particular emphasis is placed on Category 5 303(d) listed parameters for BBC reaches, but other interconnected trends and parameters are discussed.

Regarding water quality criteria, WY2024 results were generally consistent with recent monitoring years. State water quality criteria were met for pH, turbidity, and metals (with few exceptions), but frequently exceeding criteria for temperature, dissolved oxygen, and *E. coli* bacteria. Spatial patterns emerged from upstream to downstream stations with significant increases in pH and dissolved oxygen, and apparent influences from tributary stations such as increased copper concentrations from Peterson Channel and Cold Creek. From the historical dataset collected under this project (spanning over a decade), multiple significant long-term trends in water quality were also identified including increasing 7-DADMax temperatures and base flow turbidity at several stations and decreasing base flow nitrate + nitrate at all mainstem stations.

Characterization of water quality along BBC relative to state water quality criteria is crucial to identify where water quality improvement activities should be prioritized. Likewise, understanding significant temporal trends in water quality can help inform whether management practices are successful and how water quality in the creek responds to evolving conditions in the environment (climate change and urban growth). In addition to supporting designated beneficial uses including primary contact recreation and salmonid spawning, rearing, and migration (Ecology 2008), improved water quality supports public health by reducing risk of contact with bacterial pathogens and improves climate resiliency by sustaining diverse natural ecosystems.

4.1. TMDL Parameters

Low dissolved oxygen and pH measurements at the upstream station BBC10.4 may be related to natural conditions in wetlands and groundwater sources located near the upstream reach of BBC. Relatively low water temperatures at BBC10.4 may also be related to this, but the dramatic increase in 7-DADMax water temperature exceedance frequency at BBC8.8 (and subsequent decrease) may be related to nearby land use. BBC flows through a golf course immediately upstream of BBC8.8 where sections of the creek are fully exposed, or have minimal riparian cover, which can lead to a spike in water temperature. Existing plantings along the BBC greenway have begun to mature, but riparian cover is still fairly limited along the upstream reach. While increasing riparian cover has been prioritized, improving trends may not be significant due to higher temperatures from climate change and time requirements for plant canopy establishment.

Unlike temperature, dissolved oxygen, and pH, which appear to be driven by specific landscape and hydrologic features in the upstream reach, *E. coli* appears to be influenced by a variety of basin-wide factors including the influence of septic systems during base flow at stations BUR0.0, BBC2.6, and BBC1.6

and runoff from human and animal waste during storm flow events. Septic and other human influences are discussed further below.

4.2. Trends

Select trends, identified as priority water quality indicators, and potential sources and interactions are discussed below. These key indicators were selected due to their potential impact to overall stream health, prevalence across multiple stations, or with clear relationships or causes. This section is not intended to represent all significant temporal trends identified with this evaluation.

Temperature

While water temperatures may not be improving at upstream stations, downstream stations appear to be showing a positive response to management activities such as riparian plantings. Long-term monitoring will be necessary to determine the significance of shading to reduce stream temperature as more riparian areas are planted and vegetation matures. Upstream stations are likely influenced by the presence of wetlands and exposed segments of stream as it flows through the golf course, potentially making the upper basin more vulnerable to the impacts of climate change. Decreases in water temperature in downstream reaches can be especially beneficial to aquatic life, where salmonid species can be found.

Water Quality Index

Two stations (BBC10.4 and PET0.0) had significant decreasing trends in WQI during the dry and combined seasons. Water quality at these two stations appears to be driven by unique conditions. Wetland areas upstream of BBC10.4, and runoff from commercial, industrial and roadway surfaces to Peterson Channel and shallow groundwater may be influencing the trends at these stations more than basin-wide management activities. Additional information on water quality and hydrology in the upper basin is needed to characterize the dynamics causing declines in water quality in the upper reaches of BBC. An increase in human encampments near wetland areas may be contributing to some of the indicators of water quality decline including significantly decreasing WQI scores for turbidity, TSS and bacteria. Evaluation of all sources of discharge to Peterson Channel will help identify locations for water quality management efforts to improve water quality.

Turbidity

Significant increasing trends in turbidity were detected at all stations except BBC5.2 during base flow events and at PET0.0 during storm flow events. The trends, though significant, mostly represented small increases in turbidity and may not be of immediate concern considering the relatively few water quality exceedances in WY2024 which were limited to BBC2.6 and BBC1.6. Most storm flow exceedances at BBC1.6 were associated with high turbidity at COL0.0, which is upstream of BBC1.6. Sources of increased turbidity at COL0.0 are unclear and warrant further investigation but may be related to impervious or non-vegetated areas adjacent to the creek, particularly in its upper reaches, which can cause higher flows during storm flow events and lead to erosion of the stream banks. Illicit dumping and encampments in the tributary's watershed may also be contributing to degrading stream bank stability and loss of riparian cover which can contribute to erosion. Identifying and addressing the source of high turbidity in Cold Creek may also improve turbidity at BBC1.6.

Turbidity at BBC2.6 was elevated during base flow events relative to the next upstream station BBC5.2, but no clear source has been identified that would result in this increase. However, turbidity at BBC2.6 may be influenced by increased human presence in Leverich Park. While significant differences were not detected between these locations for turbidity and TSS during storm events, TSS concentrations at BBC2.6 were substantially greater than BBC5.2 during storm events. Water quality at BBC2.6 is likely influenced by the nearly 3 miles of SR 500 within its subbasin including several mapped WSDOT outfalls. Additional sources may include construction site runoff, although turbid discharges from construction sites are prohibited by City code and monitored by municipal staff. Causes of increased turbidity between BBC5.2 and BBC2.6 should be investigated to prioritize BMP implementation. Stormwater treatment of highway runoff in this area may be beneficial.

Chloride and Conductivity

A significant stream-wide increasing trend was identified for chloride, which was monitored from WY2020-2023, for all mainstem stations and tributaries except BUR0.0. Conductivity, monitored since 2011, also exhibited a significant increasing trend at all stations except the two most upstream during dry and combined season base flow. Increases in conductivity are associated with increased concentrations of ions, including chloride. Increasing conductivity trends were identified in a similar set of stations during the 2017 Trend Analysis Report indicating that these related trends do not appear to be driven by short-term changes (Herrera 2018a). These increases in conductivity may be driven by increases in chloride but may also be impacted by other ions. Groundwater typically has higher concentrations of certain ions from natural and anthropogenic sources, which results in increased conductivity.

The increasing chloride and, potentially related, conductivity trends are likely the result of increased magnesium chloride deicer salt application during winter weather. Application of magnesium chloride deicers may contribute to an accumulation of salts in the soils that are transported to groundwater via infiltration through porous soils or directly to the stream through stormwater runoff. While increasing trends in concentrations have been observed for base and storm flow, concentrations are well below the EPA chronic water quality criteria of 230 mg/L. However, deicers can reduce soil water retention and nutrient storage ability, which can negatively impact plant health and increase potential for streambed erosion due to loss of root structure from plant mortality, which may impact water quality parameters such as turbidity and temperature. Salts increase corrosion of road surfaces and other infrastructure, increasing maintenance costs. The City should be strategic in the application of deicer to minimize use to mitigate impacts and slow accumulation over time.

4.3. Sources and Impacts

4.3.1. Tributaries

Tributary stations exhibited unique water quality characteristics from the mainstem BBC stations that may be impacting water quality at downstream stations. In addition to the differences in water quality between tributary and mainstem stations, the tributary stations, particularly BUR0.0 and COL0.0 had larger differences between base and storm flow concentrations than other BBC stations.

The furthest upstream tributary, Peterson Channel, is primarily fed by groundwater and industrial noncontact cooling water during base flow. High groundwater entering perforated stormwater pipes provides flow to the channel year-round. The stormwater system also carries runoff from streets and parking lots in commercial, industrial and residential areas during rain events. After crossing under I-205, Peterson Channel continues flowing east through a residential area and along the southern border of the golf course, entering BBC immediately downstream of station BBC8.8 and upstream BBC8.4 at Burton Road.

Copper concentrations in Peterson Channel have been relatively high on occasion and appeared to have an impact on downstream station BBC8.4, which showed a significant increase in copper concentrations compared to upstream station BBC8.8. Copper concentrations are generally of low concern in this reach of BBC and are not of concern in Peterson Channel where no recent copper criteria exceedances were identified, but impacts to downstream BBC stations are still worth characterizing. This apparent impact was most pronounced during base flow events. Elevated total copper concentrations could originate from highway or other high traffic use areas. Identifying sources of copper that may be entering the shallow groundwater would help in developing the most effective water quality treatment to remove metals in stormwater runoff.

Burton Channel tributary, like Peterson, also originates east of I-205 but flows are predominantly driven by precipitation through runoff and infiltration. After crossing under the freeway, the small tributary flows through piped and open channel segments in and around residential properties. Station BUR0.0, just upstream of the BBC confluence, had several unique water quality characteristics including elevated zinc and low hardness during storm events but appeared to have the lowest flow of all stations according to visual observations. Ecology's 2022 Category 5 listings include Burton Channel for copper and zinc which was supported by high metals concentrations at BUR0.0. The impact of metals on aquatic toxicity increases with decreasing hardness, so the relatively minor individual contributions of zinc coupled with low hardness may impact toxicity downstream. Stormwater runoff from impervious surfaces in the immediate vicinity of the tributary may be driving both high zinc concentrations and low hardness during storm events. While most stormwater in the BUR0.0 drainage basin is controlled by infiltration facilities, untreated runoff from residential areas, Burton Road and I-205 is conveyed directly to Burton Channel through over 20 outfalls. Stormwater runoff, which typically has much lower hardness than groundwater, can carry common urban stormwater contaminants including metals to urban streams. The feasibility of treating stormwater in this subbasin, particularly from the highway and Burton Road, should be evaluated to address high metals concentrations in the channel.

Cold Creek flows through residential, commercial and industrial properties in unincorporated Clark County before entering BBC just west of I-5. Cold Creek is primarily groundwater driven during base flow and exhibits unique base flow water quality characteristics relative to nearby BBC stations, including colder temperatures during the summer and high conductivity and hardness. Storm flow characteristics measured at COL0.0 often had higher turbidity and TSS than other stations and may have impacted conditions at the downstream station BBC1.6. High turbidity and TSS concentrations may be related to its proximity to the freeway and contribute to the elevated concentrations at BBC1.6. Elevated turbidity has also been measured during storm flow at BBC2.6, upstream of the Cold Creek confluence, also contributing to high turbidity at BBC1.6. Storm flow metals concentrations were also high at COL0.0 compared to other mainstem stations and may be contributing to general increases in these concentrations downstream. The Cold Creek watershed is primarily residential with some commercial and industrial land use, but much of the channel runs through properties owned by the Bonneville Power Administration and Washington State Department of Transportation. The drainage area in the immediate vicinity of the monitoring station is primarily state-owned and forested land. Evidence of illicit dumping and unauthorized camping has been noted by field staff in the area, resulting in exposed soils and likely contributing to the substantial water quality changes between base and storm flow events. Protection and restoration of vegetation in riparian areas and providing additional stormwater treatment in the COL0.0 subbasin could improve water quality conditions in the stream.

4.3.2. Septic Indicators and Direct Human Impacts

Nitrate + nitrite concentrations in BBC are similar to nitrate concentrations measured in shallow groundwater wells from the uppermost component of the Unconsolidated Sedimentary Aquifer which may be a source of base flow in some segments of BBC (Herrera and PGG 2019). A significant decreasing trend in nitrate + nitrite from 2011-WY2024 was detected at all mainstem stations for base flow (dry and combined seasons) and at the most upstream stations (BBC10.4 and BBC8.8) for total nitrogen.

The decrease in nitrate + nitrite concentrations over time may be related to a decrease in septic system contribution by the removal of 165 on-site septic systems within the watershed in the past five years. Increased maintenance frequency of septic systems providing inadequate treatment, driven by Clark County Public Health inspections, may also be reducing nitrate concentrations. In addition to nitrogen, phosphorus, bacteria and chloride are parameters often associated with septic inputs. Although trend analyses of these parameters do not show a similar decrease, nitrates from septic systems tend to be more mobile because they do not absorb to soil. Phosphorus and bacteria, when bound to soil particles, may remain in place and only reach surface waters through erosional processes. Bacteria growth can be limited by environmental conditions and may die off before reaching a waterbody.

One trend observed in this study was increasing chloride concentrations at most sites. Selected for monitoring in this project as a common indicator of septic influences, the increasing trend is more likely to have been caused by the use of magnesium chloride deicers in the watershed. Although a significant increasing trend was detected for SRP at most stations, data from the lab frequently showed the dissolved fraction of phosphorus was greater than the total phosphorus concentration. This discrepancy is likely related to laboratory methodology issues and the trend analysis for SRP may not accurately reflect changes in dissolved phosphorus in the waterbody. Herrera has worked with the laboratory to resolve the issue and has modified the current monitoring plan to use field filtration instead of laboratory filtration to reduce the potential for cross contamination. The issue will continue to be monitored.

Human presence in and around sensitive riparian areas can cause immediate and long-term changes to the environment and appear to be playing a part in declining water quality trends throughout the watershed. The Burnt Bridge Creek greenway has been significantly impacted by damage to vegetation, soil compaction, trash and human waste. With a goal to reduce incidents of homelessness and mitigate the adverse impacts of unsanctioned camping, the Vancouver Municipal Code was updated to establish impact zones protecting sensitive resources. Camping, and the use of fires, is now restricted within 200 feet of waterbodies and on land used for water, wastewater and stormwater facilities. A Homelessness Emergency Action Plan was created to guide coordination and response from supporting agencies and organizations.

The City's Homeless Assistance and Resources Team, along with staff from many departments, including Public Works, Police and Fire, has been conducting site clean-ups and providing resources and support to help individuals find safe and permanent shelter. The summer 2024 Point in Time survey identified 488 individuals experiencing homelessness within the City limits. This represents an increase of approximately eight percent from 2023, which is generally in line with other cities in the country. Encampments can often become concentrated near creeks and surface waters because riparian corridors can provide shelter from the elements and some limited safety. Efforts to build safe stay units and transitional housing is ongoing with the support of many partners in the community.

A microbial source tracking study for the creek was initiated in WY2025 to evaluate sources of bacteria in the watershed (Herrera 2025b). This study will use DNA analysis to differentiate fecal bacteria between human, dog, avian and cow to provide more data on specific sources of bacteria at different locations in the watershed. This information can be used to help reduce bacteria levels that limit water quality in the creek.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Monitoring Stations and Frequency

No changes to monitoring locations or sampling frequency are proposed for WY2025. Building upon the existing consistent dataset will support data analysis and interpretation of management activities in the future.

Monitoring at the same 11 stations (and 8 continuous temperature monitoring stations) should continue to include base flow and storm sampling at the same frequency defined in the QAPP:

- Five storm events in the wet season from October through May
- Three base flow events in the wet season from November through April
- Four base flow events in the dry season from June through September

The total number of samples collected annually would be 144 samples (including 12 duplicate samples).

5.2. Monitoring Parameters and Methods

The monitoring parameters and analytical methods used in recent monitoring should be continued in the future, with the following exceptions:

- Analyze sources of microbial contamination through microbial source tracking (MST). A QAPP Addendum has been finalized and approved by the City to characterize how human and key animal sources of *E. coli* concentrations vary across BBC (Herrera 2024b). MST sampling is scheduled for three storm events and three dry base events in WY2025. *E. coli* remains a priority contaminant for BBC with WY2024 storm flow concentrations exceeding the water quality criteria at all stations and base flow concentrations exceeding the criteria at six stations.
- Field filter orthophosphate and dissolved metals. A QAPP Addendum has been finalized and approved by the City to field filter orthophosphate as SRP and dissolved metals copper, lead, and zinc. Field filtration has been implemented into the 2024-2027 sampling regime due to intermittent observations of SRP fraction exceedances and subsequent QA issues of high SRP to TP ratios during laboratory filtration of orthophosphate and dissolved metals (Herrera 2024c).

5.3. Uncertainty and Data Gaps

Conclusions and recommendations are based on the available data. Alternative causes to impaired water quality and potential solutions may be identified with collection of different types of data. Limitations to current data and potential new areas to investigate are listed below:

- Statistical power of spatial and temporal trend analyses was limited by the total number of samples collected and the period of time the samples were collected under. Certain trends may be present but could not be identified as statistically significant with the available data.
- Temporal trends are based on the full datasets available for each parameter and may not capture changes in trends in recent years due to management activities or urban growth in the basins. For example, a trend identifying decreasing dissolved oxygen at a station over the full project dataset may imply that recently implemented water quality improvements are not working, but short-term increasing trends may be present or may be masked by other variables.
- Previous monitoring programs in BBC have not included stream discharge measurements. Clark County and USGS previously operated gages in the creek, but both have been discontinued. Monitoring the creek's response to precipitation is beneficial for timing storm flow monitoring events and may result in more representative and meaningful storm flow monitoring data. In addition, more in-depth relationships may be identified between stream flow and contaminant concentrations with continuous flow monitoring data available.
- During monitoring activities, field staff have observed evidence of human habitation near monitoring stations. It is presumed that human encampments are common along the creek, but data on the specific distribution and density of such camps within the BBC drainage are unavailable. Such information may be useful in determining the impact of human encampments on water quality.
- Other City and regional water quality improvement projects have been implemented which may relate to water quality improvements in BBC. Similar to the SCIP identified above, information on the implementation dates and extent of these programs has not been compared to monitoring data to identify impact on water quality.

5.4. Additional Studies and Analyses

Additional studies to fill data gaps, prioritize additional actions for improving the water quality and overall watershed health, and identify additional sources impacting water quality are described below. Upon publication of Ecology's TMDL Advance Restoration Plan, these specific recommendations may need to be adapted to align with support findings and recommendations of the TMDL Advance Restoration Plan. Studies considered to be of greatest potential value include:

- Continuous stream flow monitoring to document low flow conditions, quantify stormwater inputs, evaluate long-term hydrologic trends, and inform fish habitat restoration needs by installing one or more continuous gage stations (e.g., reinstall at USGS gage stations near BBC1.6 or BBC0.0 at the mouth of Vancouver Lake and/or Clark County gage at BBC5.9, currently measuring water level (stage) for the NPDES regional monitoring project). In addition, instantaneous flow measurements at tributary stations may also be helpful at estimating pollutant loads from these sources and prioritizing tributary basins for water quality improvement projects.
- Targeted source tracking sampling to identify where water quality characteristics change along the length of the creek. For example, turbidity concentrations increased substantially during storm flow events between BBC5.2 and BBC2.6. Select source tracking sampling may be beneficial to further prioritize areas for water quality improvements or enforcement.

- Annual benthic macroinvertebrate sampling at selected stations with calculation of the B-IBI and other metrics, to better understand impacts and trends in habitat quality and inform restoration and/or protection priorities.
- Conduct high-level surveys on distribution of human encampments along BBC to inform decision-making on the relative impact of these encampments and monitor response to management activities regarding services for people experiencing homelessness.
- Climate modeling to understand near- and long-term impacts of climate change and identify actions to mitigate or protect against those impacts.
- Hydrogeological investigations to further characterize groundwater flow and near-creek hydraulic conductivity in the watershed and inform potential impacts of groundwater driven contamination to the creek.

5.5. Water Quality Improvement

Ecology is developing a TMDL Advance Restoration Plan that will drive activities to address water quality issues prior to the development of a formal TMDL. The TMDL Advance Restoration Plan is currently in draft review by regulators and stakeholders. The desired outcome is for the City to voluntarily meet water quality standards through the implementation of BMPs. The City is already taking an active and multi-faceted approach to improve water quality in the BBC Watershed.

We recommend that the City continue its existing and planned activities that address pollutant sources (e.g., reduce the number of septic systems through connection to sanitary sewer), reduce water temperature through increased riparian vegetation and urban tree cover, and provide additional treatment of stormwater through construction and maintenance of stormwater facilities. Specific recommendations are described below.

Septic systems

The City has estimated that at least 165 septic systems within the watershed have been disconnected over the last five years. This may be related to the stream-wide significant decreasing trend in base flow nitrate + nitrite concentration. The City has secured funding for enhancing SCIP, but additional funding sources may need to be identified for continued implementation of the program. The City has estimated that over 2,000 septic systems are currently in use throughout the watershed and 530 of those are within 1,500 feet of the creek. We recommend the City continue to prioritize the SCIP program and target the septic system clusters near the creek in order to reduce nutrients and potentially improve dissolved oxygen concentrations. The City should continue to document new sewer connections to facilitate future effectiveness evaluations.

Stormwater treatment

The City should consider a stormwater retrofit study for the subbasins draining to BBC2.6 and Burton Channel. Both subbasins are impacted by highway runoff and WSDOT stormwater funds for stormwater treatment improvements and retrofit may be available. For the BBC2.6 subbasin, stormwater treatment of runoff from roadways that comprise substantial portions of the subbasin such as Northeast St. Johns Road and Northeast 15th Avenue would benefit water quality. Both Burton Channel and Cold Creek have 303(d) listings for copper and/or zinc and would benefit from stormwater treatment. However, much of the Cold Creek tributary area is outside of City limits, and Clark County oversees implementation of stormwater improvement projects in that basin. For the BUR0.0 subbasin, Burton Road could be evaluated to see if it could be a candidate for bioretention facilities distributed along the roadway or regional facility improvements.

Riparian Cover and Stream Restoration

To address water temperature criteria exceedances, continued emphasis on restoring riparian cover along the stream is recommended. New plantings should be prioritized in areas with minimal pre-existing riparian cover while emphasis should be placed on ensuring established riparian cover is protected. Additional partnership opportunities could also be explored with private parties such as the Royal Oaks Country Club to improve riparian cover along the reach immediately upstream of BBC8.8, where 7-DADMax exceedances were most frequent. With continuing impacts of climate change leading to hotter summer temperatures, improving riparian cover, particularly in upper reaches of the creek including the recently City-acquired property near BBC10.4, should continue to be a priority to address high water temperatures and low dissolved oxygen concentrations.

We also recommend pursuing partnerships and funding for stream restoration such as reconnecting floodplains, restoring wetlands, and addressing erosion of streambanks.

Encampments and Illicit Discharge

In October 2024, the City passed an ordinance that banned camping within 200 feet of certain surface waters including BBC, Peterson Channel, and Burton Channel. This may be a useful enforcement tool for the City to reduce impacts from camp sites near the creek and tributaries that may have been contributing to water quality degradation. At the most recent point in time survey of unsheltered homelessness (July 2024), the City's Homeless Assistance and Resources Team identified 488 people in Vancouver experiencing unsheltered homelessness which represented a roughly eight percent increase from the previous year. Coordination with Clark County and other stakeholders to ensure accessible alternatives are available will be an important step in ensuring the success of this approach.

Illicit dumping of household waste was noted on several occasions at monitoring stations along BBC including at the upstream station BBC10.4 and at Cold Creek during the WY2024 monitoring period. While the extent and impact of pollution point sources like these are difficult to quantify, additional community awareness of the impact of dumping or tools for reporting illicit dumping may be beneficial to reduce occurrences and reduce cleanup times. In addition to general awareness, coordination with and support for community cleanup groups may be helpful to mitigate dumping, particularly in areas with trail and park access to the creek.

Tributaries

Drainages of tributaries to BBC should also continue to be prioritized for improvements in certain cases. Prioritizing erosion control, illicit dumping cleanup, encampment enforcement, and other in-stream restoration projects in this basin will help mitigate impacts of high storm flow concentrations on downstream stations.

This page intentionally left blank

6. REFERENCES

APHA, AWWA, and WEF. 1998. Standard Methods for the Examination of Water and Wastewater. 20th edition. Edited by A.E. Greenberg, American Public Health Association; A.D. Eaton, American Water Works Association; and L.S. Clesceri, Water Environment Federation.

Clark County. 2020. Quality Assurance Project Plan for Status and Trends: Monitoring of Urban Streams in Clark and Cowlitz Counties in the Lower Columbia River Region. Clark County Public Works, Vancouver, Washington. September.

Clark County. 2023. Lower Columbia Urban Streams (LCUS) Monitoring: Annual Status Report (2021–2022). Clark County Public Works, Clean Water Division, Vancouver, Washington. October.

Ecology. 2002. A Water Quality Index for Ecology's Stream Monitoring Program. Washington State Department of Ecology, Olympia, Washington. Publication No. 02-03-052. December. <https://fortress.wa.gov/ecy/publications/publications/0203052.pdf>.

Ecology. 2008. Burnt Bridge Creek Fecal Coliform Bacteria, Dissolved Oxygen, and Temperature Total Maximum Daily Load, Water Quality Design (Quality Assurance Project Plan). Washington State Department of Ecology, Olympia, Washington. Publication No. 08-03-110. July. <https://fortress.wa.gov/ecy/publications/publications/0803110.pdf>.

Ecology. 2014. The Water Quality Index Spreadsheet. Version 6. Washington State Department of Ecology, Olympia, Washington. June. < https://ecology.wa.gov/Asset-Collections/Doc-Assets/Research-Data/Monitoring-Assessment/River-stream-monitoring/water-quality-index-version-6>.

Ecology. 2018. Water Quality Program Policy 1-11. Washington State Department of Ecology. Water Quality Program. Olympia, Washington. Publication No. 18-10-035. November. <https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d/Assessment-policy-1-11>.

Ecology. 2019. Chapter 173-201A WAC Amendments. Adopted January 23, 2019. Effective February 23, 2019. Washington State Department of Ecology. Water Quality Program. Olympia, Washington.

Ecology. 2024. Paired watershed retrofit & restoration study. Stormwater Action Monitoring. Washington State Department of Ecology. Accessed February 13, 2025. <https://ecology.wa.gov/Regulations-Permits/Reporting-requirements/Stormwater-monitoring/Stormwater-Action-Monitoring/SAM-effectiveness-studies/Paired-watershed-retrofit-and-restoration-study>.

EPA. 2001. Ambient Water Quality Criteria Recommendations, Information Supporting the Development of State and Tribal Nutrient Criteria, Rivers and Streams in Nutrient Ecoregion I. U.S. Environmental Protection Agency, Office of Water, Washington, DC. EPA 822-B-01-012. December.

EPA. 2008. Results of the Interlaboratory Testing Study for the Comparison of Methods for Detection and Enumeration of Enterococci and Escherichia coli of Combined Sewer Overflows (CSOs). U.S. Environmental Protection Agency Office of Water. EPA 821-R-08-006. September.

EPA. 2011. Federal Register 40 CFR Part 136 – Guidelines for Establishing Test Procedures for the Analysis of Pollutants. U.S. Environmental Protection Agency, Water Programs, Washington, DC. Accessed May 26, 2011. <https://www.federalregister.gov/documents/2007/03/26/07-1455/guidelines-establishing-test-procedures-for-the-analysis-of-pollutants-analytical-methods-for>.

Finch. 2018. Recreational Use Criteria: Preliminary Decisions. Water Quality Program. Department of Ecology, State of Washington. Accessed January 22, 2019.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical Methods in Water Resources, Elsevier, Amsterdam.

Herrera. 2011a. Burnt Bridge Creek Ambient Water Quality Monitoring Project – Quality Assurance Project Plan. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. August 15.

Herrera 2011b. Toxics in Surface Runoff to Puget Sound, Phase 3 Data and Load Estimates. Prepared for Washington Department of Ecology, Olympia, Washington, by Herrera Environmental Consultants, Seattle, Washington. April.

Herrera. 2012a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2011 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. March 6.

Herrera. 2012b. Burnt Bridge Creek Ambient Water Quality Monitoring Project – Quality Assurance Project Plan: 2012 Addendum. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. May 2.

Herrera. 2013a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2012 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. March 27.

Herrera. 2013b. Burnt Bridge Creek Ambient Water Quality Monitoring Project – Quality Assurance Project Plan: 2013 Addendum. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. May 29.

Herrera. 2014a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – Monitoring and Trend Analysis Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. June 30.

Herrera. 2014b. Burnt Bridge Creek Ambient Water Quality Monitoring Program – Quality Assurance Project Plan: 2014 Ambient Monitoring. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. July 3.

Herrera. 2015a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2014 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. March 10.

Herrera. 2015b. Burnt Bridge Creek 2015 Monitoring – Modifications to QAPP. Technical Memorandum prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. June 15.

Herrera. 2016a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2015 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. March 24.

Herrera. 2016b. Burnt Bridge Creek 2016 Monitoring – Modifications to QAPP. Technical Memorandum prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. May 26.

Herrera. 2017a. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2016 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. February 21.

Herrera. 2017b. Burnt Bridge Creek 2017 Monitoring – Modifications to QAPP. Technical Memorandum prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. May 17.

Herrera. 2018a. 2017 Trend Analysis Report. Burnt Bridge Creek Ambient Water Quality Monitoring Program. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. March 20.

Herrera. 2018b. Burnt Bridge Creek 2018 Monitoring – Modifications to QAPP. Technical Memorandum prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. May 11.

Herrera. 2019a. Quality Assurance Project Plan: Burnt Bridge Creek Water Quality Monitoring Program 2019–2021. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland Oregon. October 19.

Herrera. 2019b. Burnt Bridge Creek Ambient Water Quality Monitoring Program – 2018 Monitoring Report. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. March 4.

Herrera. 2022a. Burnt Bridge Creek 2021–2023 Monitoring – QAPP Addendum. Technical Memorandum prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. January 26.

Herrera. 2022b. Water Year 2020–2021 Monitoring Report. Burnt Bridge Creek Water Quality Monitoring Program. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. January 25.

Herrera. 2022c. 2021–2022 Summary Report. Columbia Slope Water Quality Monitoring Project. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. July 7.

Herrera. 2023. Quality Assurance Project Plan. Burnt Bridge Creek Water Quality Monitoring Program 2024–2027. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. December 29.

Herrera. 2024a. Water Years 2022-2023 Monitoring Report. Burnt Bridge Creek Water Quality Monitoring Program. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. January 5.

Herrera. 2024b. Water Year 2025 Quality Assurance Project Plan Addendum for Microbial Source Tracking. Burnt Bridge Creek Water Quality Monitoring Program 2024–2027. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. December 23.

Herrera. 2024c. Water Year 2025 Quality Assurance Project Plan Addendum. Burnt Bridge Creek Water Quality Monitoring Program 2024–2027. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon. November 15.

Herrera and PGG. 2019. Integrated Scientific Assessment Report, Vancouver Watershed Health Assessment. Prepared for the City of Vancouver, Washington, by Herrera Environmental Consultants, Inc., Portland, Oregon, and Pacific Groundwater Group, Seattle, Washington. February 20.

King County. 2018. Stormwater Action Monitoring Status and Trends Study of Puget Lowland Ecoregion Streams: Evaluation of the First Year (2015) of Monitoring Data. Prepared by King County in collaboration with U.S. Geological Survey, Ecology, Puget Sound Partnership for Ecology, Stormwater Action Monitoring. Science and Technical Support Section, Water and Land Resources Division, Seattle, Washington.

McCarthy, S. 2020. Burnt Bridge Creek Watershed Fecal Coliform Bacteria, Temperature, Dissolved Oxygen, and pH: Source Assessment. Publication 20-03-016. Washington State Department of Ecology, Olympia, Washington. October. <https://fortress.wa.gov/ecy/publications/SummaryPages/2003016.html>.

NPS. 2018. The Cultural Landscape of Fort Vancouver National Historic Site: Indian Country, pre-1824. National Park Service. Updated February 8, 2018. <https://www.nps.gov/articles/fovaclrindiancountry.htm>.

Portland BES. 2025. City of Portland Rainfall HYDRA Network – Hayden Island Rain Gage. Oregon Water Science Center, USGS, Portland, Oregon. Accessed January 7, 2025. <or.water.usgs.gov/non-usgs/bes/hayden_island.rain>.

Tetra Tech. 2015. Burnt Bridge Creek Biologic Condition Assessment: 2015 Monitoring Report. Prepared for City of Vancouver, Washington, by Tetra Tech. November 2015

Vancouver. 2022. Climate Action Framework. City of Vancouver, Washington. December. <https://www.cityofvancouver.us/wp-content/uploads/2023/08/vancouvercaf_final_121422.pdf>

Vancouver. 2023. Stormwater Management Action Plan. City of Vancouver, Washington, Surface Water Management. March. <https://www.cityofvancouver.us/wp-content/uploads/2023/06/smap_march_2023.pdf>.

Vancouver. 2024. Urban Forestry Work Plan 2025-2026. City of Vancouver, Washington, Public Works Environmental Services. <https://www.cityofvancouver.us/wp-content/uploads/2025/01/Work-Plan-25-26.pdf>

WSDA. 2022. Ambient Monitoring for Pesticides in Washington State Surface Water. Washington State Department of Agriculture Natural Resources Assessment Section. Publication No. 102-737. April.

WSDA. 2024. Burnt Bridge Creek Summary of 2022 Surface Water Monitoring Program Results. Washington State Department of Agriculture Natural Resources Assessment Section. Publication No. 102-737. April.

WHO. 2003. Chloride in Drinking-Water. Background document for development of WHO Guidelines for drinking-water quality. World Health Organization, Geneva. (WHO/SDE/WSH/03.04/03). Originally published in 1996, revised 2003.

This page intentionally left blank