INTEGRATED SCIENTIFIC ASSESSMENT REPORT

VANCOUVER WATERSHED HEALTH ASSESSMENT

Prepared for
City of Vancouver, Washington

Prepared by
Herrera Environmental Consultants, Inc.
and
Pacific Groundwater Group

PGG

HERRERA

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VANCOUVER WATERSHED HEALTH ASSESSMENT

Prepared for
City of Vancouver Surface Water Management
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Vancouver, Washington 98661

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February 20, 2019

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ABBREVIATIONS AND ACRONYMS

B-IBI	Benthic Index of Biotic Integrity
BMP	best management practice
°C	degrees Celsius
CARA	critical aquifer recharge area
cfs	cubic feet per second
CFU/100mL	colony-forming units per 100 milliliters
City	City of Vancouver
CPU	Clark Public Utilities
DDE	4,4′-dichlorodiphenyldichloroethylene
Ecology	Washington State Department of Ecology
EIM database	Environmental Information Management database
GIS	geographic information system
gpm	gallons per minute
Herrera	Herrera Environmental Consultants, Inc.
LID	low impact development
LiDAR	light detection and ranging
mgd	million gallons per day
mg/L	milligrams per liter
µg/L	micrograms per liter
msl	mean sea level
MST	microbial source tracking
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTU	nephelometric turbidity units
PAHs	polycyclic aromatic hydrocarbons
PBDEs	polybrominated diphenyl ethers

PCBs	polychlorinated biphenyls
PGG	Pacific Groundwater Group
PO_4	orthophosphate
PPCPs	pharmaceuticals and personal care products
SCIP	Sewer Connection Incentive Program
SGA	Sand and Gravel Aquifer
TGA	Troutdale Gravel Aquifer
TMDL	Total Maximum Daily Load
TSA	Troutdale Sandstone Aquifer
TSS	total suspended solids
UIC	underground injection control
USA	Unconsolidated Sedimentary Aquifer
USGS	United States Geological Survey
US EPA	US Environmental Protection Agency
VOC	volatile organic compound
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WLE	water-level elevation
WQI	water quality index
WRP program	Water Resources Protection program
WRPO	Water Resources Protection Ordinance
WS	water station
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

The City of Vancouver, Washington (City) oversees land and development activities that directly and indirectly affect the condition of watersheds, including the land and natural resources within them. The City relies solely on groundwater for its drinking water, and it has various programs to monitor and protect its watersheds and receiving waters and to comply with environmental regulations. They include, for example, water quality monitoring; installation and retrofit of stormwater facilities; maintenance programs, such as catch basin cleaning and street sweeping; restoration and urban forestry activities that increase canopy cover through tree plantings and revegetation of riparian corridors; incentive programs targeted at connecting residences on septic systems to public sanitary sewers; illicit discharge detection and elimination programs; and outreach and enforcement efforts.

Herrera Environmental Consultants, Inc. and Pacific Groundwater Group conducted a watershed health assessment, using available data, to evaluate the ecological condition of Vancouver's watersheds, to identify data gaps, and to help the City prioritize watershed management programs and activities. Vancouver includes land within five main watersheds, but the Burnt Bridge Creek watershed and, to a lesser extent, the Columbia Slope watershed, represent the City's core areas for watershed management and, therefore, were selected as the study area for the watershed health assessment.

Results of the watershed health assessment showed no obvious water level decline in City aquifers, suggesting that the City's aquifer supply (water quantity) is reliable and recent development does not appear to be impairing groundwater availability. Groundwater quality is generally very good, but it is vulnerable to contaminants introduced at the land surface, as well as pollutants from septic systems and stormwater infiltration facilities. The influence of septic systems is evidenced by detections of pharmaceuticals and caffeine in a number of groundwater sampling locations and elevated nitrate concentrations (most prominent in the shallow groundwater system). Shallow groundwater is also vulnerable to pollutants associated with stormwater infiltration and land use activities, as evidenced by trace (minute) concentrations of petroleum hydrocarbons and other organic chemicals in some shallow wells. Phosphorus in shallow and deep groundwater was detected at concentrations that can affect algal activities in surface water receptors, and it likely occurs from natural and anthropogenic sources. Past research by the Washington State Department of Ecology has found groundwater/surface water interactions along some sections of Burnt Bridge Creek, so the creek would also be vulnerable to some of the groundwater pollutants.

Water quality in Burnt Bridge Creek is generally moderate. Impairments are typical of an urban creek. Analysis of recent (2011–2017) monitoring data for Burnt Bridge Creek indicate that water quality significantly improved for total suspended solids, fecal coliform, nitrate+nitrite, total nitrogen, and dissolved oxygen at some monitoring stations. However, at one or two monitoring stations, significant water quality decline was observed for dissolved oxygen, turbidity, total suspended solids, soluble reactive phosphorus, nitrate+nitrite, and total nitrogen.

The watershed health assessment also included a spatial (GIS-based) statistical analysis to determine whether landscape conditions (such as, land use, terrain, and septic system density) and watershed management (e.g., stormwater facilities and habitat restoration) showed statistically significant correlations with water quality in the Burnt Bridge Creek watershed. Results indicate that septic systems are increasing nitrogen and fecal bacteria concentrations and that urban development is increasing phosphorus concentrations in Burnt Bridge Creek. Riparian canopy cover showed a positive water quality effect by increasing dissolved oxygen concentrations and pH, which are considered improvements because some areas of the creek occasionally have a low pH. However, the correlation analysis of riparian canopy cover showed unexpected negative relationships with increasing temperature and turbidity in stream waters. Because riparian buffers should reduce stream temperatures and turbidity, other upstream factors are likely increasing stream temperatures and turbidity. No statistically significant correlations were found between groundwater quality and the watershed attributes evaluated.

The watershed health assessment provides a good baseline of landscape conditions and City activities. Based on the assessment, recommendations for the City include:

- Continue to incentivize and otherwise encourage properties on septic systems to connect to sanitary sewers when appropriate
- Expand the Greenway/Sensitive Lands and Urban Forestry programs that increase canopy cover
- Continue to retrofit underground injection control devices that lack stormwater treatment

Opportunities for the City to improve data collection include:

- Collecting high resolution data on impervious area coverage and canopy cover at regular intervals, which would help the City track changes over time and build on the baseline of landscape conditions developed through the watershed health assessment
- Collecting additional information (such as catchment area, age, and standardized categories of treatment) on stormwater best management practices, including dry wells.

1. INTRODUCTION

1.1. OVERVIEW

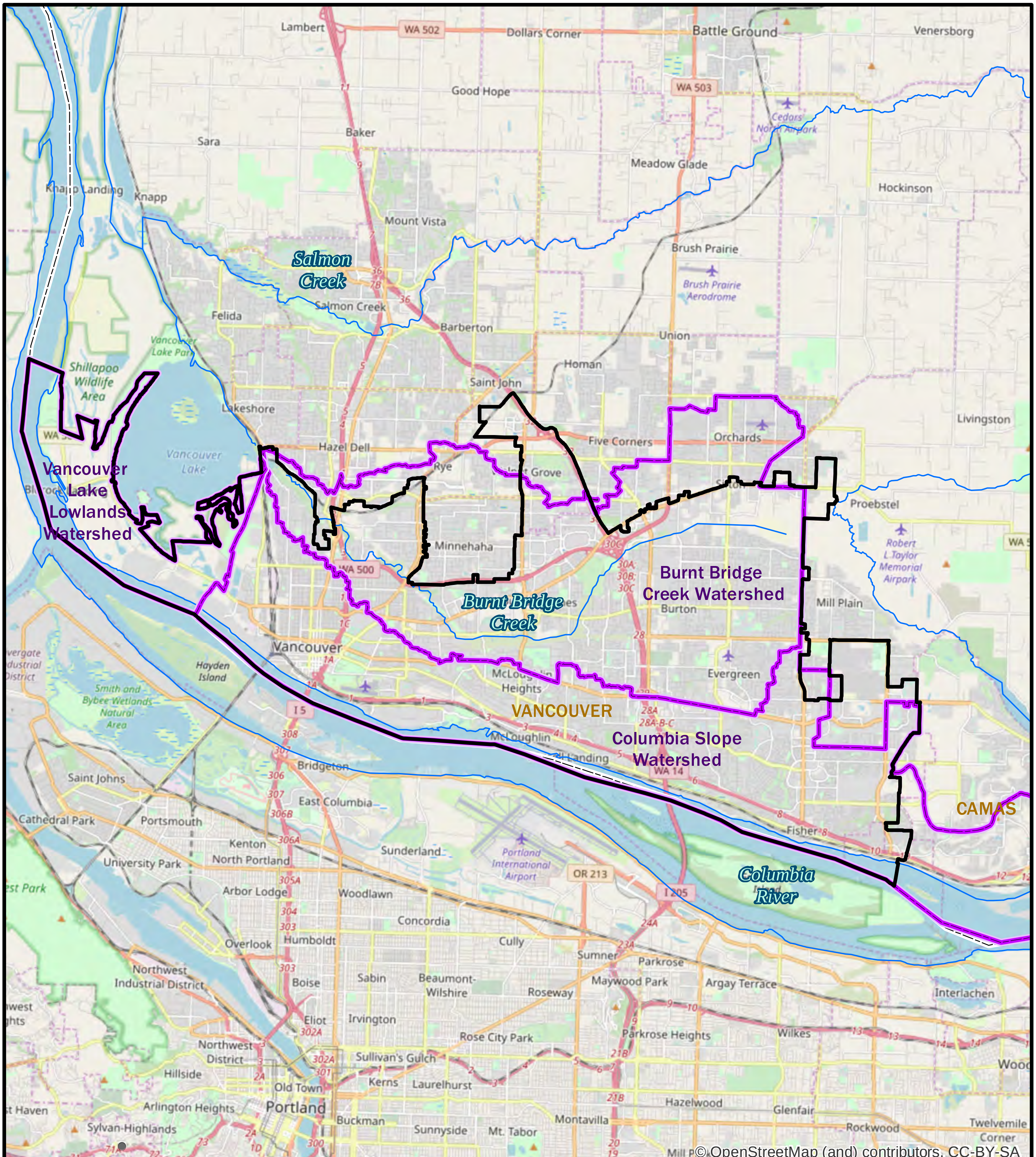
The City of Vancouver, Washington (City) oversees land and development activities that directly and indirectly affect the condition of watersheds, including the land and natural resources within them. The City relies solely on groundwater for its drinking water, and it has various programs to monitor and protect its watersheds and receiving waters and to comply with environmental regulations. They include, for example, water quality monitoring; installation and retrofit of stormwater facilities; maintenance programs, such as catch basin cleaning and street sweeping; restoration and urban forestry activities that increase canopy cover through tree plantings and revegetation of riparian corridors; incentive programs targeted at connecting residences on septic systems to public sanitary sewers; illicit discharge detention and elimination programs; and outreach and enforcement efforts.

Herrera Environmental Consultants, Inc., and Pacific Groundwater Group (PGG) conducted a watershed health assessment, using available data, to evaluate the ecological condition of Vancouver's watersheds, to identify data gaps, and to help the City prioritize watershed management programs and activities. *Watershed health* is often broadly defined to encompass various ecological attributes of a watershed. For example, the US Environmental Protection Agency (US EPA) defines six attributes of watershed health: landscape condition, habitat condition, hydrology, geomorphology, water quality, and biological condition (US EPA 2018). The watershed health assessment (i.e., the project) included three main tasks: 1) review and evaluate available information about existing watershed health; 2) evaluate the effectiveness of the City's watershed management programs; and 3) prepare watershed report cards.

This report describes the methods and presents the results of the first and second tasks. It includes a summary of data gaps and recommendations to acquire that missing data. This report also includes Herrera's and PGG's recommended strategies and BMPs to protect and improve watershed resources and to support beneficial uses for human and natural communities. Herrera and PGG will submit watershed report cards (for the third task) as a separate project deliverable.

1.2. STUDY AREA AND VICINITY

As shown on Figure 1, most of Vancouver lies within the Burnt Bridge Creek and Columbia Slope watersheds, although the city limits include land within the Lacamas Creek and Vancouver Lake Lowlands watersheds, as well as a small area within the Salmon Creek watershed. The Burnt Bridge Creek and Columbia Slope watersheds represent the core area of the City's watershed management and, therefore, were selected as the study area for the watershed health assessment.



Legend

- Watershed boundary
- Vancouver City Limits
- State boundary
- River

Figure 1.
Watershed Health Assessment Study Area.

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0 6,000 12,000 24,000
Feet

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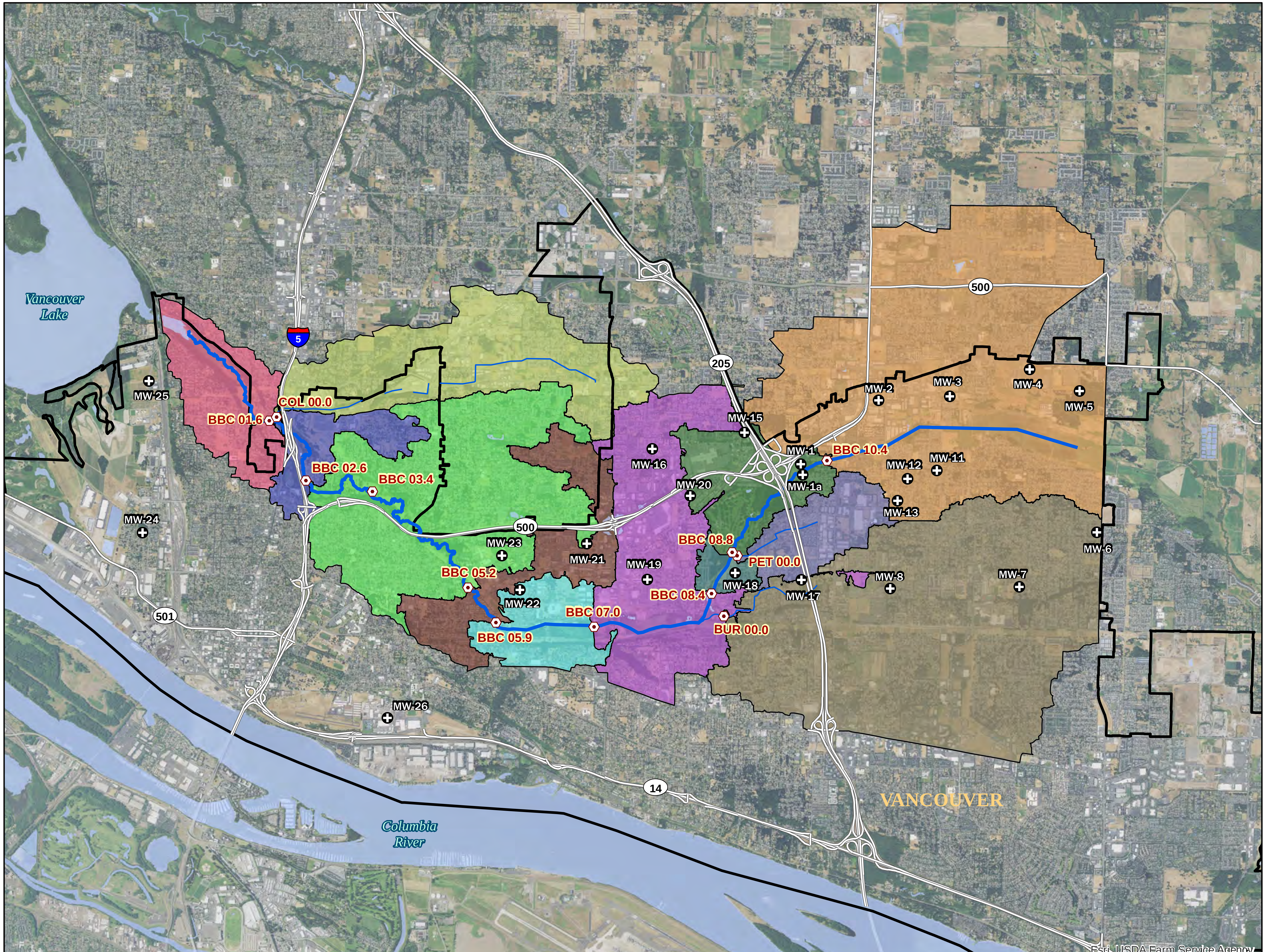
The Burnt Bridge Creek watershed encompasses approximately 28 square miles of which 70 percent is within Vancouver city limits. More than 80 percent of the watershed is in residential land use. Commercial and industrial uses cover about 10 percent of the land area in the watershed. Agricultural land uses are primarily in the upper (northeast) portion of the watershed and cover less than 10 percent of the land area. Together, natural areas and open water comprise about only 2 percent of the watershed area.

The Columbia Slope watershed encompasses approximately 25 square miles, including hillsides between Vancouver Lake and the Lacamas Creek that drain to the Columbia River. Approximately 10,411 acres of the watershed are within Vancouver city limits. Land use in the watershed is predominantly residential (approximately 86 percent) and commercial/industrial (approximately 13 percent). The westernmost part of the watershed includes a small portion of the Vancouver Lake Lowlands.

Most of the Vancouver Lake Lowlands (i.e., the low-lying area surrounding Vancouver Lake) are within the Vancouver Lake Lowlands watershed; the rest are in a small northwest portion of the Columbia Slope watershed. The Vancouver Lake Lowlands are important wintering, migration, and nesting habitats for waterfowl (National Audubon Society 2018). Most of the Vancouver Lake Lowlands are outside of the City's jurisdiction, so they were not evaluated for this watershed assessment.

Figure 2 shows the surface water basins and groundwater well locations that were used for the Burnt Bridge Creek watershed assessment. The water quality component of this watershed assessment focused primarily on Burnt Bridge Creek because there was adequate watershed monitoring data and information available to delineate watershed subbasins.

Figure 2.
Watershed Health Assessment - Surface Water and Groundwater Monitoring Locations and Burnt Bridge Creek Watershed Subbasins.



Legend

- Groundwater monitoring well
- Water quality monitoring location
- Vancouver City Limits

Subbasin boundary

- BBC 0.0
- BBC 1.6
- BBC 10.4
- BBC 2.6
- BBC 5.2
- BBC 5.9
- BBC 7.0
- BBC 8.4
- BBC 8.8
- BUR 0.0
- COL 0.0
- PET 0.0
- Burnt Bridge Creek
- BBC Tributary

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0 2,500 5,000 10,000 Feet

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2. DATA SOURCES

The project scope did not include collection of any new data. This section describes the data sources that were reviewed for the project. A variety of ecological, water quality, hydrologic, and other data have been collected by the City, other agencies, and various stakeholders. While water quality in Burnt Bridge Creek has been monitored since the early 1970s, data on water quality and other watershed health attributes in the Columbia Slope and Vancouver Lake Lowlands watersheds are limited.

2.1. SURFACE WATER DATA

Surface water data used for the project include surface water quality data collected from 2011 through 2017 for the City's Burnt Bridge Creek Ambient Water Quality Monitoring Program. Statistically significant trends in water quality between 2011 and 2017 documented in the Burnt Bridge Creek Trend Analysis Report (Herrera 2018) are also presented. The City's monitoring program included monitoring of 11 water quality parameters at 11 stations on Burnt Bridge Creek and its tributaries (Figure 2).

Studies of surface water quality in the Columbia Slope watershed are limited. Many studies have taken place on the lower Columbia River, to which the springs and seeps of the Columbia Slope discharge. A comprehensive, bi-state study, including water quality in the lower Columbia River, was completed in 1996. The final report prepared for that study (Tetra Tech 1996) summarized findings of about 50 reports generated during a large-scale, 6-year investigation of the lower Columbia River.

Two studies of stormwater discharges to the Columbia River were reviewed. Stormwater was collected during ten rainfall events in 1992 through 1994 at two outfall basins close to Interstate 5 (I-5). Parameters measured included metals, nutrients, and other conventional parameters (CH2M Hill 1995). In 2009, stormwater samples were collected by the United States Geological Survey (USGS) at two outfall locations in west Vancouver on the Columbia River as part of a larger study of stormwater and wastewater contaminants entering the Columbia River. Stormwater was analyzed for halogenated compounds, pesticides, polycyclic aromatic hydrocarbons (PAHs), trace elements, and oil and grease (Morace 2012).

Although the reports by Tetra Tech (1996), CH2M Hill (1995), and Morace (2012) were reviewed for the project, their data were not used in the analyses because of their age or limited applicability to the project.

2.2. GROUNDWATER DATA

Hydrogeologic conditions within the study area have been investigated by several agencies, including USGS, Ecology, Clark County, and consultants, including PGG and Robinson & Noble, among others. Surficial soils were mapped and described by the US Department of Agriculture, Natural Resources Conservation Service (NRCS).

Sources of groundwater quality data reviewed for this watershed assessment include:

- City of Vancouver standard compliance monitoring of its municipal water supply wells
- City of Vancouver monitoring of its network of shallow groundwater monitoring wells
- Ecology's Environmental Information Management (EIM) database
- Clark County Public Health data from focused sampling projects and building-permit applications, including both data from the Public Health department database (Clark County 2018) and unpublished data provided by Clark County Public Health.
- Clark Public Utilities (CPU) groundwater quality survey

Locations of the City's water supply wells are shown on Figure PGG-1.[1] For standard compliance monitoring, the City typically takes samples from the wells after treatment; therefore, the sampling data may not reflect the occurrence of compounds removed via treatment, such as volatile organic compounds (VOCs). PGG communicated directly with City staff to identify where groundwater contaminants have been detected and which treatment has been applied. The City also provided groundwater-level data from its water stations, which PGG used to assess the "water-supply sustainability" component of watershed health.

The City's shallow groundwater monitoring network consisted of 24 wells located near areas of stormwater infiltration, septic system concentrations, and areas where groundwater is close to the ground surface (Figure PGG-1). Although the wells were initially installed for monitoring groundwater levels, water quality monitoring was added in 2015 and included sampling in 12 of the wells. The monitoring network, sampling methodologies, and water quality data from the untreated groundwater samples were summarized in depth by PGG (2018).

Ecology's online EIM database includes water quality data from shallow wells (piezometers) installed by Ecology along Burnt Bridge Creek for a total maximum daily load (TMDL) study (Sinclair and Kardouni 2012) and data submitted from contaminated site investigations and cleanups performed by private entities. Treatment is typically not applied to TMDL study wells because they are primarily investigative.

Clark County Public Health collects nitrate data for new wells to obtain building permit approval and has performed its own studies to sample wells for nitrate concentrations (Joe Ellingson, Clark County Public Health, personal communication, 2018). PGG submitted a data request to

[1] All PGG figures are located in Appendix A of this report.

CPU and received a dataset with well information and nitrate concentrations. In 1991 and 1992, CPU sampled multiple wells and compiled additional water quality data to characterize various water quality parameters throughout Clark County.

2.3. Geographic Information System Data

Land cover and land use were evaluated through use of GIS datasets that included LiDAR elevation data, the 2011 National Land Cover Database (NLCD 2011), City of Vancouver datasets (septic system locations, stormwater infrastructure and treatment BMPs, and riparian plantings), and Clark County datasets (stormwater infrastructure and treatment BMPs). The NLCD includes land cover (20 classes), percent impervious area, and percent canopy grids with 30-meter pixels for the entire United States.

The stormwater infrastructure datasets include 25 categories of BMPs, consisting of various types of manholes and multiple categories of detention, infiltration, and treatment facilities. The City maintains maintenance records for dry wells that indicate conditions and observations, including whether shallow groundwater is observed.

Subbasin maps in the Burnt Bridge Creek watershed have been refined through monitoring and inspection efforts over the past decade. Though the larger outfall basins have been mapped for the Columbia Slope, not all subbasins have been delineated. Water quality data are too limited to support subbasin analysis.

2.4. City Programs and Activities

Information on City programs and activities was provided by City staff and compiled from maintenance records, email correspondence, and the City's website.

2.5. Previous Data and Multi-Disciplinary Studies

Additional multi-disciplinary studies provided by the City were also reviewed. A complete list of documents and data that were reviewed as part of this project are included in the *References* section (Section 8) of this report.

3. WATERSHEDS OVERVIEW

Herrera and PGG collected no new data for the project. The description of hydrology in this section focuses on groundwater because only limited stream gauge data were available.

3.1. GENERAL

Burnt Bridge Creek is a highly modified, urban stream that flows westward 12.6 miles from its agricultural origins, through the heart of Vancouver, to its terminus at Vancouver Lake (Figure 3). Burnt Bridge Creek's watershed covers approximately 28 square miles, and, as with most urban watersheds, the stream has been affected by roadways, utilities, and other infrastructure.

Historically, the upper portion of Burnt Bridge Creek, from Northeast 162nd Avenue to East 18th Street, flowed through a marshland without a defined channel. The marsh was drained for agriculture in the mid-1800s, but a strong connection between the shallow groundwater system and the creek remains. The substrate underlying Burnt Bridge Creek is highly permeable alluvium of the Terrace Landscape Unit, which also includes the foothills and slopes along the Columbia River. Gravels, sands, silts, and clays were deposited in the area when multiple breaches of ice dams impounding large lakes in Idaho and Montana occurred and sent massive floods through the Columbia River gorge and Portland Basin. The porosity of these sediments creates a close connection between groundwater and Burnt Bridge Creek, allowing stream flow to infiltrate into the shallow groundwater and vice versa.

The Columbia Slope watershed covers about 25 square miles between Vancouver Lake and the Lacamas Creek watershed (Figure 4). It is part of the Columbia River Landscape Unit and is composed of riverine floodplain areas draining multiple hillside seeps and streams supplied by groundwater, surface water runoff, and infiltrated urban stormwater to the Columbia River.

West of the Columbia Slope watershed, in the Columbia River floodplain, are the Vancouver Lake Lowlands. Vancouver Lake, covering about 2,300 acres, is the largest lake in the Portland/Vancouver metropolitan area. The large shallow lake remains connected to the river by tidally influenced flows in and out of the lake through Lake River. Lake River is a 14-mile-long slough that also transports flow from the Salmon Creek watershed (which covers about 90 square miles) and other smaller waterbodies before it connects to the Columbia River near Ridgefield, Washington. Burnt Bridge Creek flows through a wetland before discharging to Vancouver Lake but only contributes about 2 percent of the total lake water budget (Sheibley et al. 2014). A direct connection between the lake and the Columbia River was constructed in the 1980s through a narrow, gated, flushing channel, but flows were not significantly increased by that effort, and the lake remains shallow, with a mean depth of 3 to 5 feet.

3.1. LAND COVER AND LAND USE

Table 1 provides a breakdown of land use and land cover contributing to each Burnt Bridge Creek monitoring station. Monitoring stations, which are at the base of each basin, are shown on Figures 2 and 3.

Table 1. Land Use and Cover in the Burnt Bridge Creek Watershed.

		Land Use				Land Cover	
Monitoring Station/ Basin	Basin Area (acres)	Agriculture (percent cover)	Commercial/ Industrial (percent cover)	Forest/Field /Other (percent cover)	Residential (percent cover)	Tree Canopy Cover (percent cover)	Impervious Surface Cover (percent cover)
BBC 10.4	4,398	9%	9%	2%	80%	12%	44%
BBC 8.8	5,784	7%	10%	2%	81%	13%	45%
PET 0.0	483	0%	17%	0.1%	83%	16%	55%
BBC 8.4	9,989	4%	8%	1%	87%	16%	46%
BUR 0.0	4,064	0.3%	5%	1%	94%	19%	47%
BBC 7.0	11,870	3%	9%	2%	86%	16%	47%
BBC 5.9	12,388	3%	9%	2%	85%	16%	46%
BBC 5.2	13,177	3%	10%	2%	85%	16%	47%
BBC 2.6	15,477	3%	9%	2%	87%	16%	46%
COL 0.0	1,795	0.2%	13%	0.3%	86%	16%	44%
BBC 1.6	17,566	3%	9%	2%	86%	16%	46%

BBC = Burnt Bridge Creek; BUR = Burton Channel; COL = Cold Creek; PET = Peterson Channel

Moving downstream along the main stem, the cumulative basin areas increase from 4,398 acres at monitoring station BBC 10.4 (at stream mile 10.4) to 17,566 acres at monitoring station BBC 1.6 (at stream mile 1.6; Figure 2). Basin areas for the three tributaries are smaller than those along the main stem. Burton Channel represents the largest tributary basin (4,064 acres at monitoring station BUR 0.0) compared to Cold Creek (1,795 acres at monitoring station COL 0.0) and Peterson Channel (483 acres at monitoring station PET 0.0).

The basins consist of primarily (80 to 94 percent) residential land use with some (5 to 17 percent) commercial and industrial land uses. (Areas of commercial and industrial land uses were combined for the analysis.) All basins along the main stem of Burnt Bridge Creek have approximately 10 percent commercial/industrial land use, 2 percent forest/field/other land use, 15 percent tree canopy cover, and 45 percent impervious surface cover. Compared to the six downstream basins along the main stem (BBC 8.4, BBC 7.0, BBC 5.9, BBC 5.2, BBC 2.6, and BBC 1.6), the two most upstream basins along the main stem (BBC 10.4 and BBC 8.8) have more agricultural land use (7 to 9 percent versus 3 percent) and slightly less residential land use and tree canopy cover.

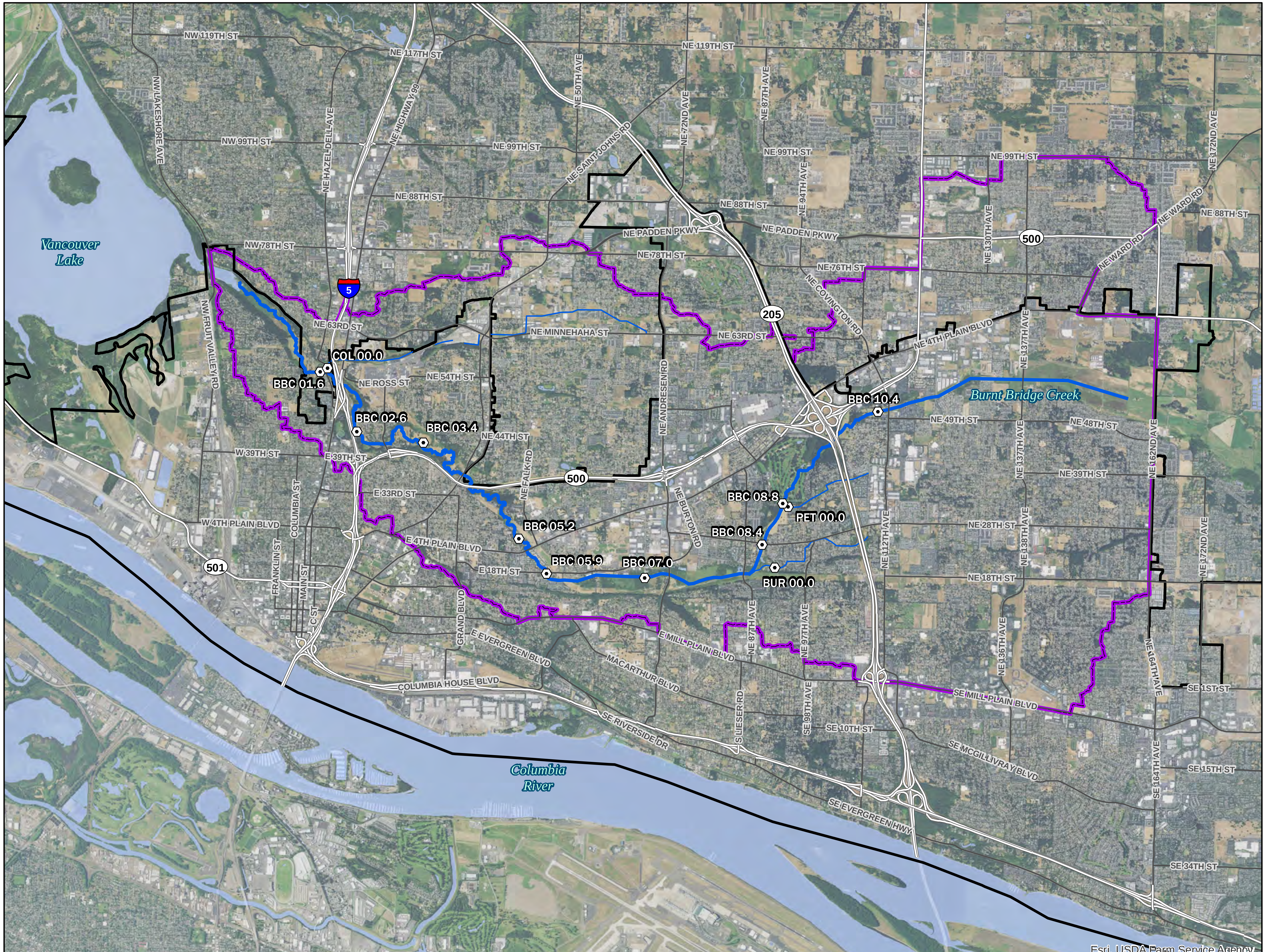

Figure 3.
Burnt Bridge Creek Watershed.

Legend

- Watershed boundary
- Vancouver City Limits
- Water quality monitoring location
- Major road
- Burnt Bridge Creek
- BBC Tributary

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0 2,500 5,000 10,000 Feet

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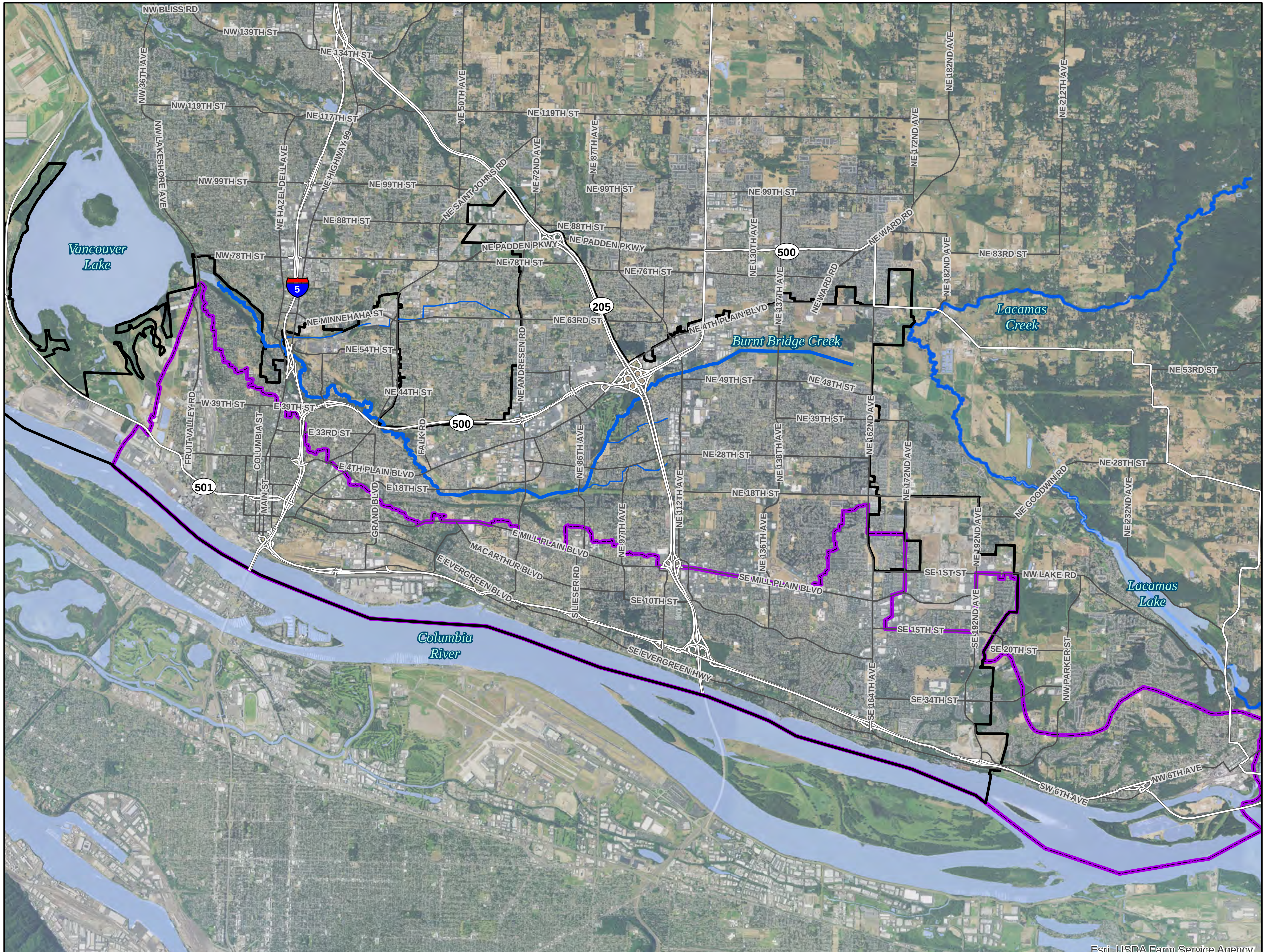

Figure 4.
Columbia Slope Watershed.

Legend

- Major road
- Major Creek
- Tributary
- Vancouver City Limits
- Watershed boundary

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Feet

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The six downstream basins along the main stem are very similar (within 2 percent) in all land use and cover categories are also presented in Table 1. Of all the basins, the three tributary basins have the lowest percentages (less than 1 percent) of agricultural land use. The Peterson Channel (PET 0.0) and Cold Creek (COL 0.0) basins have the highest percentage of commercial/industrial land use (17 and 13 percent, respectively). The Burton Channel basin (BUR 0.0) has the highest percentage of residential land use (94 percent) and tree canopy cover (19 percent).

Table 2 provides a breakdown of land use and land cover in the Columbia Slope watershed.

Table 2. Land Use and Cover in the Columbia Slope Watershed.

Basin Area (acres)	Land Use				Land Cover	
	Agriculture (percent cover)	Commercial/ Industrial (percent cover)	Forest/Field/ Other (percent cover)	Residential (percent cover)	Tree Canopy Cover (percent cover)	Impervious Surface Cover (percent cover)
10,411	1%	13%	2%	84%	17%	52%

3.2. SURFACE WATER HYDROLOGY

Burnt Bridge Creek is approximately 12.6 miles long, flowing from a channelized agricultural ditch, through the urban landscape, to Vancouver Lake. It is a sinuous to meandering, single-thread channel that flows within a wide, meadow-like floodplain and valley throughout much of its length. Parts of the creek pass through culverts and have been channelized within developed areas.

Two minor tributaries originate east of Interstate 205 (I-205) and flow into Burnt Bridge Creek east of Northeast 86th Avenue: Peterson Channel and Burton Channel. In addition to base flow, Peterson Channel conveys industrial discharge and urban stormwater runoff to Burnt Bridge Creek near the southern end of the Royal Oaks Country Club golf course. Burton Channel joins Burnt Bridge Creek south of Burton Road, near the southern end of Meadowbrook Marsh. A third significant tributary, Cold Creek, flows west through unincorporated Clark County and joins Burnt Bridge Creek just west of I-5 and approximately 2 miles upstream of Vancouver Lake (Figure 2).

Both Ecology and the USGS have measured streamflows on Burnt Bridge Creek in the past; however, none of the gauges are currently in operation. USGS streamflow monitoring occurred from October 1998 to September 2000 and from October 2011 to September 2013. Ecology monitored streamflows from May 2008 to November 2009. Flow data compiled by Ecology (Sinclair and Kardouni 2012) suggest that summer base flows in Burnt Bridge Creek may range from about 3 to 12 cubic feet per second (cfs), whereas winter base flows may be on the order of 10 to 20 cfs with flood flows as high as 150 cfs. Maximum daily flows occurred in November 1998 (149 cfs) and January 2012 (123 cfs) for the earlier and later time periods, respectively. Figures 5 and 6, generated by USGS, plot discharge data during each monitoring time period (USGS 2018).

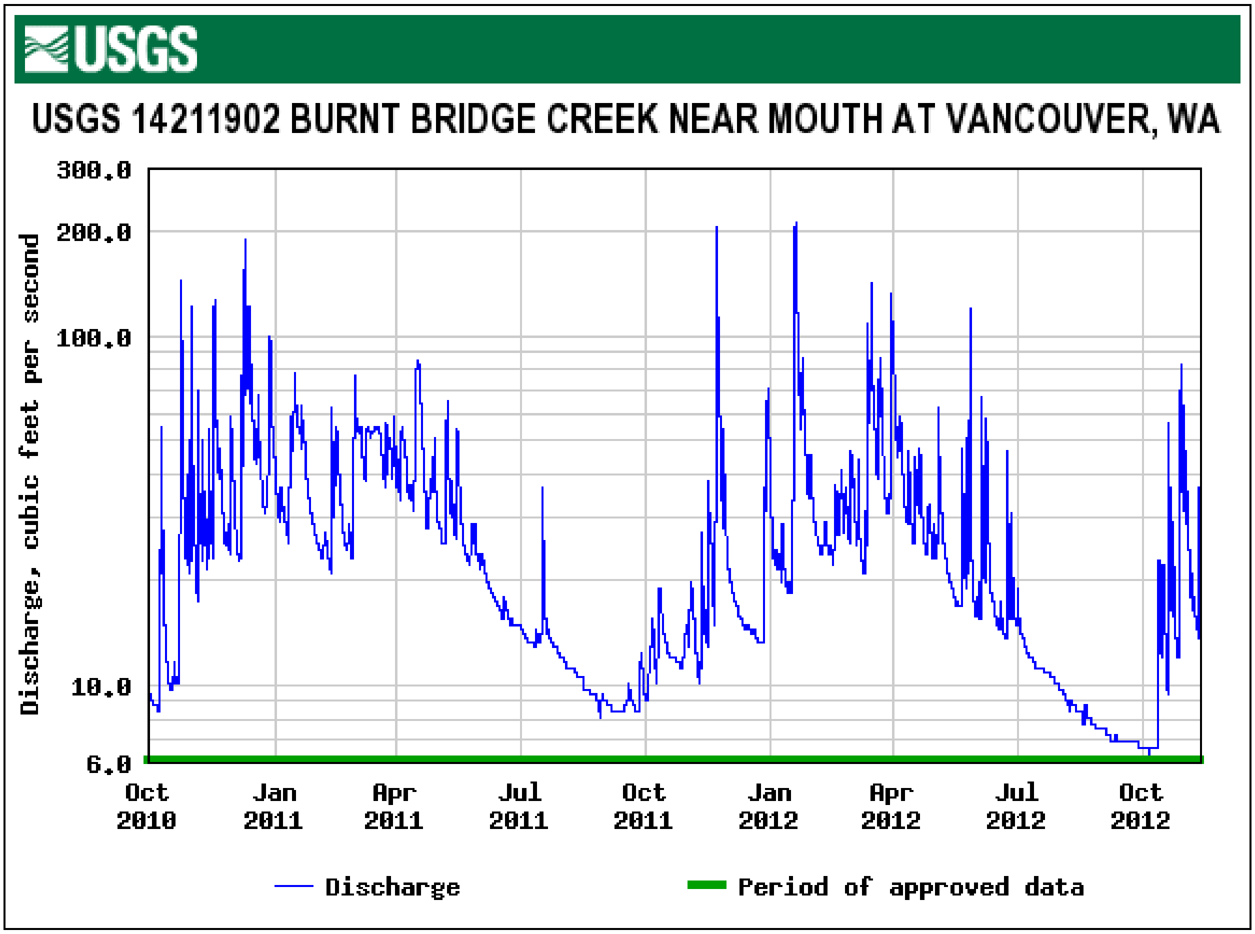

Figure 5. USGS Discharge Data for Burnt Bridge Creek Near Mouth, October 2010–October 2012.

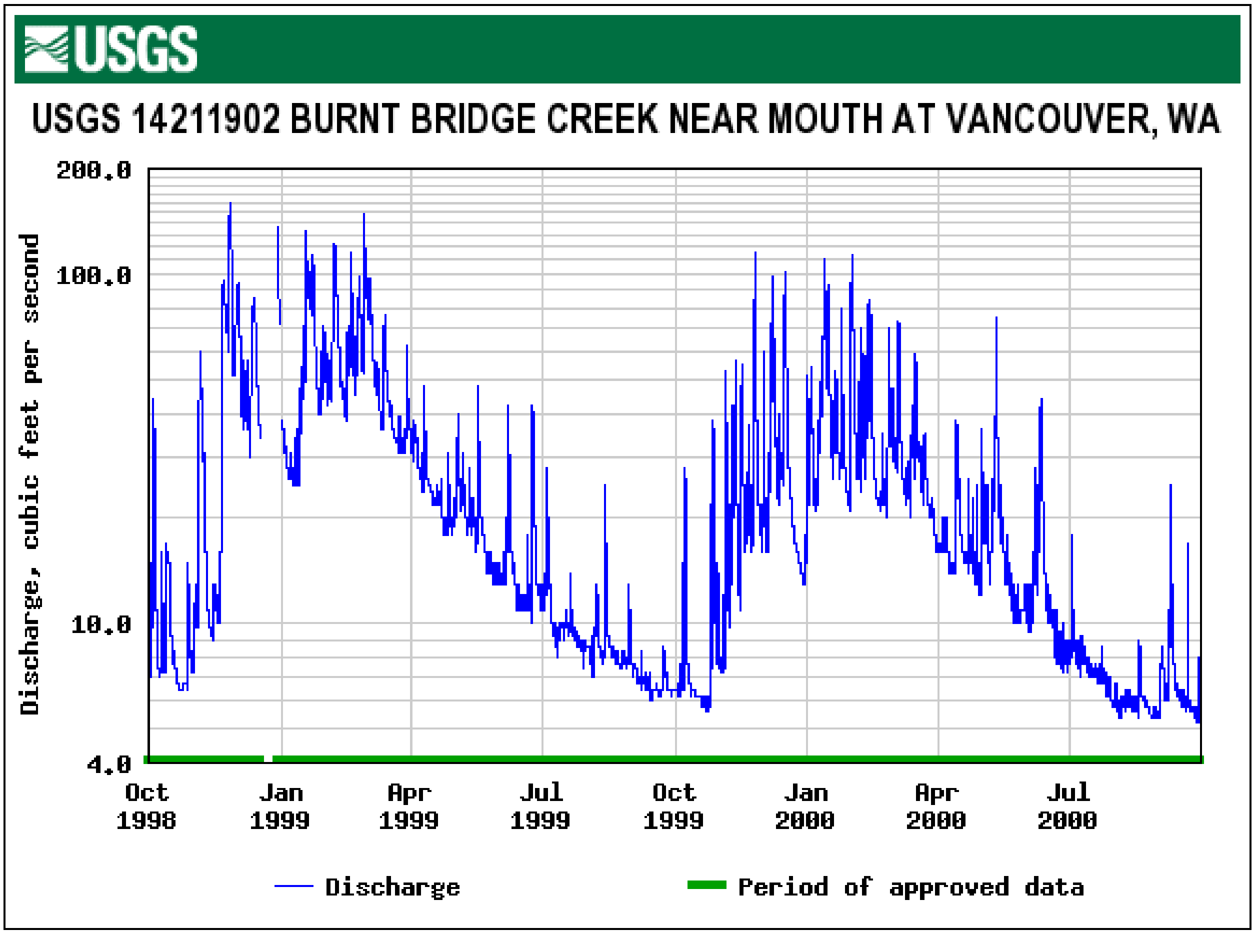

Figure 6. USGS Discharge Data for Burnt Bridge Creek Near Mouth, October 1998–July 2000.

In the Columbia Slope watershed, a number of small ponds, marshes, and wetland areas are sustained by groundwater spring flows, surface water runoff, and stormwater infiltration. Flows within the watershed are influenced by surface and subsurface flows from the adjoining Terrace unit and Columbia River stage.

The USGS estimated total discharge from the springs mapped on Figure PGG-3 as 25 cfs in 1949 but noted that discharge declined to 14.5 cfs in 1988—a 42 percent reduction between measurement events (McFarland and Morgan 1996). More recent data are not available.

The Vancouver Lake Lowlands contain fine-grained sand and silt in which drainage patterns are controlled by stage levels of the Columbia River, which change during the course of a day in response to tidal fluctuations, dam releases, and regional precipitation runoff events.

3.3. GROUNDWATER HYDROLOGY

3.3.1. Surficial Soils

Most soils within the study area are well-drained, except for some peaty, low-permeability wetland soils along the upper and middle reaches of Burnt Bridge Creek. The well-drained surficial soils are generally derived from their parent geologic materials (discussed below) and are particularly relevant to this watershed assessment because they control infiltration from the land surface to the shallow groundwater flow system. Infiltration is the basis for groundwater recharge and availability and can carry contaminants from the land surface (or from shallow, constructed, infiltration facilities) to the water table.

Soils in the study area have been mapped in detail by the NRCS, with each soil type assigned to a "hydrologic soil group" (HSG) that characterizes its runoff and drainage characteristics under a variety of conditions. HSGs are grouped by saturated hydraulic conductivity (Ksat) values and by depths to underlying confining layers and seasonal high groundwater. Four primary HSGs (A, B, C, and D) correspond to increasing runoff potential and decreasing drainage capacity. For instance, in the absence of shallow groundwater (i.e., where the water table is deeper than 40 inches below land surface), HSGs are related to Ksat accordingly:

HSG	Ksat (inches per hour)
A	>1.42
B	0.57 – 1.42
C	0.06 – 0.57
D	<0.06

Where the seasonal high-water table or a confining layer is shallower than 40 inches, HSGs require higher Ksat values to achieve similar drainage characteristics. The NRCS also defines "dual hydrologic soil groups" where natural saturation of a high Ksat soil constrains its drainage capacity but drainage could be increased if the soil were artificially drained. For instance, a "B/D" soil drains like a "D" soil when wet but like a "B" soil when artificial drainage lowers the water table.

PGG translated the NRCS soils map to an HSG map (Figure PGG-2). As noted above, most soils within the study area are well-drained (Groups A and B). Such higher Ksat soils are typically associated with higher susceptibility for groundwater contamination if mobile contaminants are introduced to surficial soils. Groundwater susceptibility and vulnerability are further discussed in Section 4.2.2.

3.3.2. Geologic Units

The principal geologic units underlying the study area can be divided into four major units including from youngest to oldest:

- Recent Alluvium (including peat deposits)
- Pleistocene Alluvial Deposits
- Upper Troutdale Formation
- Lower Troutdale Formation
- Sandy River Mudstone

The first three units combine to form the Upper Sedimentary Subsystem that occurs over large portions of the Portland Basin (McFarland and Morgan. 1996). Surficial exposures of these units (as defined by Washington Department of Natural Resources 1:100,000 coverages [WDNR 2016]) are shown on Figure PGG-3, and regional, conceptual geologic cross-sections are shown on Figures PGG-4 and PGG-5. The last two units comprise the Lower Sedimentary Subsystem.

3.3.2.1. Recent Alluvium

The Recent Alluvium occurs in the lower elevation areas along the Columbia River and Vancouver Lake, and in the lower elevation areas along Burnt Bridge Creek. The Recent Alluvium primarily consists of fine-grained sand and silt but may locally contain coarser sand and gravel along the lower portions of Burnt Bridge Creek. Peat deposits occur primarily in the upper reaches of Burnt Bridge Creek east of I-205, where beaver dams provided opportunity for accumulation of organic matter, and in the central portion of the greenway where wetlands previously existed (PBS 2003). The alluvium and peat deposits are typically no more than 25 feet thick along Burnt Bridge Creek, but they may be as much as 50 to 200 feet thick along the Columbia River and beneath the Vancouver Lake Lowlands.

3.3.2.2. Pleistocene Alluvial Deposits

The Pleistocene Alluvial Deposits blanket most of the upland areas within the study area. The deposits were laid down during catastrophic floods of the Columbia River that occurred in the Late Pleistocene (the Missoula Floods). The flood events were a result of periodic failures of ice dams that impounded huge lakes in Idaho and Montana. Waitt (1985) estimates that there may have been as many as 40 flood events between about 12,000 and 18,000 years ago. Sudden outbursts from the ice dams sent massive flood waters across eastern Washington, through the Columbia River gorge, and into the Portland Basin. A bedrock constriction south of Kelso, Washington, caused a temporary impoundment of the flood water within the Portland Basin, raising waters to as high as 370 feet near Camas.

The flood waters carried a massive load of all sizes of detritus and gravel-laden ice. When the current velocity dropped, the loads were rapidly deposited in slack water. The resulting deposits are very complex in texture and may contain poorly sorted material ranging in size from clay to boulders or cleaner sand and gravel where there was local channeling of faster moving water. A large portion of the flood waters was directed down the present channel of the Columbia River; however, a secondary channel carried water from the Lacamas Lake area westward through Burnt Bridge Creek and then back to the main channel near the City's Water Station #1.

The Pleistocene Alluvial Deposits have been grouped into two lithological subunits. The "gravel subunit" is a basaltic sand and gravel unit with varied amounts of cobbles and boulders. The "sand and silt subunit" is composed of a fine-grained, micaceous, arkosic sand stratified with silt and clay. The coarser deposits are found mostly along the Columbia River and Burnt Bridge Creek, whereas the finer grained (slack water) deposits are found in Salmon Creek basin and East Fork of the Lewis River basin. Soil horizons may have formed within the Pleistocene Alluvial Deposits during quiescent periods between flooding events.

3.3.2.3. Upper Troutdale Formation

The Pliocene Upper Troutdale Formation underlies the Pleistocene Alluvial Deposits and is composed of unlithified and semi-lithified sediments including basaltic gravels with a matrix of micaceous, silty sand. The unit may contain abundant cobbles in many areas as well as silt and clay subunits. The upper portion of the Upper Troutdale Formation tends to be compact and may be extensively weathered due to an unconformity between the unit and the overlying flood gravels. In the study area, the Upper Troutdale Formation is exposed along the southern edge of the upland below the City's Ellsworth water station on the Columbia Slope. The thickness of Upper Troutdale Formation varies from about 100 to 350 feet. The thickest deposits occur along a structural ridge that extends southeast-northwest from the Ellsworth Springs area to where Burnt Bridge Creek discharges to Vancouver Lake.

3.3.2.4. Lower Sedimentary System

The Lower Sedimentary System consists of the Lower Troutdale Formation and the Sandy River Mudstone. The Lower Troutdale Formation comprises conglomerate and sandstone, whereas the Sandy River Mudstone comprises finer-grained mudstone, siltstone, claystone, and sand. The two formations "inter-finger," providing a sequence of aquitards and aquifers including two confining units, an intervening aquifer, and a basal aquifer that rests upon regional bedrock.

3.4. AQUIFERS AND AQUITARDS

3.4.1. Unconsolidated Sedimentary Aquifer

The Unconsolidated Sedimentary Aquifer (USA) is the uppermost hydrostratigraphic unit in the study area. The aquifer consists mostly of the catastrophic flood deposits of late Pleistocene age (Pleistocene Alluvial Deposits) that mantle the upland areas near Vancouver and Orchards. The aquifer also includes water-bearing Recent Alluvium along Burnt Bridge Creek and in the Columbia River and Vancouver Lake Lowlands areas. The USA is largely unconfined in the Burnt Bridge Creek basin and along the Columbia River where there is a general absence of a lower-permeability, confining layer. The USA behaves more as a confined aquifer in the Vancouver Lake Lowlands, where an extensive silt layer overlies the more permeable portions of the Recent Alluvium and Pleistocene Alluvial Deposits. Perched water conditions may occur locally within the lower reaches of Burnt Bridge Creek due to localized, fine-grained deposits or buried soil horizons within the gravel subunit.

In Figures PGG-4 and PGG-5, the USA upgradient of the flow restriction is labeled the "Upper Orchards Aquifer," and the USA downgradient of the restriction is labeled the "Lower Orchards Aquifer." The USA is used extensively for municipal and industrial water supply. The City operates five water stations that tap the Upper Orchards portion of the USA and three water stations that tap the Lower Orchards portion (Table 3). The productivity of most of these supply areas is very high due to the highly permeable nature of the USA. Extensive testing indicates transmissivity values of between 500,000 and 2,000,000 gallons per day per foot (gpd/ft) for the USA in the Burnt Bridge Creek watershed and between 2,000,000 and 13,500,000 gpd/ft in the Vancouver Lake Lowlands area (PGG 2012). Yields from the USA in some areas of the Burnt Bridge Creek watershed are limited by aquifer thickness (i.e., the relatively thin aquifer limits available drawdown).

Table 3. City of Vancouver Water Stations.												
Identifier			Configuration								Use	
Water Station	Source Number	Basin[a]	Total Wells	Active Wells	Inactive Wells	Aquifer(s)	Capacity (gpm)	Monitoring	Treatment[b]	2013–2017 Average mgd	Status
WS #1	S01	VLL	13	12	1	USA (Lower Orchards)	22,770	M, WL	Cl, Fl, PTA	7.30	Permanent
WS #3	S02	VLL	3	3	0	USA (Lower Orchards)	5,800	M, WL	Cl, Fl	2.84	Permanent
WS #4	S03	CS	6	6	0	USA (Lower Orchards)	6,970	M, WL	Cl, Fl, PTA	2.94	Permanent
WS #6	S04	BBC	4	1	3	USA (Upper Orchards)	400		Cl, Fl	0.00	Emergency
WS #7	S05, S10	BBC	2	2	0	Upper Troutdale, SGA	650, 500	M, WL	Cl, Fl, Fe/Mn	0.47	Permanent
WS #8	S06	BBC	3	2	1	USA (Upper Orchards)	1,275	M, WL	Cl, Fl	1.11	Permanent
WS #9	S07	BBC	6	5	1	USA (Upper Orchards)	9,060	M, WL	Cl, Fl	6.50	Permanent
WS #14	S08	BBC	3	3	0	USA (Upper Orchards)	2,905	M, WL	Cl, Fl, PTA	1.65	Permanent
WS #15	S09	BBC	4	3	1	USA (Upper Orchards)	2,120	M, WL	Cl, Fl, NaOH	0.88	Permanent
ELL WTP	S11, S12	CS	3	3	0	SGA	6,900, 2,800	M, WL	Cl, Fl, Fe/Mn	1.77	Permanent

[a] Basin designations for City water stations are based on hydrogeologic interpretation rather than the surface-water drainage basins delineated. While WS #14 is located just outside the BBC drainage basin, impacts of pumping are most closely affiliated with groundwater in the BBC Basin. Similarly, WS #4 is more hydrogeologically affiliated with the VLL Basin.

[b] Treatment:

PTA = packed tower aeration to deal with PCE/TCE contamination, with the exception of WS #14, where PTA is used to stabilize pH.

Cl = chlorine. Fl = fluoride. Fe/Mn = pressure filtration to treat for iron and manganese.

BBC = Burnt Bridge Creek CS = Columbia Slope ELL WTP = Ellsworth Water Treatment Plant gpm = gallons per minutes M = metered for water use mgd = million gallons per day SGA = Sand and Gravel Aquifer USA = Upper Sedimentary Aquifer VLL = Vancouver Lake Lowland WL = water-level monitoring WS = water station

3.4.2. Troutdale Gravel Aquifer

The Troutdale Gravel Aquifer (TGA) occurs within the Upper Troutdale Formation deposits. The aquifer typically responds as a semi-confined to unconfined system in the Burnt Bridge Creek watershed because there is no extensive, confining layer that separates the TGA from the overlying USA. In the Vancouver Lake Lowlands, the TGA responds as a confined aquifer due to the presence of the silt deposits that occur within the upper portions of the Recent Alluvium.

The transmissivity of the TGA is much lower than that of the USA, with typical values of between 50,000 and 250,000 gpd/ft (PGG 2012). The TGA is an important supply source for many domestic wells in the study area, but it is of lesser importance for municipal and industrial supply. In the TGA, well yields are typically much lower (i.e., <500 gallons per minute [gpm]) than in the USA because of the lower transmitting capacity of the TGA. Only one of the City's water supply wells taps the TGA (Table 3).

3.4.3. Lower Sedimentary Subsystem Aquifer and Aquitards

The lower sedimentary subsystem includes the following aquifers and aquitards:

- Confining Unit 1 (CU1)
- Troutdale Sandstone Aquifer (TSA)
- Confining Unit 2 (CU2)
- Sand and Gravel Aquifer (SGA)

Confining Unit 1 is a regionally extensive sequence of silt and clay deposits that forms a major aquitard ranging from 50 to nearly 300 feet thick within the Portland Basin. Well logs often describe the clay soils as "sticky," indicating the unit has high plasticity and is unlikely to contain secondary fracturing that would enhance vertical permeability. Drillers' logs for deeper wells in the area indicate that CU1 is laterally continuous and has consistent soil and hydraulic characteristics (PGG 2008). CU1 isolates groundwater flow in the upper sedimentary subsystem from groundwater flow in the lower sedimentary subsystem.

Hydrostratigraphic units beneath CU1 are well-differentiated in the Orchards area and near Portland's South Shore Wellfield area as three distinct units: TSA, CU2, and SGA. The TSA is composed of coarse-grained sandstone and conglomerate with lenses and beds of fine to medium sand and silt. The TSA is underlain by CU2, although CU1 and CU2 cannot be differentiated where the TSA is not present. The SGA has both coarser-grained (sandy gravel) and fine-grained (sandy) facies. As one moves north from the Columbia River, both the TSA and SGA are largely composed of fine sand and there is less intervening silt and clay, and it becomes more difficult to differentiate between the units underlying the CU1 aquitard. Furthermore, variable occurrence of CU2 sediments beneath the Vancouver Lake Lowlands translates to variable degrees of confinement and hydraulic separation beneath the TSA and SGA.

The SGA is generally highly confined and exhibits moderate transmissivity. The City operates two wells completed in the SGA (Table 3). The SGA is also tapped by the City of Portland's South Shore Wellfield. In that wellfield, the SGA is interpreted to directly underlie the Columbia River alluvium and is, therefore, less confined. Nevertheless, the overall confined nature of the SGA limits recharge to the aquifer, and development of the SGA initially led to declining groundwater levels. Over time, pumping rates and groundwater levels stabilized to a new equilibrium, thus indicating that pumping drawdowns induced increased leakage from the upper sedimentary system and the Columbia River.

3.5. GROUNDWATER PROCESSES

3.5.1. Recharge and Discharge

The USGS has estimated groundwater recharge in the Portland Basin from incident precipitation, septic effluent, and dry well discharge (Snyder et al. 1994). Figure PGG-6 presents the USGS estimates of combined precipitation and dry well recharge (averaged of 3,000-foot-square "cells"), which generally range from 0 inches per year (in highly urbanized areas) to 32 inches per year (in areas with significant dry well infiltration). Figure PGG-6 shows boundaries for the Burnt Bridge Creek watershed and a subarea of the Columbia Slope watershed hydrogeologically interpreted as associated with groundwater discharge to Columbia Slope springs (excluding hydrogeologic interpretation of the Vancouver Lake Lowlands basin). Based on the USGS estimates, annual precipitation and dry-well recharge averages 33.5 cfs (21.7 million gallons per day [mgd]) in the Burnt Bridge Creek watershed and 14.9 cfs (9.6 mgd) in the Columbia Slope subarea. Maximum recharge was estimated to occur between the months of November and January, with little recharge occurring during the dry season months of July through September. The USGS recharge assessment was performed based on 1974 land cover conditions; since then, ongoing development has likely increased overall recharge in areas with new impervious surfaces that discharge runoff to infiltration facilities. In much of the Burnt Bridge Creek watershed, relatively shallow depths to groundwater (discussed below) and the relatively high permeability of the Pleistocene Alluvial Deposits sediments (discussed above) are expected to cause relatively short time lags for recharge originating at the land surface to reach the underlying water table.

Groundwater within the study area discharges to Burnt Bridge Creek, the Columbia River, groundwater springs, and wells. Burnt Bridge Creek derives its base flow from shallow groundwater in the USA (Section 4.2), whereas deeper groundwater (in the USA, TGA, and underlying units) discharges to the Columbia River. Burnt Bridge Creek streamflow data summarized by Ecology (Sinclair and Kardouni 2012) suggest base flows generally ranging from about 3 to 15 cfs, although higher values may occur during wet-year winters. Springs along the Columbia River reflect discharge from the USA and TGA. The USGS estimated total discharge from the springs mapped on Figure PGG-3 as 25 cfs in 1949 but noted that discharge declined to 14.5 cfs in 1988 (McFarland and Morgan 1996).

Groundwater withdrawals in the study area are predominantly associated with the City's water stations (mapped on Figure PGG-1 and listed in Table 3). The City defines a water station ("WS") as a grouped set of wells (wellfield) or individual well that pumps water from one or more aquifers."

Recent average annual groundwater withdrawals by City wells totaled 39.4 cfs (25.5 mgd) based on 2013 to 2017 data provided by the City, with 16.4 cfs (10.6 mgd) taken from wells in the Burnt Bridge Creek watershed, 2.7 cfs (1.8 mgd) taken from the wells in the Columbia Slope hydrogeologic subarea, and 20.3 cfs (13.1 mgd) taken from wells in the Vancouver Lake Lowlands.[2] Figure PGG-7 shows that the City's overall groundwater withdrawals declined slightly between 2003 and 2017; however, withdrawals from wells in the Burnt Bridge Creek watershed have increased by around 20 percent.

3.5.2. Groundwater Levels and Flow Paths

Figure PGG-8 shows groundwater elevation contours for the USA along with water-level elevations (WLEs) in USA wells measured by the USGS and the City. Groundwater flows from areas of high WLEs ("recharge areas") to areas of low WLEs ("discharge areas"). Groundwater movement in the Burnt Bridge Creek watershed is generally towards the southwest (Columbia River), with local components interpreted as flowing towards Burnt Bridge Creek. Lack of groundwater level data immediately south of the creek prevents confirmation of convergent groundwater flow towards the creek, and the creek may gain a portion of its flow from perched aquifers above the regional water table (see Section 4.2.1). A ridge of lower-permeability Troutdale deposits (shown on the hydrogeologic cross-section in Figure PGG-4[2]) restricts groundwater movement from the Upper Orchards Aquifer portion of the USA (generally within the Burnt Bridge Creek watershed) to the Lower Orchards Aquifer portion (generally within the Vancouver Lake Lowlands). Very steep hydraulic gradients occur in the area of the restriction. WLEs upgradient of the ridge are typically 150 to 200 feet higher than below the ridge, where WLEs are about the same as the Columbia River.

Whereas WLEs in the Upper Orchards Aquifer area are largely influenced by local precipitation recharge, WLEs in the Vancouver Lake Lowlands are largely influenced by Columbia River stage. A mound of elevated WLEs (>250 feet mean sea level [msl]) north of Burnt Bridge Creek is interpreted by the USGS as potentially reflecting locally lower values of USA permeability (McFarland and Morgan 1996).

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[2] For the purpose of this accounting, City water stations were designated among these three areas based on topographic and hydrogeologic considerations, with Water Stations 1, 3, and 4 hydrogeologically designated to the Vancouver Lake Lowlands; Ellsworth Springs designated to the Columbia Slope; and Water Stations 7, 8, 9, 14, and 15 hydrogeologically designated to the Burnt Bridge Creek watershed. Averages were calculated based on data provided by City of Vancouver. Note that the cross-section is conceptual and shows the TGA exposed at the land surface in the ridge vicinity. Actually, the ridge is buried beneath USA sediments.

Figure PGG-9 shows depth to groundwater in the USA estimated by Clark County (Clark County, 2008). A large portion of the Burnt Bridge Creek watershed has the water table within 10 feet of the land surface. Shallow depths to water provide relatively fast pathways to the water table from septic systems, dry wells, or contaminants that infiltrate the land surface. As previously noted, perched conditions occur above the regional USA water table and may, therefore, be associated with localized areas of shallower depth to groundwater.

Figure PGG-10 shows groundwater elevation contours for the TGA (McFarland and Morgan 1996). TGA water levels in the Burnt Bridge Creek watershed are generally lower than USA water levels, indicating a downward gradient consistent with what would be expected in a recharge area. Groundwater flow in the TGA is generally to the south and southwest towards the Columbia River and Vancouver Lake Lowlands.

Overall, groundwater flow paths within the study area originate at the land surface, pass through underlying aquifers and aquitards, and discharge to surface water features. Most of the groundwater within the Burnt Bridge Creek watershed is derived from local groundwater recharge; thus, associated water quality is susceptible to contaminants introduced at (or near) the land surface. Whereas most locally-recharged groundwater is expected to remain within the USA, downward leakage between aquifers dictates that the TGA is recharged by water originating in the USA, and that water in the TGA can leak downward to recharge yet deeper aquifers. As one gets deeper in the groundwater flow system, the geographic extent of recharge areas becomes more regional (e.g., groundwater in the SGA may have originated in more distant areas). Wells pumping from specific aquifers generally capture water moving along the flow paths associated with those aquifers. For some aquifers, areas also exist where pumping near the Columbia River could capture water from the river itself; although none of the City's wells have been identified as groundwater sourced from surface water features.

3.5.3. Groundwater/Surface Water Interactions

Groundwater in the USA interacts with both Burnt Bridge Creek and the Columbia River. Ecology evaluated groundwater/surface-water interactions along Burnt Bridge Creek based on stream seepage evaluations, installation and monitoring of instream piezometers, collection and evaluation of groundwater quality samples, and monitoring of streambed thermal profiles (Sinclair and Kardouni 2012). The seepage surveys, performed during the summer/fall of 2008, showed an overall gain of 2.1 to 3.1 cfs from groundwater to the creek between the headwaters and Vancouver Lake. However, gradients measured in the instream piezometers and streambed thermal profiles largely showed losing conditions beneath the streambed. Although local variations are expected in gaining and losing conditions, Ecology interpreted the discrepancy between the evaluations as indicating that shallow perched aquifers within the USA are likely discharging to the creek, whereas the creek bed is typically higher in elevation than the regional water table in the USA. As discussed in Section 4.2.1 mapping of WLEs in the USA is insufficient to demonstrate the relationship between the creek and the regional water table.

The USGS monitors the Columbia River stage at gage 14144700 (Columbia River at Vancouver WA). PGG has performed a number of groundwater level monitoring studies in the Vancouver Lake Lowlands and has determined that groundwater levels in the USA are highly responsive to tidal variations in the Columbia River. From a water budget perspective, the Columbia River is likely to exhibit a net gain in flow from groundwater discharge. Discharge from springs emanating from the USA and TGA within the Columbia Slope watershed naturally reaches the Columbia River. Tidal variations and groundwater withdrawals close to the river likely cause instances of reverse flow, where water from the Columbia River may enter the USA for short periods of time.

4. WATERSHED HEALTH ASSESSMENT

4.1. SURFACE WATER QUALITY

4.1.1. Burnt Bridge Creek

State surface water quality standards have been established to restore and maintain the chemical, physical, and biological integrity of Washington's waters as required by the federal Clean Water Act. The standards are designed to protect public health; public recreation in the waters; and the propagation of fish, shellfish, and wildlife (Washington Administrative Code [WAC] 173-201A). Water quality in Burnt Bridge Creek has been monitored extensively for more than 40 years, including a TMDL study by Ecology with 19 monitoring sites throughout the watershed in 2008–2009 (Ecology 2008). Monitoring data have shown that segments of Burnt Bridge Creek do not meet state water quality standards for temperature, dissolved oxygen, pH, and/or fecal coliform bacteria at varying times of the year.

Results of analyses of surface water data collected between 2011 and 2017 for the Burnt Bridge Creek Ambient Water Quality Monitoring Program are reported in the 2017 Trend Analysis Report (Herrera 2018) and briefly described below. The long-term program has included monitoring of 11 parameters (temperature, dissolved oxygen, pH, conductivity, turbidity, total suspended solids (TSS), total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate+nitrite, and fecal coliform) at 11 stations along Burnt Bridge Creek and its three tributaries. Data collected from 2004 to 2007 at four stations was also used in the trend analysis.

Temporal trends in parameter concentrations were identified for data from 2011 through 2017 using Kendall's Tau correlation test and presented in Table 4. Significant differences between historical (2004 to 2007) and recent (2011 to 2017) data at four stations were identified using the Mann-Whitney U test and are also presented in Table 4.

Table 4. Temporal Trend Analysis Summary for Burnt Bridge Creek.

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

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

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

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

significant water quality improvement
significant water quality decline
significant change in pH or conductivity

Median water quality index (WQI) scores for each station and based on 2011 to 2017 data are shown in Table 5. The overall WQI was in the moderate concern range (40 to 79) for all 11 stations based on median scores for 2011 through 2017, with higher scores (53 to 70) at the upstream stations from BBC 10.4 to BUR 0.0 and lower scores (43 to 49) at the downstream stations from BBC 7.0 to BBC 1.6. A significant decreasing trend from 2011 to 2017 in the overall WQI was identified only at Peterson Channel (PET 0.0; see Table 5). The relative concern for WQI parameters includes:

- Low concern for pH (ten stations), turbidity (eleven stations), and TSS (nine stations)
- Low to moderate concern for dissolved oxygen (six and five stations, respectively)
- Moderate concern for bacteria (eleven stations) temperature (eight stations) and total phosphorus (nine stations)
- Moderate to high concern for total nitrogen (six and five stations, respectively)

Table 5. Median Annual Water Quality Index Scores for Burnt Bridge Creek.

Station	Years	FC	DO	pH	TP	TSS	Temp	TN	Turbidity	Overall WQI Score
BBC 10.4	7	73	53	74	78	95	87	1	95	60
BBC 8.8	7	74	86	94	62	79	78	1	92	69
PET 0.0	7	70	78	96	21	90	78	67	97	58[a]
BBC 8.4	7	74	74	97	45	83	80	7	93	53
BUR 0.0	7	60	83	96	81	91	86	1	98	70
BBC 7.0	7	72	71	96	41	77	65	34	87	43
BBC 5.9	7	71	57	96	49	89	74	43	92	43
BBC 5.2	7	69	83	95	49	86	74	40	93	49
BBC 2.6	7	69	84	91	49	84	73	40	93	48
COL 0.0	7	56	90	88	53	88	90	43	91	47
BBC 1.6	7	63	82	91	43	81	72	43	90	45

[a] Annual WQI Score shows significant decreasing trend over time using Kendall's Tau Correlation with an alpha of 0.05.

Low Concern WQI = 80–100

Moderate Concern WQI = 40–79

High Concern WQI = 1–39

DO = dissolved oxygen

FC = fecal coliform

TP = total phosphorus

TSS = total suspended solids

Temp = temperature

TN = total nitrogen

WQI = water quality index

Spatial trends between stations were evaluated using the Friedman test, which detected significant differences between stations. Results of the Friedman test were presented on boxplots (such as those shown in Figures 7a and 7b), in which significantly different stations are identified with a letter not shared by another station. The boxplot for total phosphorus in Figure 7a shows that Peterson Channel (PET 0.0) was significantly different than all other stations and appears to contribute to the increase in total phosphorus concentrations downstream. Year-round flows in Peterson Channel are supported by high localized groundwater and discharges of industrial cooling water that have been drawn from deeper wells used by a computer chip manufacturing facility located near Northeast 112th Avenue. Background concentrations of phosphorus in regional groundwater aquifers are elevated relative to recommended concentrations in surface water for healthy streams. See Section 4.2.3.2 for more information.

The boxplot for total nitrogen in Figure 7b shows that total nitrogen concentrations were significantly greater at BBC 10.4 than all other stations and that the three most downstream stations (BBC 5.2, BBC 2.6, BBC 1.6, and Cold Creek) were not significantly different from each other.

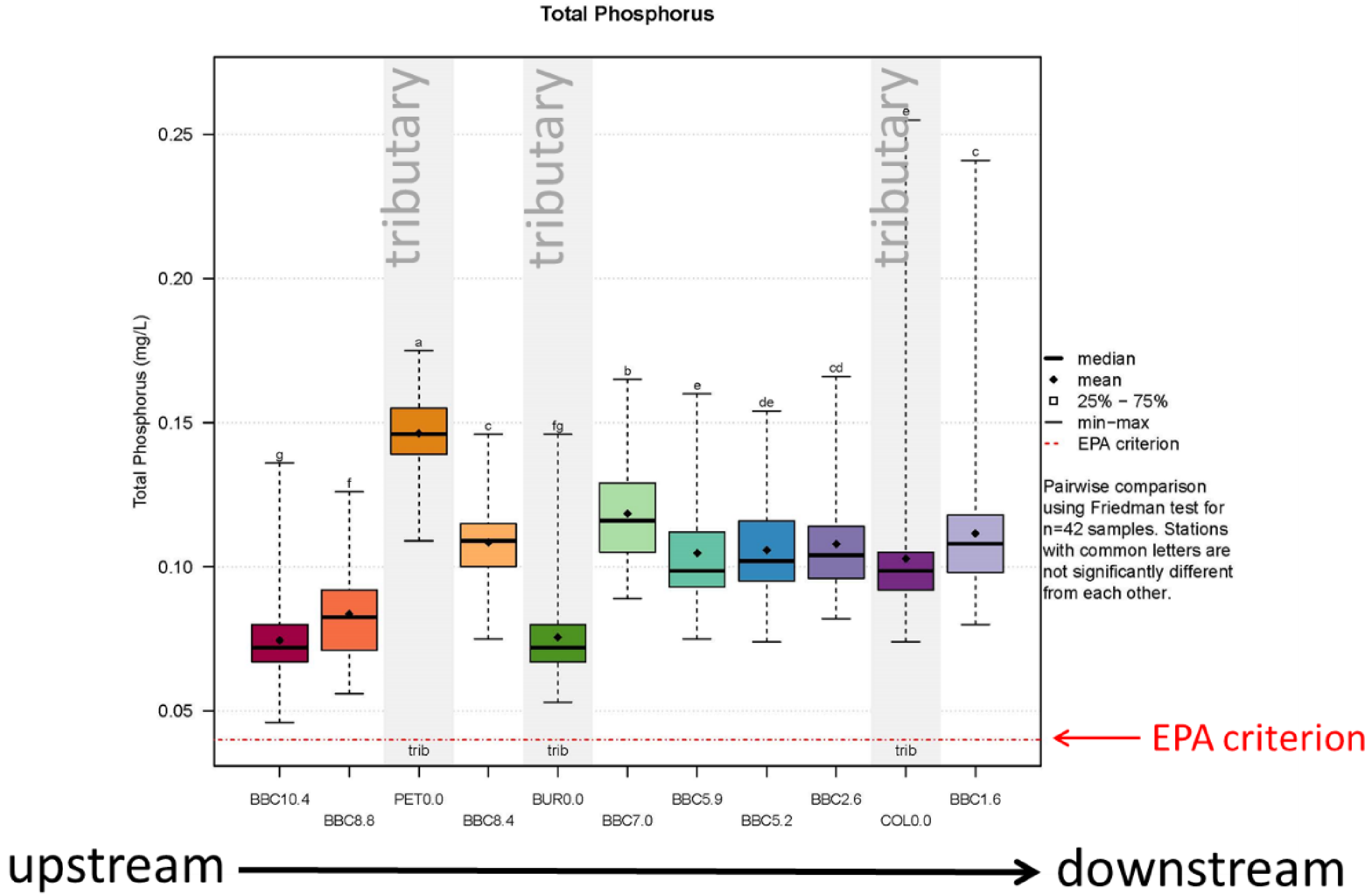

Figure 7a. Total Phosphorus Boxplot.

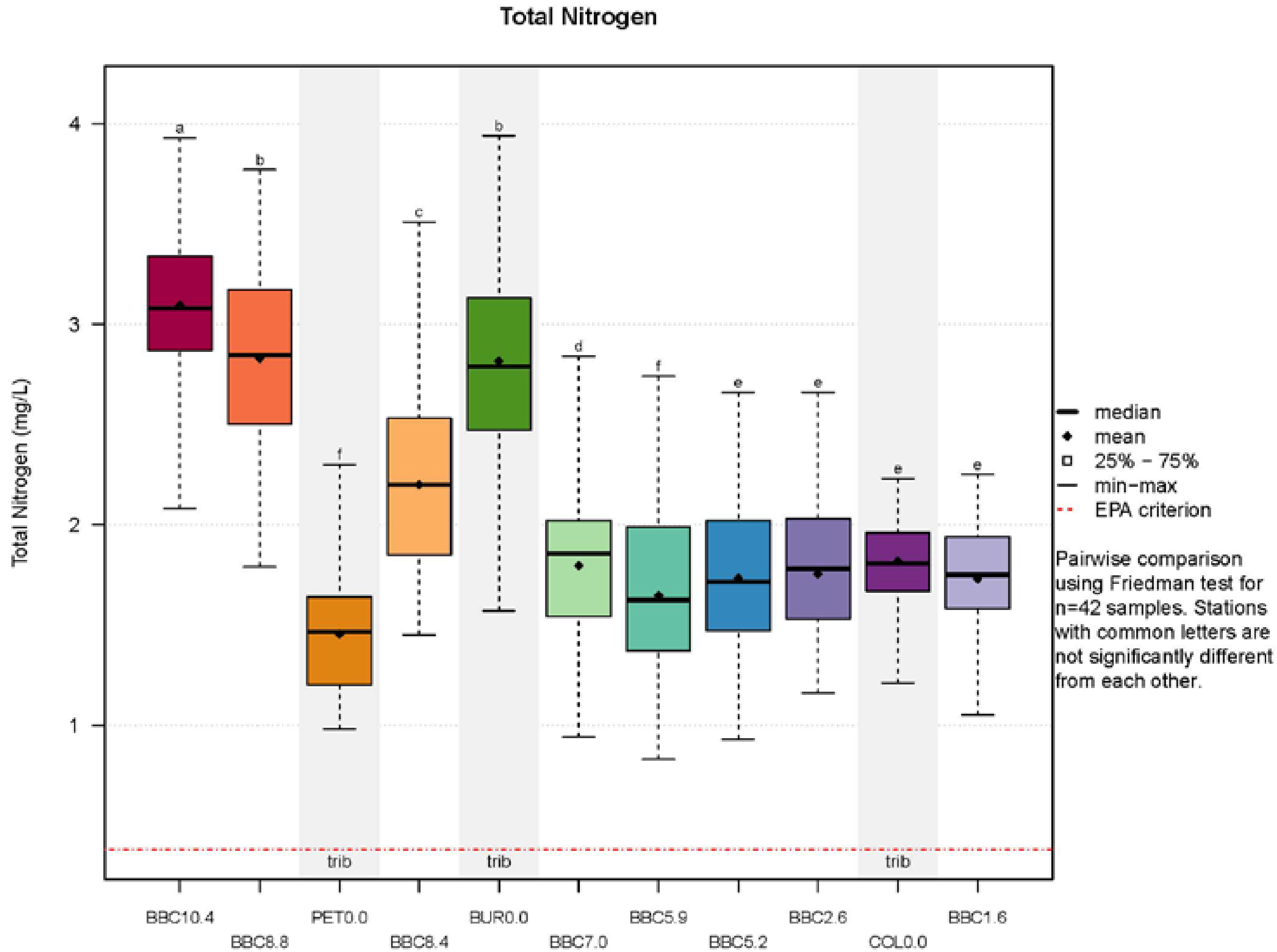

Figure 7b. Total Nitrogen Boxplot.

Summary statistics (e.g., sample size, mean, median, percentiles) were calculated for each parameter by station. Figure 8 shows the median total phosphorus values for 42 samples taken from 2011 to 2017 per station. Median concentrations tend to increase moving downstream, with the notable spike in the main stem downstream of Peterson Channel. The US EPA criterion for total phosphorus is less than or equal to 0.040 milligram per liter (mg/L) based on the 25th percentile of medians for 171 streams in the Willamette Valley Ecoregion (US EPA 2001).

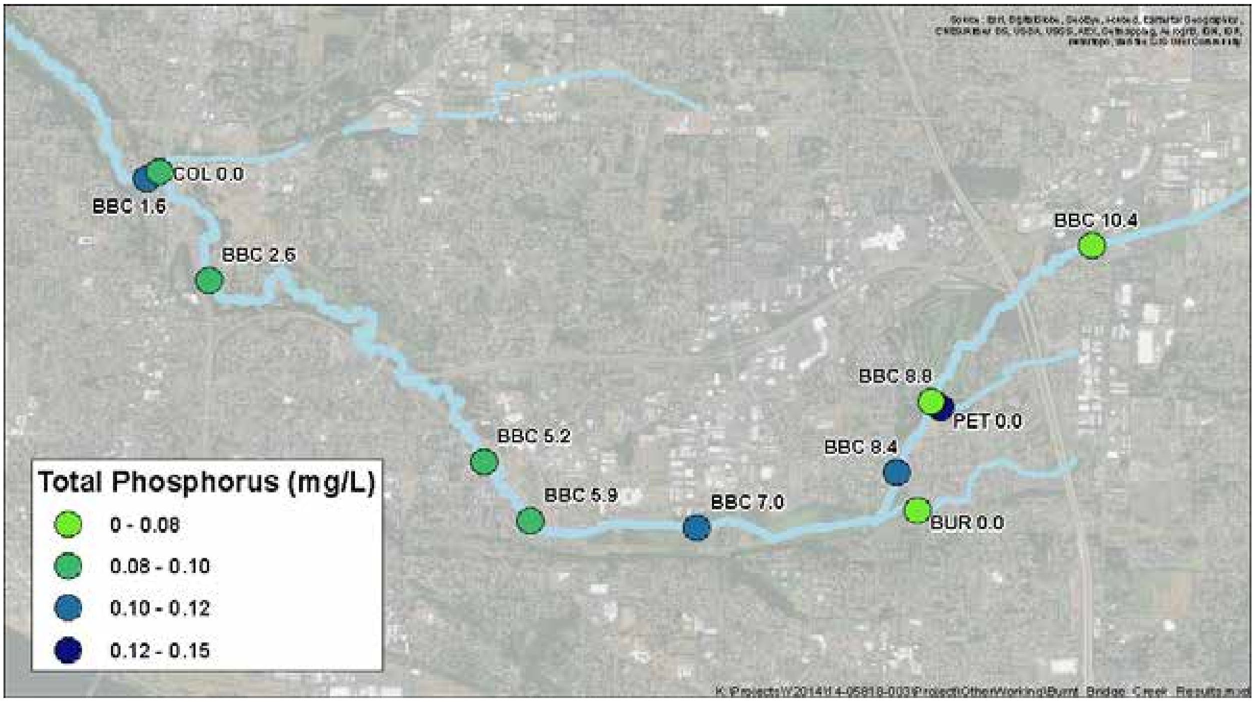

Figure 8. Median Total Phosphorus Along Burnt Bridge Creek.

4.1.2. Columbia Slope

Springs and seeps along the Columbia Slope are supplied by groundwater, surface water runoff, and stormwater infiltration. Flows discharge directly to the Columbia River or enter wetland areas along the shore. Water quality data are scarce for the springs and seeps that form along the Columbia Slope, but flows were measured by the USGS in 1949 and 1988.

Subbasins in the upper reaches of the Columbia Slope watershed discharge untreated stormwater from residential and arterial roadways to groundwater and surface waterbodies that eventually reach underlying aquifers and the Columbia River. Stormwater runoff from urban areas typically carries contaminants that can be harmful to human health and aquatic life.

The final report for the Lower Columbia River Bi-State Study (Tetra Tech 1996), which summarized findings of over 50 technical reports generated during a large-scale, 6-year investigation, found impairment to fish and wildlife (chemical, biological, and habitat) as well as recreation (fishing and water sports). The report concluded that fish-eating wildlife had been contaminated by organic compounds such as organochlorine pesticides, discussed evidence of potentially harmful levels of pollutants in river water and sediment (e.g., heavy metals, pesticides, dioxins, furans), and that contact with water was occasionally unsafe due to bacteria levels. Although the study focused on the Columbia River, not springs from the Columbia Slope, it identifies contaminants that could come from untreated stormwater in the basin.

Recent monitoring by USGS of toxics in stormwater and wastewater discharges to the Columbia River showed relatively high suspended sediment and measurable concentrations of herbicides, pesticides, PAHs, polybrominated diphenyl ethers (PBDEs), trace elements (arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc), and oil and grease. Many of these contaminants can bioaccumulate through the food web to the detriment of fish, wildlife and human health (Morace 2012).

4.1.3. Vancouver Lake Lowlands

Vancouver Lake is connected to the Columbia River through Lake River and a flushing channel constructed in the 1980s. Water levels in the lake fluctuate with tidal cycles and river stage but the lake remains shallow with a mean depth of 3 to 5 feet. Lake River (a slough) also transports flow to the Columbia River from the Salmon Creek watershed and other smaller waterbodies.

Water quality concerns include algae and cyanobacteria blooms, supported by high levels of nutrients (phosphorus and nitrogen), with elevated water temperature, high turbidity, invasive plant species, pathogens, and toxins. (Sheibley et al. 2014). Vancouver Lake is on the 303(d) list of impaired waters for total phosphorus and bacteria in water as well as polychlorinated biphenyls (PCBs), 4,4′-dichlorodiphenyldichloroethylene (DDE), toxaphene, and dioxin in fish tissue (Ecology 2018c). Common carp, largemouth bass, and largescale suckers were selected for Ecology’s 2007 state fish tissue study (Coots 2007).

In a 2-year USGS nutrient study of Vancouver Lake (Sheibley et al. 2014), Lake River was identified as the dominant source of water to the lake, averaging 85 percent of water inputs. Other water inputs include the flushing channel contributing 10 percent, Burnt Bridge Creek contributing 2 percent, and groundwater and precipitation contributing less than 2 percent. Nutrient loads were proportional to flow contributions to the lake; Lake River at 88 percent of total nitrogen and 91 percent of total phosphorus, the flushing channel at 4 percent nitrogen and 7 percent phosphorus, and Burnt Bridge Creek at 4 percent nitrogen and 14 percent phosphorus. The study also determined that nitrogen loads were an order of magnitude higher than phosphorus loads across all sources.

4.2. GROUNDWATER

Key features reliant on groundwater within the study area include the City’s water supply wells and Burnt Bridge Creek. The City derives all of its water supply from the underlying aquifer system, and Burnt Bridge Creek derives its base flow from shallow groundwater in the USA (including perched aquifers overlying the regional water table).

Watershed health, for both the underlying aquifer system and the USA, encompasses elements of both groundwater availability (water quantity) and groundwater quality. While primarily dependent on the water budget (inflows versus outflows), groundwater availability can also be affected by water quality if impaired quality affects the ability to use groundwater for intended purposes. This section addresses both elements for evaluating watershed health from the perspective of groundwater dependent features.

The groundwater evaluation was performed for the entire study area. Although no division was made between the Burnt Bridge Creek and Columbia Slope watersheds, which are based on surface topography, the groundwater evaluation included distinctions between individual aquifers (where possible). The water quantity (availability) assessment was based on water-budget analysis and trends in groundwater levels. The groundwater quality assessment focused on the following water quality parameters: nutrients (nitrogen and phosphorus), arsenic, and selected organics (VOCs, petroleum hydrocarbons, pesticides, and pharmaceuticals and personal care products [PPCPs]).

4.2.1. Groundwater Availability

This section addresses groundwater availability from the perspective of the water budget, streamflow/springflow trends, and groundwater level trends. Water quality conditions are described below and have not significantly impaired groundwater availability. Using a water budget to compare inflows (e.g., recharge) to outflows (e.g., pumping withdrawals and discharge to surface waters) supports a general, broad-scale assessment of groundwater availability. Reviewing trends in surface water discharge is useful for interpreting how shifts in the water budget are affecting hydrologic features. Finally, reviewing groundwater level trends supports assessment of whether changes in the balance between inflows and outflows is causing changes in groundwater storage that could translate to potential changes in long-term groundwater availability and support of stream base flows.

Quantities of groundwater recharge and discharge in the study area are estimated in Section 3.5.1. Relative to the 48.4 cfs of precipitation and dry well recharge estimated for the combined Burnt Bridge Creek and Columbia Slope watersheds (for 1974 conditions, though current recharge may be higher due to development), base flow in Burnt Bridge Creek is on the order of 8 cfs (about 17 percent of recharge); discharge to Columbia Slope springs is on the order of 14.5 cfs (about 30 percent of recharge); and the City's groundwater pumping is on the order of 19.2 cfs (about 40 percent of recharge). Discharge to Burnt Bridge Creek, the Columbia Slope springs, and groundwater withdrawals account for 86 percent of recharge. While *all* terms should be considered approximate, the remainder between recharge and these three discharge terms (approximately 14 percent) is expected to percolate to deeper aquifers and discharge directly to the Columbia River.

Water is available to support increased pumping withdrawals over time by the City and other users. However, balancing the water budget suggests that changes in recharge (e.g., via dry-well infiltration) or pumping will affect discharge to surface water features. The apportionment of hydrologic impacts associated with such changes cannot be predicted with a water budget. If Burnt Bridge Creek gains much of its base flow from shallow perched aquifers, new pumping may have a greater effect on Columbia Slope springs and direct groundwater discharge to the Columbia River. A groundwater flow model would be needed to estimate how new pumping affects other terms in the water budget.

Data are largely unavailable to demonstrate how changes in land use and pumping are affecting changes in streamflow and springflow. About 6 years of streamflow data are available for Burnt Bridge Creek,[3] and typical climatic variability dictates that a longer record would be needed to identify trends. The USGS measured discharge from Columbia Slope springs in 1949 and 1988 and found a 42 percent reduction between measurement events. Such a significant reduction could reflect the influence of increased pumping withdrawals over that 39-year period; however, measurement sparsity precludes any assessment of seasonal or year-to-year variability.

Changes in groundwater availability respond to changes in inflows and outflows to the groundwater flow system and are reflected by groundwater level trends. To assess whether changes to the water budget have affected groundwater availability, PGG assessed trends in USA and TGA static water-level elevations (WLEs) at the City's water stations within (and near) the Burnt Bridge Creek watershed (Figure PGG-11). The figure shows around 15 feet of variation over 36 years of available data spanning a 41-year record. The figure demonstrates that WLEs are highly responsive to precipitation (groundwater recharge), with WLEs rising in response to wetter periods and falling in response to drier periods. Although the City's 2015 Comprehensive Water System Plan (Carollo 2015) indicates that WLEs are affected by City groundwater withdrawals (which have increased in the Burnt Bridge Creek watershed between 2002 and 2017), Figure PGG-11 suggests there is no evidence for significant WLE declines in the USA or TGA in light of observed variability.

Figure PGG-12 shows WLE trends in the deeper groundwater flow system (SGA) and shows that the SGA experienced a significant decline between 1997 and 2005 (concurrent with an expansion in deep groundwater withdrawals by both Washington and Oregon purveyors) followed by stabilization as the groundwater system reached a new equilibrium. The SGA is still sensitive to annual variations in groundwater withdrawals (Carollo 2015). Any new *long-term* withdrawal from the SGA will shift the equilibrium and cause a further declining trend likely followed by stabilization (with lesser declines in shallower aquifers)[4]. Overall, while the groundwater system is expected to respond to groundwater withdrawals, available data suggest that recent development does not appear to be affecting groundwater availability for water supply.

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[3] Measured near the mouth in water years 1999, 2000, 2009, 2010, 2011, and 2012.

[4] Stabilization is expected as long as withdrawals do not exceed aquifer recharge. Recharge is sourced by precipitation but can also be sourced by the Columbia River if pumping causes sufficient drawdown in adjacent aquifers.

Ongoing development within the study area is associated with increased impervious surfaces and increased groundwater withdrawals.[5] Because runoff from impervious surfaces in the study area is typically infiltrated to groundwater, and because impervious surfaces cause reduced losses to plant evapotranspiration, ongoing development in the study area is expected to *increase* groundwater recharge. Other factors, such as climate change, will also affect recharge but have not been evaluated (e.g., over the long term, warming increases evaporative losses and thus *reduces* available recharge). Recharge cannot be measured directly, and *estimation* of recharge trends (based on other factors) is beyond the scope of this study. From a water budget perspective, increased groundwater withdrawals may offset the effects of increased recharge to some degree.

4.2.2. Groundwater Vulnerability and Susceptibility

Groundwater vulnerability to contamination can be defined as "the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer" (National Research Council 1993). Vulnerability assessment by the City noted that vulnerability includes hydrogeologic "susceptibility" (the relative ease of contaminants to migrate through the subsurface) and the contamination risks arising from potential contaminant sources associated with existing land use practices (Hoiland 2017). Because study area soils are generally permeable and depths to groundwater in the uppermost aquifer (USA) are generally shallow, groundwater beneath the study area is considered to be relatively susceptible to contaminants that infiltrate near the land surface. Relative to the USA, the deeper aquifers (TGA and SGA) are less susceptible to contamination. However, these TGA and SGA are largely recharged by groundwater passing through the USA and are, therefore, still somewhat susceptible to contamination. As groundwater recharge from the land surface moves through the subsurface, it is either intercepted by wells or discharges to surface water features such as springs, streams, rivers, lakes, and wetlands. In some locations, pumping near the Columbia River may capture water from the river by drawing surface-water into the aquifer.

Potential contaminant sources within the Vancouver city limits include infiltration facilities (dry wells and perforated drainage pipes), septic tanks, underground storage tanks, older sanitary sewer installations, contaminated sites, commercial/industrial sites that store and use hazardous materials, and former landfills. Contaminant loading can also include illegal dumping, miscellaneous spills, and various sources of broad-scale non-point pollution (e.g., residential use of potentially hazardous materials).

To protect the City's groundwater sources from contamination, the City's 1996 Water Comprehensive Plan defined "Zones of Contribution" as areas providing groundwater to wells over defined travel times. In 2002, the City, working with Ecology, found that defined Zones of Contribution would not provide sufficient groundwater protection and developed a Water

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[5] Changes in *net* groundwater withdrawals could also be affected by reductions in agricultural withdrawals.

Resources Protection Ordinance (WRPO) recognizing that any contamination in any part of Vancouver poses a threat to underlying aquifers. The WRPO designates the entire city as a Critical Aquifer Recharge Area (CARA), which is treated as a single, large Wellhead Protection Area. Management practices and restrictions listed in the WRPO apply to all businesses, industries, government facilities, and residents in the CARA. In addition, the following Special Protection Areas are defined around each wellhead and provide more stringent local protective restrictions:

- A 1,900-foot radial buffer is assumed to represent a roughly 1-year travel-time Zone of Contribution in which the City will not allow development of high-risk industries or installation of septic systems, dry wells, or other infiltration systems without prior approval.

To address the risks associated with potential contaminant sources, the WRPO establishes BMPs for the CARA, which include minimum standards, greater standards, and additional restrictions applicable to Special Protection Areas.[6] Minimum standard BMPs relate to stormwater management, storage and handling of hazardous materials, and pesticide and fertilizer management. Greater standards apply to specific facilities and include: safe co-storage of hazardous materials, secondary containment infrastructure, preparation of spill and emergency response plans, training of hazardous-material operators, regular inspections, and maintenance records and reports. Specific activities prohibited within Special Protection Areas include: new bulk petroleum fuel operations, new septic systems (where sewer is available), new stormwater infiltration facilities (where alternatives are available), and new underground storage tanks for heating oil and hazardous materials.

In 2006, recognizing the local reliance on groundwater for water supply in Clark County, Washington, and the vulnerability of the groundwater system, the US EPA designated the “Troutdale aquifer system” as a sole or principal source of drinking water.[7] In this case, the US EPA defined the Troutdale aquifer system as including the TGA and TSA along with “other consolidated sand and gravel aquifer units” (e.g., the SGA) and “overlying unconsolidated alluvium and flood deposits” (e.g., the USA). The federal government defines a sole source aquifer as one that provides at least 50 percent of the drinking water consumed in an area where there is no feasible alternative source. The finding was based on the facts that:

- The aquifer system is the principal source of drinking water for over 90 percent of the people in the Troutdale aquifer system area, and there are no alternate sources that can physically, legally, and economically supply all those who depend upon the aquifer for drinking water.
- Contamination of the aquifer system would create a significant hazard to public health. The aquifer system is vulnerable to contamination because recharge occurs essentially

[6] <https://www.cityofvancouver.us/sites/default/files/fileattachments/public_works/page/1033/finalwrpordinancerevised2016.pdf>

[7] <https://www.federalregister.gov/documents/2006/09/06/E6-14710/sole-source-aquifer-designation-of-the-troutdale-aquifer-system-clark-county-wa>

over the entire area, the aquifer is highly permeable, and there are many human activities that have released, or have the potential to release, contaminants to the aquifers.

The hydrogeologic basis for the vulnerability of study area aquifers described above can be further assessed by reviewing groundwater quality for evidence of impacts from land-use activities. The following section addresses groundwater quality in the aquifers underlying the study area for various parameters of concern.

4.2.3. Groundwater Quality

Groundwater quality data were compiled and reviewed from PGG monitoring data (PGG 2018), water supply testing data (Vancouver 2018) and the Ecology EIM database.

The groundwater quality assessment focused on the following: nutrients (nitrogen and phosphorus), arsenic, and selected anthropogenic organic contaminants (VOCs, petroleum hydrocarbons, pesticides, and PPCPs). Data were not assessed for iron and manganese because they are not health threats.

4.2.3.1. Nitrogen

Nitrogen is an essential nutrient for the growth of plants and algae. It is typically found in groundwater in the inorganic forms of nitrate and nitrite (although nitrite is often absent or present in minimal concentrations when oxygen is present). Nitrate is a common groundwater contaminant, derived from natural and anthropogenic sources. Natural sources include atmospheric deposition, wildlife waste, and decay of natural organic matter. Anthropogenic sources include fertilizers, domesticated animal waste (e.g., pets, manure), human waste (septic systems and leaky sewers), and combustion (contributing to atmospheric nitrate deposition and roadway runoff). Nitrate is highly soluble and readily transported in groundwater.

The drinking water standard for nitrate is 10 mg/L. Concentrations of less than 1 mg/L are typical of uncontaminated (i.e., background) water quality in groundwater. Concentrations of 2 to 5 mg/L indicate anthropogenic influence, and concentrations of 5 to 10 mg/L indicate sufficient contamination to warrant concern. While there are no protective limits on nitrate+nitrite for aquatic habitat in Washington under Chapter 173-201a WAC, Ecology's (2012) Burnt Bridge Creek ambient water quality monitoring project compared results to a reference level of 0.15 mg/L nitrate+nitrite based on the 25th percentile of medians for 171 streams in the Willamette Valley Ecoregion (US EPA 2001). This reference level reflects actual conditions in multiple streams and is not necessarily indicative of risk to aquatic habitat.

Nitrate concentrations in the study area generally reflect low (<2 mg/L) to moderate (2 to 5 mg/L) levels of nitrate contamination. Concentrations of concern (5 to 10 mg/L) occur locally but do not cover extensive areas. Figure PGG-13 maps the geographic distribution of nitrate in groundwater compiled from the following data sources:

- Maximum concentrations recorded from the City's water stations and their shallow monitoring well network
- Data compiled by Clark County over multiple years
- Data compiled by CPU during a 1990–1991 study of regional groundwater quality
- Maximum concentrations recorded per well from Ecology's EIM database of contaminated and monitoring sites

Figure PGG-13 shows the locations of septic systems and dry wells and attempts to differentiate wells by completion depth (although completion depths were not available for most wells). Of the 840 wells shown on the figure, nitrate is <2 mg/L in 53 percent of the wells, 2 to 5 mg/L in 40 percent of the wells, 5 to 10 mg/L in 5 percent of the wells, and >10 mg/L in 2 percent of the wells. Areas of elevated nitrate are highly localized, with few broad areas of uniformly higher concentrations. Slightly elevated concentrations (and sparse data) are noted in the area between water stations WS-9 and WS-7, and multiple wells with concentrations of concern are located near the former water station WS-6 (no longer in operation). Overall, there is no strong relationship between areas of elevated nitrate and areas of dense septic tanks or dry wells, which is consistent with the geostatistical analysis summarized in Appendix B. The dataset is dominated by wells sampled by CPU in 1990 to 1991 (88 percent of mapped wells), and, while 27 years have passed since CPU's sampling exercise, review of nitrate concentrations in the City's water stations (discussed below) does not show significant increases in nitrate concentrations over time.

Figure PGG-14 shows a whisker plot of nitrate concentrations grouped by various data sources and by aquifer (where known) and includes nitrate concentrations measured in Burnt Bridge Creek. Where multiple analyses were available from an individual well, all values were considered in calculating statistics. Outlier values are presented as individual points. In general, the data show increasing aquifer susceptibility as a function of shallowness in the groundwater flow system. Among the City's water stations, the highest nitrate concentrations are found in the uppermost aquifer (USA), with decreasing concentrations in progressively deeper aquifers (TGA and SGA, respectively).[8] Within the USA, the City's shallow monitoring wells and monitoring wells in Ecology's EIM database generally show lower nitrate concentrations than the City's USA production wells. The monitoring wells have higher outlier concentrations than the production wells—possibly reflecting the fact that the production wells draw groundwater from more extensive areas (thus providing geographic "average" concentrations), whereas monitoring wells withdraw water from locally adjacent areas. Nitrate concentrations in Burnt Bridge Creek are very similar to those in the City's shallow (USA) monitoring wells, and less than concentrations in City water stations completed in the Upper Orchards (USA) aquifer. Burnt Bridge Creek samples are taken during low-flow periods, which are dominated by groundwater contributions to base flow.

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[8] Data from the Lower Orchards Aquifer (USA) are largely outside the Burnt Bridge Creek watershed because they are associated with water stations in the Vancouver Lake Lowlands.

Figure PGG-15 shows time-series plots of nitrate concentrations in the City's water stations between 1978 and 2017. The graph shows that most water stations have nitrate values between 2 and 5 mg/L, while deep wells completed in the SGA have concentrations <1 mg/L.[9] The time-series data show stable, gently increasing, and gently decreasing trends. Wells with increasing trends generally show stabilization over the past 10 to 15 years and, therefore, provide no suggestion that current land use is likely to cause significant increases in nitrate concentrations.

4.2.3.2. Phosphorus

Phosphorus is also an essential nutrient for plant and algal growth. Phosphorus in groundwater largely occurs as orthophosphate (PO_4), the dominant component of the soluble reactive form of total phosphorus. Phosphorus generally does not constitute a health concern for drinking water. However, because PO_4 is chemically accessible for uptake by algae in surface water, and because groundwater provides base flow to Burnt Bridge Creek, phosphorus concentrations in groundwater are relevant to the health of the creek. Furthermore, phosphorus is typically more important than nitrogen for freshwater algae growth because nitrogen is more abundant than phosphorus in relation to algal growth requirements.

Sources of phosphorus include animal wastes, human wastes (including septic tank effluent and sewage), fertilizers, mineralization of organic material, inorganic phosphate minerals, and motor oil. Among anthropogenic sources, septic systems provide the highest PO_4 concentrations, with concentrations in stormwater orders of magnitude lower than septic system effluent. Natural sources (buried organic matter and phosphate minerals) can also provide a significant source of PO_4 in groundwater. Adsorption and precipitation in the presence of dissolved oxygen limits the mobility of PO_4 in the subsurface, such that subsurface transport is generally considered to be a low risk. However, prolonged loading at high concentrations (e.g., from infiltration of treated sewage or septic effluent, fertilizer applications) can overwhelm the adsorptive capacity of soils and reduce dissolved oxygen from microbial activity, permitting PO_4 to migrate from its source. The City recently commissioned a detailed review of the occurrence, sources, transport and geochemistry of phosphorus in the subsurface (PGG 2018), from which some of the interpretation below is derived.

Data are limited regarding natural background phosphorus concentrations in groundwater, with considerably more data available from surface waters. Surface water data from undisturbed areas suggest that phosphorus concentrations vary considerably due to local mineralogy, hydrogeology, and (presumably) riparian biomass cycling. In surface water, total phosphorus exceedance of 0.1 mg/L is generally considered a strong indication of agricultural or urban land-use water-quality impairment (Mueller et al. 1995; USGS 1999). Geochemical studies of PO_4 in groundwater indicate that concentrations near active sources or phosphate-rich mineral deposits can range widely from 0.01 to 1 mg/L, depending more on aquifer pH and redox (oxygen) conditions than on source concentrations (Robertson et al. 1998; Wilson et al. 1999).

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[9] Most of the samples are obtained after treatment, although existing treatments do not remove nitrate. Several samples with elevated nitrate from Ellsworth Springs wells are interpreted by the City as reflective of water in the distribution system rather than raw groundwater from the wells.

There is no groundwater maximum contaminant level for phosphorus. Aquatic water quality standards for Washington surface water (Chapter 173-201a WAC) do not set limits for phosphorus in the Willamette Ecoregion; however, an “action level” of 0.02 mg/L is set to protect lakes in the Puget Lowlands ecoregion. Ecology’s Burnt Bridge Creek ambient water quality monitoring project (Sinclair and Kardouni 2012) employed a reference value of 0.04 mg/L for total phosphorus based on the 25th percentile of medians for 171 streams in the Willamette Valley Ecoregion (US EPA 2001), which is similar to the range of action levels referenced in Chapter 173-201a WAC. Where natural phosphate minerals are abundant and geochemical conditions are permissive, groundwater concentrations may exceed desirable action levels for surface-water receptors (PGG 2018).

Figure PGG-16 presents a whisker plot of PO_4 data from a variety of sources, including:

- A single 2003 sampling event from the City’s water stations and several test wells at Vancouver Lake Park (in the Vancouver Lake Lowlands)
- Quarterly sampling (up to 11 events) from 12 of the City’s shallow groundwater monitoring wells
- Limited data from three monitoring wells at cleanup sites from Ecology’s EIM database
- Sampling in 2008–2009 from monitoring wells and piezometers completed along Burnt Bridge Creek, referenced in Ecology’s TMDL Study (Sinclair and Kardouni 2012)
- Samples taken directly from Burnt Bridge Creek by Herrera between 2011 and 2017

All sample groups are derived from the shallow hydrologic system (USA or Burnt Bridge Creek), with the exception of the City’s water stations, for which wells are completed in the USA, TGA, and SGA. This broader dataset shows the highest range of PO_4 concentrations, with the two highest values (outliers) derived from USA test wells at Vancouver Lake Park in the Vancouver Lake Lowlands. All other datasets show similar ranges of PO_4 concentration, except for outlier values from the City’s shallow monitoring wells. The similarity between PO_4 concentrations from most USA wells and Burnt Bridge Creek reflects the fact that groundwater provides base flow to the creek. Except for the notably higher values in several test wells at Vancouver Lake Park, no geographic trend was observed across the combined dataset.

Geochemical evaluation performed by PGG (2018) suggests that groundwater PO_4 concentrations are consistent with the presence of phosphate minerals in oxic groundwater at neutral pH. Phosphate minerals likely originate from a combination of naturally occurring sources (e.g., subsurface organic matter and aquifer mineralogy) and anthropogenic sources (e.g., septic systems, stormwater infiltration, and fertilizer applications). Where phosphate minerals and adsorbed phosphate are present, changes in redox conditions and pH exert strong control on solubility and mobility of phosphorus, leading to variable dissolved concentrations. Regardless of source, the fact that all measured PO_4 concentrations exceed the action level defined by Chapter 173-201a WAC suggests that stream base flows will continue to exhibit PO_4 concentrations that are capable of supporting algal growth.

4.2.3.3. Arsenic

Arsenic is a metalloid that occurs in many minerals (usually in combination with sulfur and metals) and also as a pure elemental crystal. Arsenic is classified as a Group-A carcinogen, and the US EPA states that all forms of arsenic are a serious risk to human health. In the Pacific Northwest, arsenic can occur at naturally high levels in groundwater due to the geochemistry of local sediments. Chapter 246-290 WAC defines a drinking water standard of 10 micrograms per liter (µg/L). In contrast, Chapter 173-200 WAC defines a groundwater contaminant level of 0.05 µg/L, which is below the laboratory detection limit of US EPA method 200.8 (0.27 µg/L), below the Model Toxics Control Act state background level of 5 µg/L, and below typical background concentrations of arsenic (Hinkle and Polette 1999). Under Chapter 173-200 WAC, background concentrations supersede the groundwater contaminant level when evaluating local potential impacts on groundwater. Given the ubiquitous nature of detectible arsenic in Washington's groundwater, arsenic concentrations are herein compared to the drinking water standard.

Sources of arsenic data compiled for this report include standard monitoring of the City's water stations (265 samples taken between 1979 and 2010) and samples taken from the City's shallow monitoring wells (94 samples taken between 2015 and 2017). None of the reported arsenic concentrations exceed the drinking water standard of 10 µg/L. All samples from the City's water stations were less than laboratory reporting limits ranging from 1 to 10 µg/L, whereas concentrations from the shallow monitoring wells range from non-detect (<1 µg/L) to 3 µg/L. Relative to the drinking water standard, arsenic does not appear to be a concern in the Vancouver area.

4.2.3.4. Anthropogenic Organic Contaminants

Occurrences of anthropogenic organic contaminants in groundwater can demonstrate its susceptibility to contamination originating at the land surface. This section summarizes the results of sampling performed by the City at its water stations and shallow groundwater monitoring network. In general, detections are relatively sparse and occur at trace levels (far below maximum contaminant levels), although local contaminated sites may have higher concentrations.

The City sampled 12 of its shallow monitoring wells in the Burnt Bridge Creek watershed at various frequencies between 2015 and 2018 for analysis of pesticides, petroleum hydrocarbons, VOCs, and anthropogenic indicators of septic effluent (caffeine and PPCPs). The following bullets summarize the results of the City's sampling program, as presented in PGG (2018):

- Among 84 pesticides and herbicides evaluated (887 samples from 11 wells), a total of eight detections (distributed among five analytes) occurred at very low concentrations. The detections occurred below the laboratory reporting limit, which means that they were present in the samples but at levels below the ability of the method/equipment to accurately quantify concentrations. In addition, five of the eight detections are considered questionable because laboratory method blanks showed similar concentrations of the same analyte. None of the five analytes are likely to have been used in the Vancouver area for over 20 years, although use of lindane for treating lice and scabies could introduce two of the analytes via septic system discharge. Overall, none of the detections suggest that current indoor or outdoor use of pesticides is contaminating the shallow groundwater associated with the sampled wells.

- Among 46 PPCPs evaluated (552 samples from 12 wells), a total of six detections (distributed among three analytes) occurred. Caffeine was not detected in any well, three pharmaceuticals were detected in one of the wells, and the discontinued antibiotic sulfamethoxazole was detected in four wells. All detections were at the parts-per-trillion level. The wells detecting PPCPs generally do not appear to be located in areas of considerably higher septic system densities than other monitoring wells. It is reasonable to expect septic effluent to introduce such compounds (as well as the nutrients discussed above) into the subsurface environment.
- Detections of petroleum hydrocarbons and VOCs indicate an anthropogenic influence on shallow groundwater quality but do not exceed water quality standards:
  - Analysis of shallow groundwater samples for petroleum hydrocarbons showed consistent occurrence of diesel-range hydrocarbons, spotty occurrence of the motor-oil fraction, and sparse detections of the gasoline fraction. Most detections were below laboratory reporting limits (thus, they could not be accurately quantified), all detections were below (mostly *far* below) groundwater quality standards, and some may reflect analytical interference from naturally occurring organic material and laboratory quality control issues.
  - Analysis for VOCs also detected several constituents not directly related to petroleum products, most of which were disinfection byproducts (trihalomethanes) and one was a common dry-cleaning solvent (perchloroethylene). All such detections were below the laboratory reporting limit and below (mostly *far* below) available groundwater quality standards.

Under its annual compliance monitoring, the City routinely analyzes samples from its water stations for organic contaminants. Samples are taken post-treatment and post chemical injection (chlorine and fluoride). Data were provided from 2013, in which all water stations were analyzed for inorganic compounds, metals, pesticides, chlorinated acids, VOCs, semivolatile organic compounds, disinfection byproducts, radionuclides, and other compounds. As expected for chlorinated water, the data show low-level detections of chlorination byproducts.[10] No other organic compound detections were present in the 2013 dataset. However, the City noted that two of its water stations in the Vancouver Lake Lowlands (WS-1 and WS-4) were fitted in 1992 with packed tower aeration treatment to address trace concentrations of perchloroethylene and trichloroethylene (detections have been below the maximum contaminant levels since 2010 and continue to exhibit downward trends).

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[10] Detections of nitrate and chlorination byproducts could be associated with possible influence of water circulating in the City's distribution system, rather than samples exclusively derived from the sampled source.

In 2008, the City sampled all of its water stations for a suite of 16 PPCPs, including caffeine, select pharmaceuticals (including hormone supplements), and select antibiotics. In contrast to the PPCPs analysis performed on the City's shallow monitoring wells, the water stations showed caffeine detections in all sampled wells but no detection of other PPCPs. Caffeine can be used as a tracer for groundwater flow paths, and even the City's deeper (SGA) sources showed the presence of caffeine. The marked difference between PPCPs analysis from the City's water stations and their shallow monitoring wells, along with the (unexpected) presence of caffeine in deeper groundwater, may raise some questions regarding data quality and/or sampling methodology. Analytical methods have improved since 2008, so resampling the water stations may be worthwhile. If the 2008 caffeine data are accurate, caffeine is the *only* detected parameter among all the data reviewed for this assessment that would suggest anthropogenic impacts on shallow groundwater may be affecting the (deeper) SGA.

4.3. Riparian and Upland Vegetation

Riparian vegetation is important to river and stream systems as a mechanism for providing cooling shade to the stream, structure from large woody debris, nutrients from small organic debris, and fish cover from woody debris and overhanging vegetation. Most of the large woody debris in the portions of Burnt Bridge Creek inspected for the biological conditions report provided poor riparian cover or cover consisting of nonnative plants. Many pieces were relatively undersized and located mainly outside of the channel during low flows. Bank shading in the sampled reaches varied from 79.9 percent to 95.5 percent (Tetra Tech 2015).

Figure 9 shows canopy cover and some of the City's priority planting areas in the Burnt Bridge Creek watershed. Canopy cover per reach varies from 12 percent to 25 percent. Canopy cover is generally low (less than 50 percent) adjacent to most of the stream channel. High canopy cover (greater than 50 percent) is primarily located in middle reaches from I-205 to Peterson Channel and in lower reaches in the vicinity of Highway 500. Priority planting areas are primarily located downstream of those two high cover areas on publicly owned properties.

4.4. Fish Presence and Aquatic Habitat

The aquatic use of Burnt Bridge Creek is designated as salmonid spawning, rearing, and migration (WAC 173-201A). According to the Washington Department of Fish and Wildlife SalmonScape database (WDFW 2018a), potential salmon populations in the Burnt Bridge Creek include fall Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and winter steelhead (*O. mykiss*). Fall Chinook salmon are documented through Lake River but not in Vancouver Lake or the most upstream reaches of Burnt Bridge Creek. Coho salmon are documented up to the I-5 crossing of the creek but are presumed present upstream of I-5. Winter steelhead are presumed present through Vancouver Lake and Burnt Bridge Creek.

A presence/absence study of salmonids in Burnt Bridge Creek performed in 2002 and 2003 (Ehlke 2003) found a few trout, one possible adult salmon, and less than a dozen juvenile salmonids near pools and riffles with good riparian canopy cover. Other species documented include cutthroat trout (*O. clarkii*), sculpin (Family Cottidae), red-sided shiners (*Richardsonius balteatus*), sticklebacks (Family Gasterosteidae), leopard dace (*Rhinichthys falcatus*), and lamprey larvae (ammocoetes) (Family Petromyzontidae). Previous studies conducted in 1997 also documented the presence of suckers (*Catostomus* sp.), mosquitofish (*Gambusia affinis*), bullhead (*Ameiurus* sp.), and peamouth (*Mylocheilus caurinus*). Factors that limit salmonid presence and habitat use in Burnt Bridge Creek include poor water quality conditions, low biological integrity, fish passage barriers, and limited riparian vegetation (Mai and Cummings 1999).

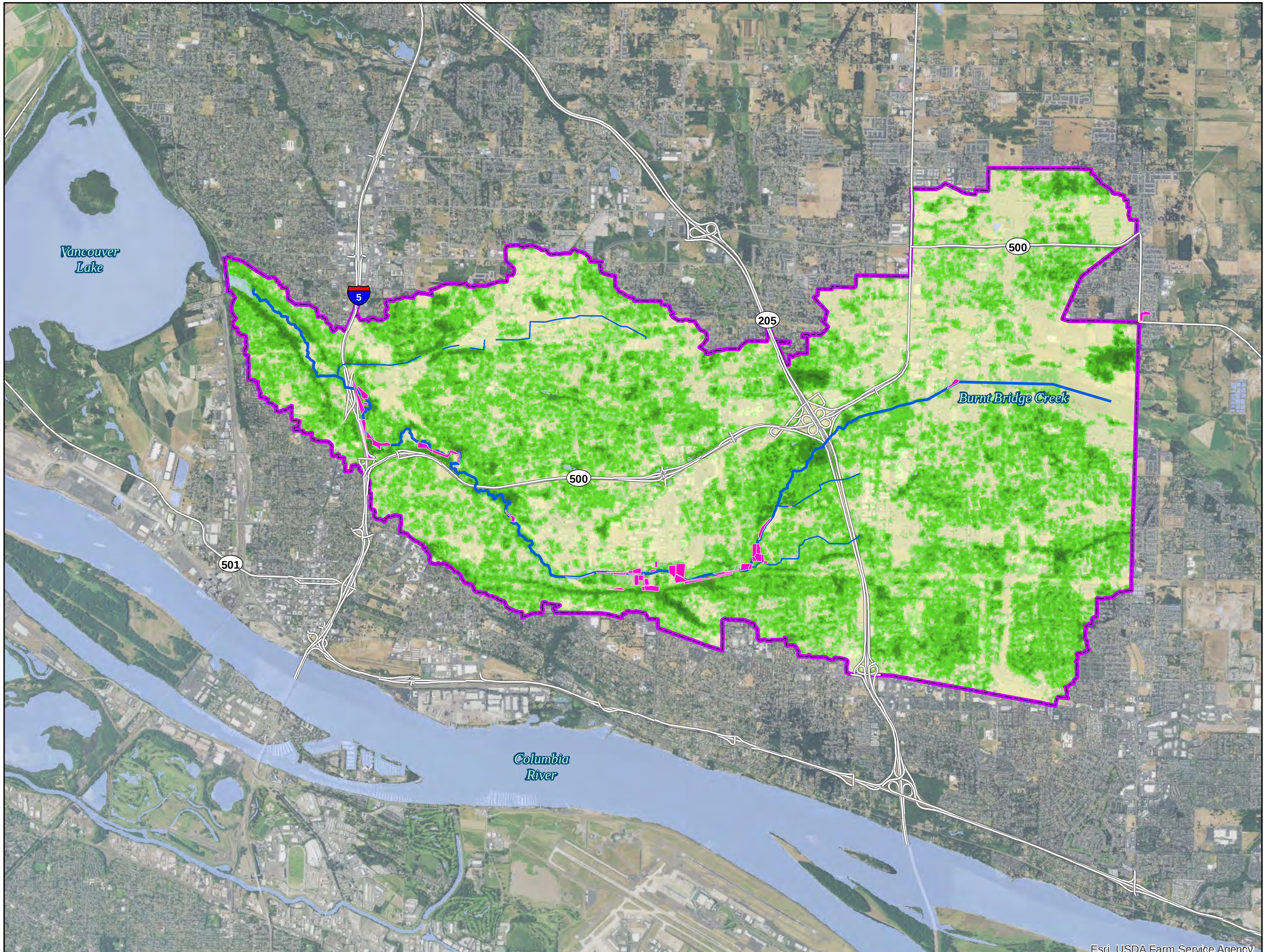
One of the key indicators of instream habitat suitability for salmon spawning, rearing, and migration is water quality. Ecology regularly monitors and assesses waters for exceedances of water quality standards and lists impaired (polluted) waters on a 303(d) list. Once a waterbody is listed on the 303(d) list, US EPA requires a TMDL plan to reduce pollution sources throughout the surrounding watershed. Burnt Bridge Creek had a TMDL study for fecal coliform bacteria, dissolved oxygen, and temperature (Ecology 2008). According to that study, potential impairment sources include urban stormwater and other nonpoint sources, illicit discharges, wildlife and other background sources.

The Columbia River has been designated for aquatic life uses of salmonid spawning, rearing, and migration (Ecology 2017). The reach of the river near Vancouver is primarily used as a migration corridor for anadromous salmon, steelhead, and trout. However, chum salmon (*O. nerka*)have a significant spawning site at the base of the Columbia Slope and are raised along with steelhead, brown trout (*Salmo trutta*), and rainbow trout (*O. mykiss*) at the Vancouver Trout Hatchery at Columbia Springs. The hatchery was established in 1938 to take advantage of the spring water at the bottom of the Columbia Slope. The hatchery is also part of WDFW's endangered chum salmon program (Columbia Springs 2018).

The Columbia River reach near Vancouver has had an approved TMDL plan for dioxin in place since 1991. A preliminary draft for a temperature TMDL was completed in 2003 but was not finalized. A work plan has recently been developed by the US EPA to move forward with a new TMDL plan for temperature in the Columbia River. Part of that planning effort included the Columbia Cold Water Refuges Project, which focused on areas where cooler tributary rivers (≥2°Celsius [°C] colder than the Columbia River) create small areas of cooler water in or next to the Lower Columbia River. Preliminary findings were recently released that identified no cold water refugia between the Washougal and Lewis Rivers (Palmer 2017). The springs and seeps along the Columbia Slope do not produce enough flow to influence river temperatures.

Vancouver Lake and the Vancouver Lake Lowlands provide shoreline and shallow water habitat for juvenile salmonids and other fish species. Common lake species include black and white crappie, brown bullhead, catfish, largemouth bass, largescale suckers, carp, and shad. Sturgeon, coho salmon, and steelhead are also known to be present (WDFW 2018c; Vancouver Lake Watershed Partnership 2008). Fish tissue studies conducted by Ecology have found elevated levels of PCBs and chlorinated pesticides in largescale suckers, common carp, and largemouth bass. Sediment samples collected from the lake did not show PCB or pesticide contamination (Coots 2007).

Figure 9.
Canopy Cover and Riparian Planting Areas.



Legend
Priority Planting Areas
Burnt Bridge Creek
BBC Tributary
Watershed boundary
Percent Canopy Cover
5%
5 to 15%
15 to 25%
25 to 50%
50 to 75%
> 75%

0 2,500 5,000 10,000 Feet

HERRERA PgG

K:\Projects\Y2017\17-06550-000\Project\Report_Figures\Canopy_Cover.mxd

Benthic macroinvertebrates are critical to the health of freshwater streams. They are integral in the food web as both prey and predator, breaking down organic matter (periphyton, leaves, and other detritus) to consume, and they become a food source for vertebrates such as fish and amphibians. Because many macroinvertebrate species are intolerant of water pollution and sedimentation, they are also valuable indicators of the biological health of the overall stream system. The Benthic Index of Biotic Integrity (B-IBI) is a quantitative method of monitoring that allows for comparison between different stream systems and tracking trends in stream health over years (Puget Sound Stream Benthos 2018).

Ecology collected two B-IBI samples along Burnt Bridge Creek: one sample on October 7, 2004, along the Alki Road crossing, a couple miles downstream of I-5, and a second sample on July 8, 2010, north of Meadowbrook Marsh Park, a couple miles downstream of the I-205 crossing. B-IBI scores of at least 35 are required to sustain viable salmonid populations (Karr et al. 2003). In 2004, the site at Alki Road scored 30.3 (poor); and Meadowbrook Marsh was also rated poor, scoring 26.5 in 2010 (Puget Sound Stream Benthos 2018). A study in 2015 on the biological condition of four sites along Burnt Bridge Creek also had B-IBI scores ranging from poor to very poor (Tetra Tech 2015). The B-IBI scores reported for Burnt Bridge Creek indicate impaired biological processes and are likely a result of urban land cover and impervious surfaces.

There are several partial fish passage barriers throughout Burnt Bridge Creek, but the few barriers located in the downstream reaches near Vancouver Lake may prevent access to the upstream reaches (WDFW 2018b; WSDOT 2018). There is one partial barrier to Burnt Bridge Creek and one complete barrier to Cold Creek (a tributary to lower Burnt Bridge Creek) at the I-5 crossing (WDFW 2018b; WSDOT 2018). Another two partial barriers in this reach of Burnt Bridge Creek are located at Northeast Hazel Dell Avenue and between Northeast Hazel Dell Avenue and I-5 (WDFW 2018b).

4.5. WILDLIFE

Priority habitats in Vancouver, such as riparian areas and wetlands, support a variety of wildlife in and around the city. According to a national inventory by the US Fish and Wildlife Service, the geographic area surrounding the Fort Vancouver National Historic Site has suitable habitat for many species either observed or known to inhabit the Vancouver area, including 18 mammal species, 82 bird species, 28 fish species, and several species of reptiles and amphibians (National Park Service 2015). Open spaces throughout the urban area host multiple species, including bald eagle, peregrine falcon, blue heron, coyote, beaver, deer, grey squirrel, several species of bats, and many species of songbirds.

Terrestrial and avian species depend heavily on nearby water habitats and are sensitive to degradation in habitat and water quality. The Columbia River and Vancouver Lake are designated shorelines of statewide significance for preservation, protection, and recreation (Vancouver 2012). Regional wetlands along the Columbia River are important wintering, migration, and nesting habitats for waterfowl.

5. ANALYSIS OF WATERSHED MANAGEMENT EFFECTIVENESS

The availability of spatial (GIS) data and long-term data records on surface and groundwater quality in the City presented an opportunity to assess whether watershed characteristics (landscape conditions such as land use, terrain, and septic system density) and watershed management activities (such as habitat restoration and stormwater treatment) were correlated with water quality. Herrera analyzed available data about landscape condition and the City's watershed management efforts—collectively, "watershed attributes"—and surface water and groundwater quality in the Burnt Bridge Creek watershed. The Columbia Slope watershed was not included because available data for that watershed are insufficient for statistical analyses.

The analysis included two phases: 1) review of existing watershed health parameters, focused on surface water quality, groundwater quality, and groundwater levels as well as watershed attributes that affect watershed health; and 2) statistical analyses (correlation and multiple regression) to identify relationships between them. The analysis, including details about the data used, methods, and results, is described in Appendix B. The results, indicating which watershed attributes are statistically correlated with improved water quality, may help the City understand those relationships, prioritize watershed management activities, and improve and prioritize data collection efforts.

Below are five hypotheses of relationships that one would expect to observe between water quality parameters and watershed attributes. Each hypothesis is followed by discussion of the actual results of the statistical analysis.

Hypothesis No. 1: Septic systems impair surface water quality.

Based on the correlation analysis of watershed management effectiveness, it appears that septic system density is correlated with some water quality parameters in Burnt Bridge Creek. The analysis showed statistically significant positive correlations between septic system density and concentrations of fecal coliform, total nitrogen, and nitrate (see Table B-5). Concentrations of these parameters are high in septic system effluent and these results suggest that water quality in Burnt Bridge Creek may be degraded by septic systems in the watershed. Quantitative microbial source tracking methods would be useful in identifying bacteria sources in the watershed.

Hypothesis No. 2: Riparian buffers improve surface water quality.

The correlation analysis also showed statistically significant correlations between riparian canopy cover and temperature, dissolved oxygen, pH, and turbidity (see Table B-5). Tree canopy cover within a riparian buffer, defined as within 50 feet of each stream bank and 0.5 mile upstream, was linked with an improvement in dissolved oxygen, but it also unexpectedly showed a correlation with increases in temperature, pH, and turbidity. In waterbodies, an increase in dissolved oxygen is more frequently associated with decreased temperature because cooler waters retain more oxygen. Similarly, increased riparian plant density also showed an unexpected correlation with higher stream temperatures. Results from this analysis suggest that increases in dissolved oxygen in the stream may not have been related to riparian canopy cover.

Riparian planting density demonstrated a positive relationship with decreased nitrate concentrations, but nitrate did not show a correlation with riparian canopy cover. Mature trees have been shown to uptake substantial amounts of nitrate from stream waters and should have more of an effect on concentration than young riparian plantings (greater canopy cover vs. greater density), suggesting that factors unrelated to riparian vegetation may be cumulatively affecting nitrate concentrations in Burnt Bridge Creek.

Collectively, the correlation analysis results did not demonstrate a relationship between water quality and riparian canopy or planting density. Because tree canopy cover within riparian buffers should reduce stream temperatures from shade and may possibly reduce turbidity by providing erosion control, other factors are likely increasing stream temperatures and turbidity. These relationships may be discernable in future analyses by refining the data analysis methodology, using alternative riparian metrics, or increased monitoring and data collection.

Hypothesis No. 3: Tree cover improves surface water quality.

Tree canopy cover within the subbasins draining to the stream monitoring stations was positively correlated with an increase in fecal coliform bacteria and not significantly correlated with any other water quality parameters (see Table B-5). Residential land use was also positively correlated with fecal coliform bacteria and tree canopy cover. Collectively, these results indicate that increased fecal coliform bacteria concentrations may be linked with residential land use and not tree canopy cover. Intuitively, tree canopy cover should reduce stormwater pollutant loadings to the stream and improve water quality by reducing pollutant concentrations in the stream. The increase in tree canopy cover with residential development in this watershed makes it difficult to discern specific benefits from an increase in tree canopy.

As Urban Forestry continues its efforts to increase tree canopy citywide, the City should continue to collect GIS data for comparing historical trends in tree canopy cover with water quality in key subbasins of Burnt Bridge Creek.

Hypothesis No. 4: Urban development impairs surface water quality.

The correlation analysis evaluated water quality relationships with residential land use, commercial/industrial land use, and impervious land cover—both separately and combined to represent urban development (see Table B-5). Commercial/industrial land use and impervious cover (but not residential land use) correlated positively with total and soluble reactive phosphorus concentrations in Burnt Bridge Creek. These findings indicate that urban development in the watershed is increasing phosphorus concentrations during summer base flow conditions.

Key sources of phosphorus in urbanized watersheds may include stormwater runoff carrying sediment from impervious surfaces (presumably roads and parking lots more than roofs), improper phosphorus content or application of fertilizers, and sanitary wastewater inputs from septic systems or storm drain cross-connections. Street sweeping, stormwater treatment, and targeted education and outreach on fertilizer application and septic tank elimination are common best management practices to control phosphorus in the watershed.

Hypothesis No. 5: Stormwater management facilities improve surface water quality.

Potential effects of stormwater management on stream water quality were evaluated by correlating base flow water quality with the density of dry well, detention, infiltration, filtration, sedimentation, and pond/wetland facilities. Detention, filtration, and infiltration facilities were correlated with improving stream temperatures (see Table B-5). Detention facilities were also correlated with lowering dissolved oxygen concentrations and pH (generally no impact). Dry wells and sedimentation facilities were correlated with improvement to total and soluble phosphorus concentrations. These findings indicate that stormwater management facilities are improving temperatures and phosphorus concentrations in Burnt Bridge Creek.

Dry well and sedimentation facility density also correlated negatively with commercial/industrial land use (see Table B-6). The lower density of these facilities in commercial/industrial areas of the watershed, combined with the finding of increasing phosphorus in commercial/industrial areas, suggests that additional stormwater management facilities in commercial/industrial areas could improve surface water quality in this watershed. Additional GIS data on basin catchment areas, stormwater facility characteristics, and water quality during storm events would allow for the evaluation of specific BMP types on water quality at a basin scale in the future.

6. STRATEGIES AND BEST MANAGEMENT PRACTICES

6.1. VANCOUVER PROGRAMS TO PROTECT AND IMPROVE WATER QUALITY

The City's Public Works Department manages programs and conducts activities that reduce flooding, protect and improve water quality, protect groundwater, and protect and restore aquatic habitat in streams and lakes within Vancouver. To integrate regional water quality efforts, the City collaborates with the Port of Vancouver, Clark County, other municipalities in the Lower Columbia River basin, and various state and federal agencies.

The City's Stormwater Management Plan (Vancouver 2018a), updated each year and available on the City's website, documents activities and BMPs used to protect and improve water quality within the city and to comply with federal and state requirements. The National Pollutant Discharge Elimination System (NPDES) Permit issued by Ecology establishes specific compliance components intended to reduce the discharge of pollutants to the maximum extent practicable and to require the use of all known, available, and reasonable methods of prevention, control, and treatment to prevent pollution of the state's water resources.

The components of the Stormwater Management Program are:

- Public Education and Outreach
- Public Involvement and Participation
- Illicit Discharge Detection and Elimination
- Controlling Runoff from New Development, Redevelopment, and Construction
- Municipal Operations and Maintenance
- Monitoring and Assessment

Additional requirements are anticipated with each new 5-year permit cycle. In 2019, watershed planning will be incorporated as a new component:

- Comprehensive Stormwater Planning

Support from the City's Urban Forestry, Community & Economic Development, Water Resources Education, Construction Services, Stormwater Operations, and Greenway Sensitive Lands programs fulfills key components of the Stormwater Management Program (Vancouver 2018).

6.2. PUBLIC EDUCATION AND OUTREACH; PUBLIC INVOLVEMENT AND PARTICIPATION

Public outreach and education efforts have been incorporated into all of the City's programs as a means of elevating awareness and encouraging individual responsibility for protecting and improving surface water and groundwater quality.

6.2.1. Water Resource Education Center

Stewardship, pollution prevention, and pollution awareness are the primary mission of the City's Water Resource Education Center, which has provided environmental education and hands-on public involvement through programs, exhibits, events, and volunteer opportunities for the community for more than 20 years. The Water Resource Education Center is part of the City's Public Works Department, and it is funded primarily through Vancouver's water utility revenues, supplemented by grants and private donations. Partnering with other departments and agencies, the outreach programs and exhibit hall provide information about stormwater, drinking water, wastewater, solid waste/recycling, solar energy, climate, fish and wildlife, native plantings, and urban forestry.

The Water Resource Education Center is a popular place for people of all ages to learn how to use water wisely and how to protect water resources. The center reaches more than 4,000 school children, as well as many other visitors, each year. A countywide Student Monitoring Network program includes students and teachers from 30 schools in Clark County. The center's wetland waterfront includes a 3,000-square-foot viewing platform with a view of one of the few remaining, natural, Columbia River riparian areas in the Vancouver-Portland metropolitan area. Those vital wetlands, under the stewardship of the Water Resource Education Center, support more than 120 species of fish and wildlife, which are honored and celebrated through multiple events each year. Hands-on science and nature activities are provided by staff, interns, and volunteers to engage hundreds of participants both on and off the site.

6.2.2. Columbia Springs

The springs and seeps along the Columbia Slope support freshwater wetlands and are an important resource for the community. Historically, the Columbia Springs, 6 miles east of Fort Vancouver, provided enough flow to power a lumber mill and, later, a grist mill for settlers in the 1800s. Later, under President Roosevelt's New Deal work program, a fish hatchery was constructed at the site in 1938. Construction of State Route 14 in 1953, and residential development following the opening of the Glenn L. Jackson Bridge in 1982, significantly reduced the amount of water available for fish. To prevent the fish hatchery from closing in 1994, community partners, including Evergreen Public Schools, the City of Vancouver, Clark County, and Clark College, partnered to establish the Columbia Springs Environmental Education Center at the site. Columbia Springs is a nonprofit organization providing thousands of children and adults outdoor experiences through field trips, summer camps, workshops, and community events.

Columbia Springs and groundwater have provided continuity for the Vancouver Trout Hatchery. The springs area has been recognized as the largest chum salmon spawning site on the Columbia River between the river mouth and the Bonneville Dam. Still using the original fish-rearing ponds, the hatchery is operated by WDFW. Approximately 300,000 steelhead, 20,000 brown trout, 80,000 rainbow trout, and 80,000 chum salmon are raised each year for release in local waterways (Columbia Springs 2018). Providing a personal connection for students with fish, Salmon in the Classroom provides over 50 Clark County teachers with aquariums, supplies, fingerlings, and eggs for students to raise and release. At the 100-acre Columbia Springs site, 2 miles of walking trails, historical displays, a visitor center, and interpretive guides foster environmental stewardship and promote sustainable activities.

6.2.3. Urban Forestry

Vancouver's Urban Forestry program works closely with Vancouver Parks and Recreation to increase tree canopy cover citywide and to improve tree health. Vancouver's urban forest comprises all the trees in parks and natural areas, along streets, and on private property. A healthy tree canopy provides numerous environmental benefits, including reductions in stormwater runoff, air pollution and greenhouse gases. According to the City's Tree Canopy Report, in 2010 there were 5,579 acres of tree canopy in Vancouver. Vancouver's tree canopy covers 18.6 percent of the city, helping to preserve watershed health and reduce runoff while improving the livability of neighborhoods. Strategies for reaching a goal of 28 percent citywide canopy cover by 2030 continue to be implemented. The Urban Forestry program was awarded a grant to complete a tree inventory of neighborhood parks throughout Vancouver. Tree composition, condition, location, and maintenance needs were documented for 2,489 trees in 19 parks. The study found that 92 percent of those trees are in good condition and 42 percent are evergreen, providing year-round benefits.

The Urban Forestry program is supported by the Urban Forestry Commission, a seven-member volunteer commission appointed by Vancouver City Council. Together, the Urban Forestry program and Commission educate citizens on the importance of preserving, managing, and enhancing existing trees and engage the community in good management practices, tree plantings, and removal of invasive species. Each autumn, the Urban Forestry program and Commission and the National Park Service host the Old Apple Tree Festival to honor the oldest apple tree in the Northwest. Planted at Fort Vancouver in 1826, the 193-year-old tree is considered the matriarch of Washington's apple industry and is a testament to effective, multigenerational stewardship. Arbor Day, the Columbia River Watershed Festival, and partnerships with Friends of Trees, neighborhoods, schools, and businesses throughout the city foster engagement throughout the community (Vancouver 2017b).

6.2.4. Solid Waste and Recycling

The City's Solid Waste and Recycling Services team provides education and assistance to citizens in managing household waste and proper disposal of yard debris. The Household Hazardous Waste program is detailed within the Clark County Comprehensive Solid Waste Management Plan (Clark County 2015). The City partners with Clark County Public Works and Public Health in outreach to businesses and citizens. Vancouver residents have access to various options for disposal of hazardous waste, which can be processed through three regional transfer stations, curbside collection of household batteries, and a paint recycling and collection program. Coupons for free leaf disposal are offered each autumn to help prevent blocking storm catch basins and flooded streets.

The City has partnered with local businesses to reduce the amount of plastic film in the environment. The Recycle Wrap/Beyond Bags Program promotes collection of plastic film and bags at local grocery stores that can be recycled into composite lumber.

Residential customers can download a free app or use the City website for current information on recycling, reusing, and disposing of unwanted materials. Details about disposal of unwanted medications, block foam, electronics, composting yard debris, recycling, and free leaf disposal coupons can also be found in the Waste Connections newsletter or the RecycleRight app.

6.2.5. Watershed Alliance

In 2007, the non-profit organization Vancouver Watersheds Alliance, now Watershed Alliance of Southwest Washington, was established to promote community engagement, support environmental restoration, encourage volunteerism, and care for water resources. Among its many activities, the Watershed Alliance has partnered with the City's Urban Forestry program and Public Works Sensitive Lands Team to plant thousands of native shrubs and trees along Burnt Bridge Creek on National Make a Difference Day and Martin Luther King Day, and to host invasive plant removal and litter cleanup events. Through Project Restore, an effective partnership with landowners is facilitating private site restoration along the Burnt Bridge Creek corridor. Watershed Alliance activities include oversight of a neighborhood grant program that awards sums up to $2,000 for tree and native vegetation plantings, pet waste and trash receptacles, and other projects that benefit the community and environment. The Watershed Alliance also works with volunteers to educate and raise awareness about the need to reduce pollutants from entering stormwater drains with storm drain murals. Most recently, the Watershed Alliance began working with the City and other local agencies on a "Don't Drip and Drive" campaign to reduce pollution from vehicle oil leaks.

6.3. ILLICIT DISCHARGE DETECTION AND ELIMINATION

6.3.1. Water Resources Protection Program

The City's Water Resources Protection program (WRP program) was initiated in 2003 to identify and eliminate existing and potential illicit discharges to the stormwater system and to reduce risks to surface and groundwater. The WRP program is designed to provide technical assistance and to initiate enforcement procedures to bring a site into compliance when necessary.

Under the WRP program, the City actively inspects and monitors industrial facilities, commercial operations, and residences for water quality compliance and BMPs. The City also works with local, state, and federal agencies and departments to locate, assess, characterize, trace, and remove sources of illicit discharges. Field assessments and outfall inspections take place throughout the year to locate and accurately map storm system features and to look for indicators of illicit discharges. Televised inspections have been helpful in identifying inappropriate or unknown connections to the stormwater system. Training is provided to City field staff to assist in detection of illicit and accidental discharges that could threaten water resources.

6.3.2. Sewer Connection Incentive Program

Vancouver's Sewer Connection Incentive Program (SCIP) was developed to protect watershed resources from failing and aging septic systems by providing an easy, affordable solution to convert from a septic system to a reliable public sanitary sewer. The SCIP program was developed in two phases.

SCIP Phase 1 began in 1993. It encouraged residents with existing septic systems and public sewer fronting their property to make the switch to public sewer. Phase 1 gave financial incentives to homeowners to eliminate their septic system and connect to the available public sewer; approximately 650 properties were converted from septic systems to public sewer.

In 1998, SCIP Phase 1 was replaced with Phase 2, expanding the program to neighborhoods that were developed at a time when it was not practical to extend public sewer because of the development's distance from any existing public sewer infrastructure. Under Phase 2, the City extends public sewer to neighborhoods that were developed prior to public sewer bring available and septic systems were allowed. The Phase 2 projects were developed and prioritized based on several factors, such as proximity to public water supply and surface waters, failing septic systems in the vicinity, and development density. The program provides the property owner with a set fee if the property is converted from septic to the new public sewer within 2 years of completion of construction. Property owners are encouraged, but not required, to eliminate their existing septic systems and connect to the new public sewer.

Phase 2 of the SCIP has extended public sewer to almost 5,000 properties within the City's sewer service area. As of 2017, the program needed to extend public sewer to almost 2,000 properties. Some of the sewer infrastructure will be constructed with development projects, and the remainder will be completed under the SCIP program by 2024/2025.

6.3.3. Coordination with Clark County Public Health

The City coordinates with Clark County Public Health to provide public sewer to properties with failing septic systems through a Demand Response piece of the SCIP Phase 2. Properties that are within 300 feet of a public sewer line, are experiencing septic system failure, and require public sewer extension to connect to the system are evaluated by the City and considered for a capital project.

Clark County Public Health maintains records for septic systems, such as as-builts and maintenance records. The City works with Public Health to identify properties that have eliminated septic systems and connected to public sewer in an effort to keep the City's information up to date. If there is uncertainty about a property's connection to public sewer, the City may confirm with dye and/or smoke tests.

6.4. Controlling Runoff from Development and Construction Sites

To protect water quality and keep stormwater collection systems clean, the City's Stormwater Control and Erosion Prevention program helps ensure BMPs are applied when carrying out any land-disturbing activity or creating impervious surfaces. Recently, the City revised associated ordinances as part of a comprehensive program to reduce pollutants in stormwater runoff from new development, redevelopment, and construction activities. Annual inspections of all stormwater treatment and flow control BMPs and facilities are required by the City's NPDES stormwater discharge permit. Low impact development (LID) practices and principles are required to be utilized whenever possible on all development projects to minimize impervious surfaces, retain native vegetation, and reduce stormwater runoff.

The City's Community and Economic Development department coordinates the overall site planning process while Surface Water Management reviews proposals for stormwater systems in new development and redevelopment. Grading plan review and construction site inspections continue to be key in preventing surface water contamination by sediment. Standard operating procedures for private stormwater facilities continue to be developed and integrated into the City's GIS and information tracking system. The City has expanded its private stormwater facility inspection program and has hired additional inspectors in this citywide effort.

6.5. Municipal Operations and Maintenance

The City has an ongoing Stormwater Operations program that maintains more than 300 miles of stormwater pipe and thousands of catch basins, manholes, dry wells, filter vaults, and storm drains. Belowground structures are cleaned through flushing and using a vacuum extractor (Vactor) to remove sediment and debris. Video inspection of stormwater infrastructure is also used to identify pipes and structures in need of cleaning, rehabilitation, or replacement. Video is helpful to verify and update stormwater utility maps and inform inspection staff about unknown or illicit connections or discharges.

Street sweeping on major arterials occurs twice a month and, similarly, minor arterials are swept every other week. The downtown/core area, which includes everything west of I-5 and south of Mill Plain Boulevard, along with adjacent commercial streets, is swept weekly—and more frequently in the autumn due to leaf litter accumulation. Though the downtown area is swept more frequently than other parts of Vancouver, it represents only 8 percent of the total miles swept. Neighborhood streets represent 37 percent and arterials represent 55 percent of all miles swept each year. Based on records from Clark County's Whatley Decant Facility, nearly twice as much material was removed by street sweeping than from cleaning catch basins.

Maintenance of stormwater infrastructure also includes working to keep ponds, swales, and bioretention facilities functioning to effectively retain and treat stormwater runoff. Operations crews ensure plantings remain viable and sediment is removed to retain storage and treatment capacity.

In 2005, a 3-mile stretch in the central riparian corridor of Burnt Bridge Creek was transformed through the Burnt Bridge Creek Greenway Improvement Project. The $10 million 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 8-mile trail follows Burnt Bridge Creek's path as it winds through neighborhoods, forested riparian areas, and open meadows and past wetlands, water quality treatment ponds, and enhanced upland and riparian habitats.

The City's Grounds Maintenance crew is responsible for parks and open spaces, cemeteries, trails, street medians, and City facilities such as fire stations, water stations, and the airpark. Their work is supplemented with crews of inmates from correction facilities and community volunteers.

An Integrated Pest Management plan, guiding selection and use of pesticides and fertilizers on all properties owned and managed by the City, has been in place since 2005. It ensures compliance with the state's pesticide restrictions for salmon-bearing streams and with the City's WRPO to protect human and aquatic life, the environment, and the municipal drinking water supply.

6.6. MONITORING AND ASSESSMENT

Water quality in Burnt Bridge Creek has been monitored by various agencies and organizations since the 1970s. Monitoring data show impairments typical to most urban streams, and the creek has not met state standards for temperature, dissolved oxygen, bacteria, and (occasionally) pH. Nutrients are also a parameter of concern, as they are across the nation, due to increased phosphorus and nitrogen in streams contributing to excess plant and algal growth.

Through the City's long-term Water Quality Monitoring Program, collected data have shown some improvement in nitrogen and bacteria concentrations, with temperature, pH, and dissolved oxygen remaining stable over the past 10 years. Ongoing stormwater management strategies continue to focus on lowering stream temperatures through increased riparian shading and reducing nutrient and bacteria concentrations through public education about responsible pet waste disposal and decreasing fertilizer use in landscaping.

6.7. COMPREHENSIVE STORMWATER PLANNING

The City adopted its first Comprehensive Plan under the Washington Growth Management Act in 1994. The plan provides direction and policy related to growth and development, including protection of environmentally sensitive areas within Vancouver's city limits. Vancouver Municipal Code Chapter 20.740, Critical Areas Protection, designates and protects wetlands, fish and wildlife habitat, conservation areas, geologically hazardous areas, and frequently flooded areas. No net loss of beneficial functions and values is required for water quality protection, habitat, food chain support, flood storage and conveyance, erosion control, and ground water recharge and discharge (Vancouver 2018b).

The City's Shoreline Master Program (Vancouver 2012) identifies the Columbia River and Vancouver Lake as shorelines of statewide significance, with management objectives to preserve and protect the resources and ecological function of the shoreline and to increase opportunities for public access and use. Environmental planning is implemented by the Community and Economic Development department with support from the Surface Water Management team for engineering direction and technical expertise in stormwater planning and review, design, and construction of water quality and quantity facilities, and water resource protection.

The City completed two stormwater retrofit planning studies that identified locations for potential retrofit opportunities in high priority subbasins. Stormwater retrofits in the Peterson Channel subbasin are nearing completion, and two projects in the East Orchards basin will begin design in 2019. Three additional studies are in preliminary stages of development and are anticipated to begin by 2020.

Many underground injection control (UIC) devices within Vancouver lack treatment and/or do not meet Ecology standards (e.g., separation from groundwater). The City has previously been awarded grant funds for stormwater retrofit projects to install treatment and infiltration for stormwater runoff in residential and commercial areas along Peterson Channel and Burnt Bridge Creek.

The Stormwater Utility funds Surface Water Engineering, Urban Forestry, Greenway and Sensitive Lands, and Stormwater Operations. It also provides funding for the City's Stormwater Capital Improvement Program (CIP), which is estimated at $30 million through 2034. Planned projects will address regulatory compliance for the City's NPDES stormwater permit, UIC, and TMDL implementation; sub-standard system and LID retrofits; system improvements in conjunction with other City infrastructure projects; property acquisition and wetland restoration; and comprehensive stormwater planning. Through 2022 the majority of the funding for capital projects will be provided through Ecology Stormwater Financial Assistance Program Grants. It is anticipated that the City will have continued success in obtaining grants, which could increase the CIP by millions of dollars annually.

Today, the many public and private water quality treatment facilities in Vancouver are considered green infrastructure, a best management stormwater control strategy known as LID, now required under the NPDES Stormwater permit. The City of Vancouver has continued to invest in critical properties along riparian corridors and has created or expanded its many programs to manage and protect vital water resources.

7. RECOMMENDATIONS

7.1. WATERSHED MANAGEMENT ACTIVITIES DEMONSTRATED TO INFLUENCE WATER QUALITY

7.1.1. Septic Systems

Based on the analysis of watershed management effectiveness, it appears that septic system density is correlated with some water quality parameters in Burnt Bridge Creek. The analysis showed statistically significant positive correlations between septic system density and concentrations of fecal coliform, total nitrogen, and nitrate.

The correlations between septic systems and water quality impairment suggest that addressing maintenance issues or removing septic systems would help improve water quality. However, failing or ineffective septic systems are not always evident. In areas with highly porous soils, septic flows may be effectively drained away from a property but without adequate treatment in the underlying soils. Consider expanding the Sewer Connection Incentive Program (SCIP) to incentivize septic disconnects in areas where sanitary sewers have been installed but connections have not yet occurred. The City should consider expanding programs to incentivize septic disconnects, maintenance, or repairs. Additional incentives should be given priority in locations where risk of contamination is higher, such as Special Protection Areas.

The City uses dye testing to verify sewer connections and identify septic tanks still in use where sanitary sewer lines are available. Septic systems that are not providing adequate treatment may be contributing to fecal coliform and nutrient loading in the watershed. Pollutant identification and correction programs that include dye studies are routinely implemented by county health departments. Optical brightener fluorescence is another method for tracing septic system waste containing laundry detergent in waters within or draining to the stream. A handheld meter measuring very low concentrations of optical brighteners has recently been experimented with as part of the Burnt Bridge Creek water quality monitoring program, but the results have yet to be evaluated.

Microbial source tracking (MST) using genetic markers of human fecal bacteria can be used to verify septic system contamination of stream waters where unusually high fecal coliform bacteria concentrations are observed and septic system inputs are suspected. A two-phased MST study of Burnt Bridge Creek was conducted from 1996 to 1999 using an *E. coli* ribotyping library method (Samadpour et al. 1999). The percentage of human-origin *E. coli* in the collected stream samples increased from 4 percent near the headwaters to 20 percent at Northeast Second Avenue. Furthermore, the results strongly indicated that the source of human *E. coli* in Burnt

Bridge Creek was septic systems and not sanitary sewers. Septic system connection to the sewer system was recommended to control human waste contamination of the stream. MST methodologies have advanced since the 1999 study was conducted and may be used effectively to identify current sources of fecal bacteria to Burnt Bridge Creek and its tributaries.

7.1.2. Riparian Plantings and Restoration

The watershed management analysis showed statistically significant, positive correlations between riparian canopy cover and some water quality parameters. Riparian canopy cover was shown to benefit (increase) dissolved oxygen and pH, it was also unexpectedly shown to increase temperature and turbidity. In addition, stormwater treatment facilities were shown to benefit (decrease) stream temperatures.

The observed beneficial correlations between riparian canopy cover and riparian plantings with some water quality parameters such as dissolved oxygen may demonstrate the effectiveness of plantings and restoration activities that increase riparian canopy cover. Continuing and expanding those programs, as feasible, is highly recommended. Documenting additional stream health metrics and water quality conditions would be useful for quantifying the benefit of these strategies over time.

7.1.3. Stormwater Retrofit for Existing Development

Although the GIS analysis did not find correlations between UIC devices (dry wells) and stream water quality other than temperature, the lack of correlation may have been due to the limited GIS data available in the analysis.

The City should continue its efforts to improve and retrofit its UIC wells by providing pretreatment or by replacing UIC wells that do not meet Ecology standards such as separation from groundwater, and by identifying opportunities for stormwater treatment in areas of existing development that currently lack stormwater treatment.

7.1.4. Operations and Maintenance

The City is routinely sweeping streets and regularly inspecting catch basins, performing maintenance on stormwater infrastructure when needed based on the inspection. Both activities are effective at removing sediment and other pollutants from receiving waters and should be continued. Inspection and maintenance records may be used to identify areas where a less frequent inspection schedule would be more appropriate than that specified in the City's NPDES Stormwater Permit. A formal submittal to Ecology is required, but it could provide more flexibility in meeting permit requirements and allow for prioritization in key basins.

7.2. DATA COLLECTION AND ANALYSIS RECOMMENDATIONS

7.2.1. Modeling for Drinking Water Protection

Modeling of Special Protection Areas for individual wells and wellfields should be conducted. Although the entire city is currently designated as a CARA, Special Protection Areas (1,900-foot radius) are designated around individual wells/wellfields; however, they are general in nature and do not reflect existing groundwater flow patterns.

The City has an active project to develop a Heights High groundwater model. The model could be used to more accurately delineate contributing areas to wells and wellfields. Such delineation could be useful for prioritizing inspections of potential contaminant sources, developing "early warning" groundwater monitoring programs, or developing response strategies should a contaminant spill occur.

In 2008, the City sampled all its water stations for a suite of 16 PPCPs, including caffeine, select pharmaceuticals, and antibiotics. Although caffeine was detected in the deeper aquifers, more recent monitoring in shallow groundwater showed no traces of caffeine. Because analytical methods have improved in the past 10 years, resampling at the water stations may be worthwhile to determine if anthropogenic influences are affecting the deeper groundwater sources.

7.2.2. Analysis of Surface Water Data

There are two key limitations to the multiple regression analysis. First, the monitoring data collected for each basin are dependent on all upstream monitoring stations. In the future, it may be appropriate to include an interaction factor in the regression equation to account for this spatial dependence. Second, the stormwater management predictor variables in the model are based solely on density and do not include area treated, which is typically much less for a dry well than an infiltration facility as an example. Including the area treated in the future may improve predictions of water quality variables in Burnt Bridge Creek.

The catchment area, treatment category, design flows, whether the facility is designed to be online or offline, and other information is not included in the datasets but would be beneficial in modeling to inform stormwater infrastructure needs. Recent capital improvement projects should be incorporated into the datasets.

Though the larger outfall basins have been mapped for the Columbia Slope, not all subbasins have been delineated. There is limited water quality data to support subbasin analysis.

7.2.3. Streamflow Monitoring of Burnt Bridge Creek

There is value in obtaining long-term flow records to assess the effects of land use, groundwater withdrawals, and other factors over time. Existing flow data for Burnt Bridge Creek are insufficient for evaluating long-term trends. Monitoring could be reinstated at either of two former USGS gaging structures (close to the creek mouth at stream mile 1.6 and farther upstream at 18th Street), with preference to the downstream site.

7.2.4. Water Quality Monitoring of Columbia Slope

There is limited water quality data to support subbasin analysis in the Columbia Slope watershed. Monitoring in select basins could provide data on water quality in the springs and identify anthropogenic influences in groundwater or surface water contributions.

The springs at the base of the Columbia Slope are representative of groundwater quality upgradient in the USA and TGA. They provide easy access for getting representative samples of upgradient groundwater quality.

High fecal coliform numbers were observed in stormwater monitoring in the Columbia Slope basin in the 1990s (CH2M Hill 1995), with illicit discharges suspected as a primary pollutant source. Stormwater monitoring would help to evaluate whether that continues to be of concern and, if so, would allow for planning of dye tests or other investigations to determine potential sources of illicit discharges and septic system inputs.

7.2.5. Better Characterization of Contribution Areas and Stormwater BMPs

Improving GIS data on stormwater BMPs by including catchment areas, fewer and more standardized categories would allow the City to map areas where stormwater is not managed through structural BMPs. Improved BMP GIS data would also help prioritize capital improvement projects such as stormwater retrofits and would allow for a more refined analysis if a watershed health assessment is conducted in the future.

7.2.6. Landscape Condition Data

One key outcome of this watershed assessment is to provide a baseline of land cover data in the City's watersheds. Collecting high-resolution data on impervious area coverage and canopy cover at regular intervals can facilitate tracking change over time. This could streamline future analyses and could also help inform watershed management activities.

The City should collect data on riparian intactness and buffer health because studies that have shown positive correlations between riparian intactness and stream health. For example, a study in Maryland compared reference (unimpacted) streams with degraded streams and found correlations between stream health (B-IBI scores) and percent adjacent forested land use, riparian width, and percent shading (<http://dnr.maryland.gov/streams/Publications/ea-03-4_phi.pdf>).

The US EPA has also developed a Recovery Potential Screening tool. It includes stressor indicators that relate to the effects of buffer encroachment on stream health. Indicators include percent impervious cover, percent urban, percent agriculture, road crossings and road density (<https://www.epa.gov/rps/stressor-indicators>).

Whether the watershed management effectiveness evaluation is repeated, or existing tools such as that available through US EPA are applied to the City's data, maintaining good data on landscape condition will allow the City to better monitor watershed health, evaluate trends, and identify opportunities for increasing riparian buffer intactness. This could be done through review of publicly available aerial photography.

7.2.7. Improve Characterization of Sewer Facilities

The City's sewer infrastructure is well-characterized for the purposes of capital project planning, sewer repairs, and sewer replacement projects. However, the GIS data provided on sewer infrastructure were limited. Incorporating other information on the sewer system, such as type, age, whether pipe is lined or unlined, and noted reaches with significant infiltration and inflow would help identify areas where contaminant loadings from sewer lines may be impacting shallow groundwater quality.

7.2.8. Account for Changes in Groundwater Recharge from Recent Development

The USGS estimated groundwater recharge from precipitation and from infiltration facilities back in 1992. Some areas have seen considerable development since 1992 (with new impervious surfaces and infiltration facilities), particularly in the western portions of the Burnt Bridge Creek watershed. Infiltrating runoff from new impervious surfaces increases recharge due to reduced evaporative losses (reduced vegetated areas). Estimating increased recharge from stormwater runoff is useful for understanding potential contaminant loading and for water resource planning (comparing groundwater withdrawal trends to increased recharge). Updating the USGS recharge assessment could also be useful for modeling groundwater flow and planning water-right optimization.

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APPENDIX A

PGG Figures

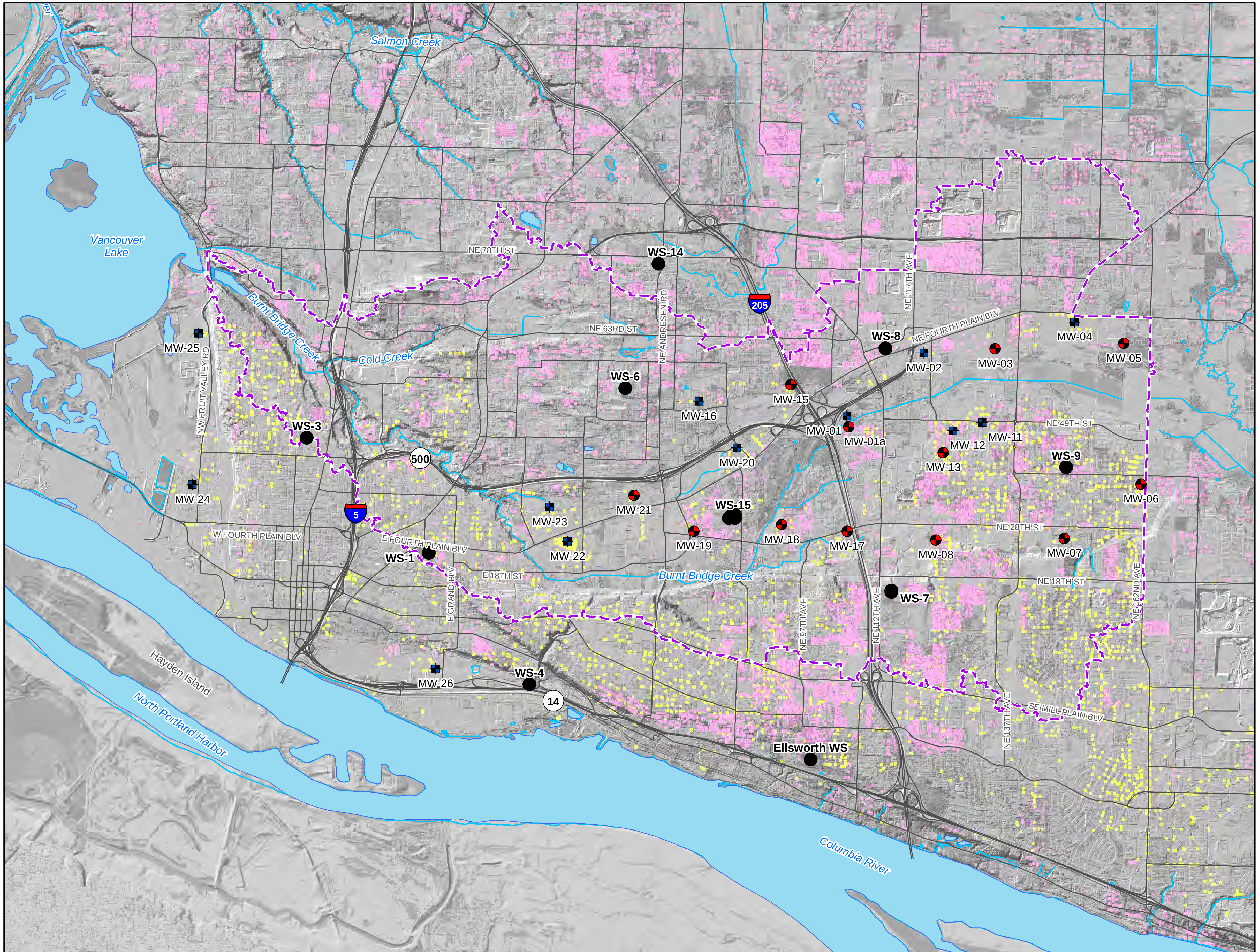

Figure PGG-1.
Groundwater Quality
Sample Locations

Legend

Project Monitoring Wells

- Water Level and Water Quality Monitoring
- Water Level Monitoring Only
- Vancouver Water Stations
- BBC Basin
- Septic Systems
- Drywells

0 2,500 5,000 10,000 Feet

HERRERA PgG

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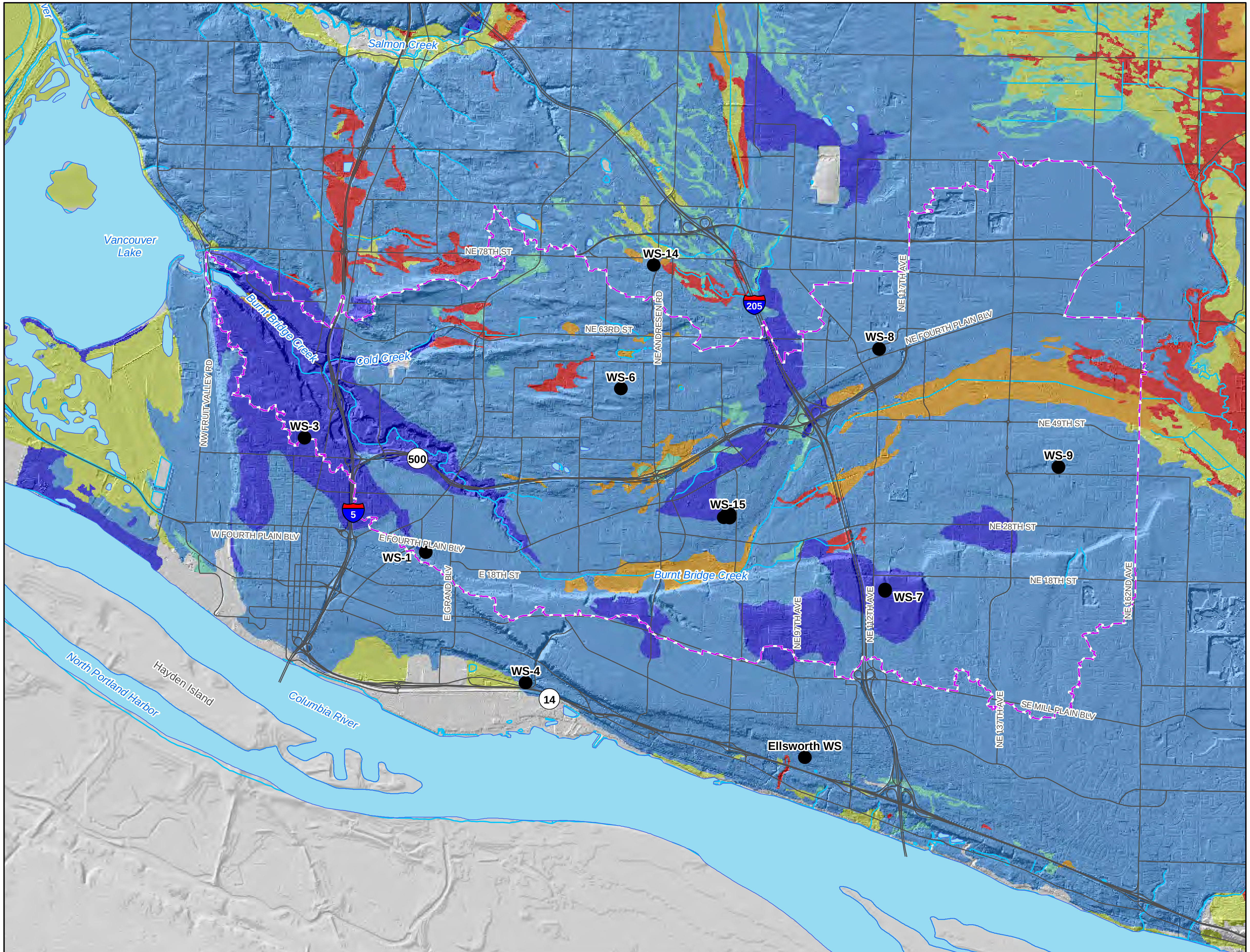
Figure PGG-2.
Hydrologic Soil Groups.



Legend

Hydrologic Soil Groups

- A
- B
- B/D
- C
- C/D
- D
- BBC Basin
- Vancouver Water Stations

N

0 2,500 5,000 10,000 Feet

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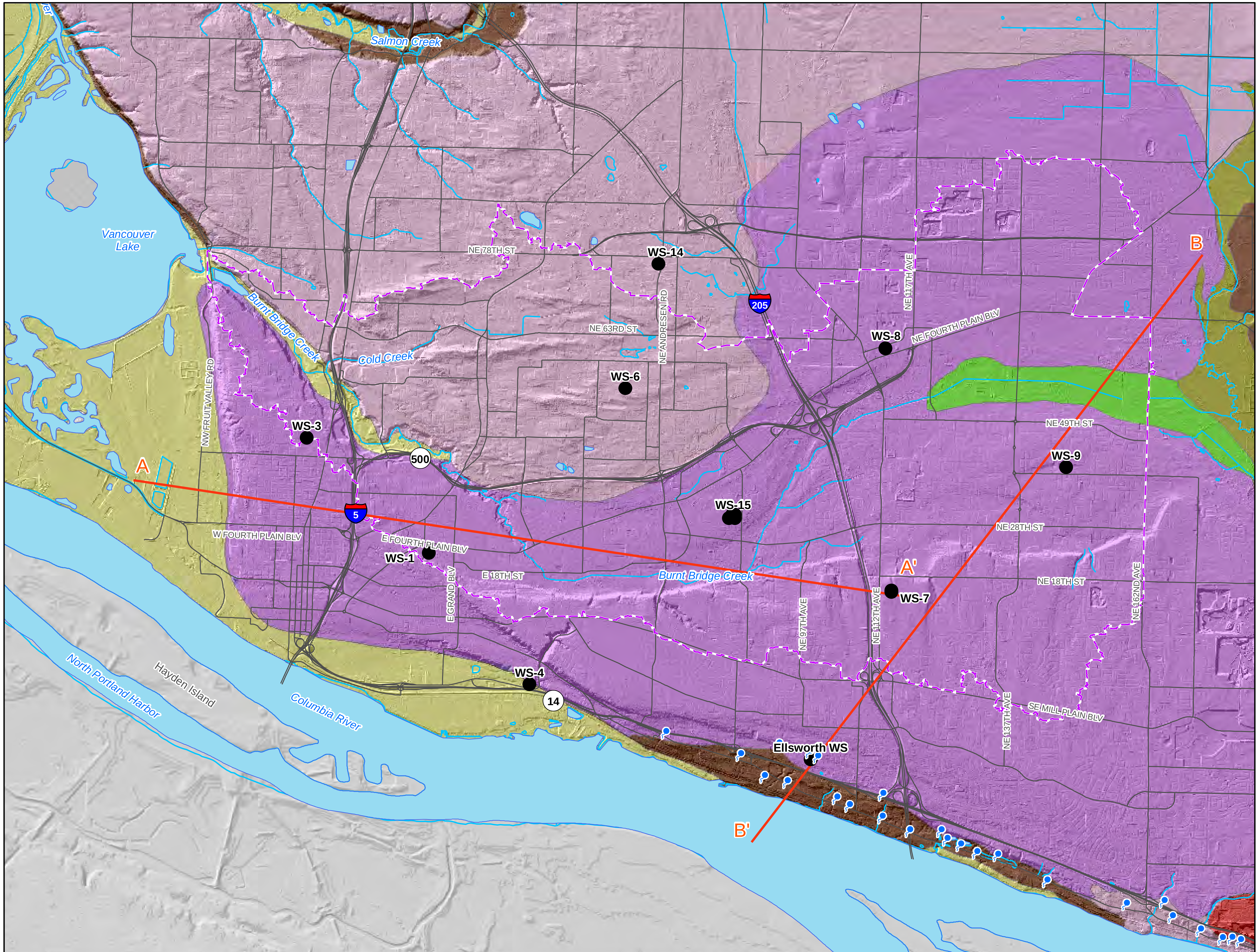
Figure PGG-3.
Surficial Geology.



Legend

- Springs (from WSP-1600)

Surficial Geology (WDNR 100k)

- Recent Alluvium
- Peat Deposits
- Alluvial Fan Deposits
- Pleistocene Alluvial Deposits, Sand & Silt
- Pleistocene Alluvial Deposits, Gravel
- Upper Troutdale Formation
- Bedrock Outcrop
- Cross-Section Alignments
- BBC Basin
- Vancouver Water Stations

N

0 2,500 5,000 10,000 Feet

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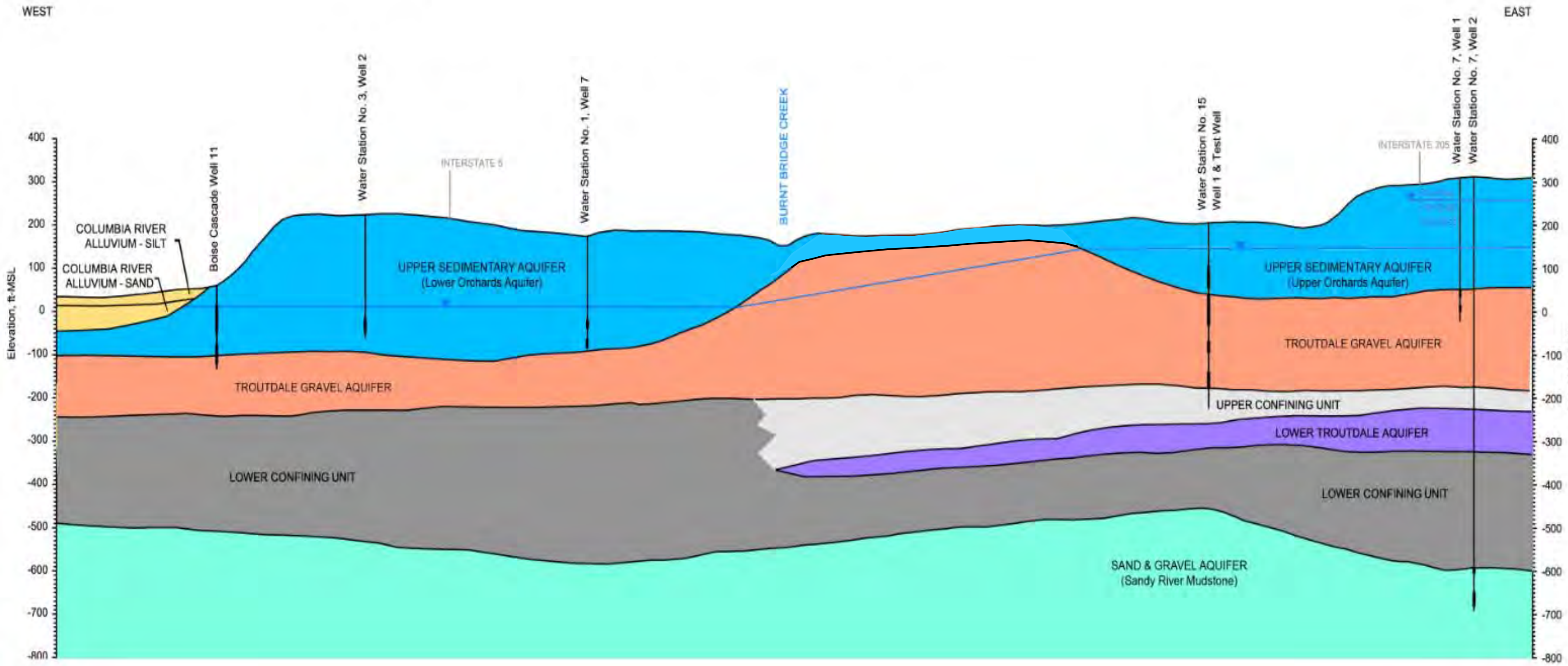
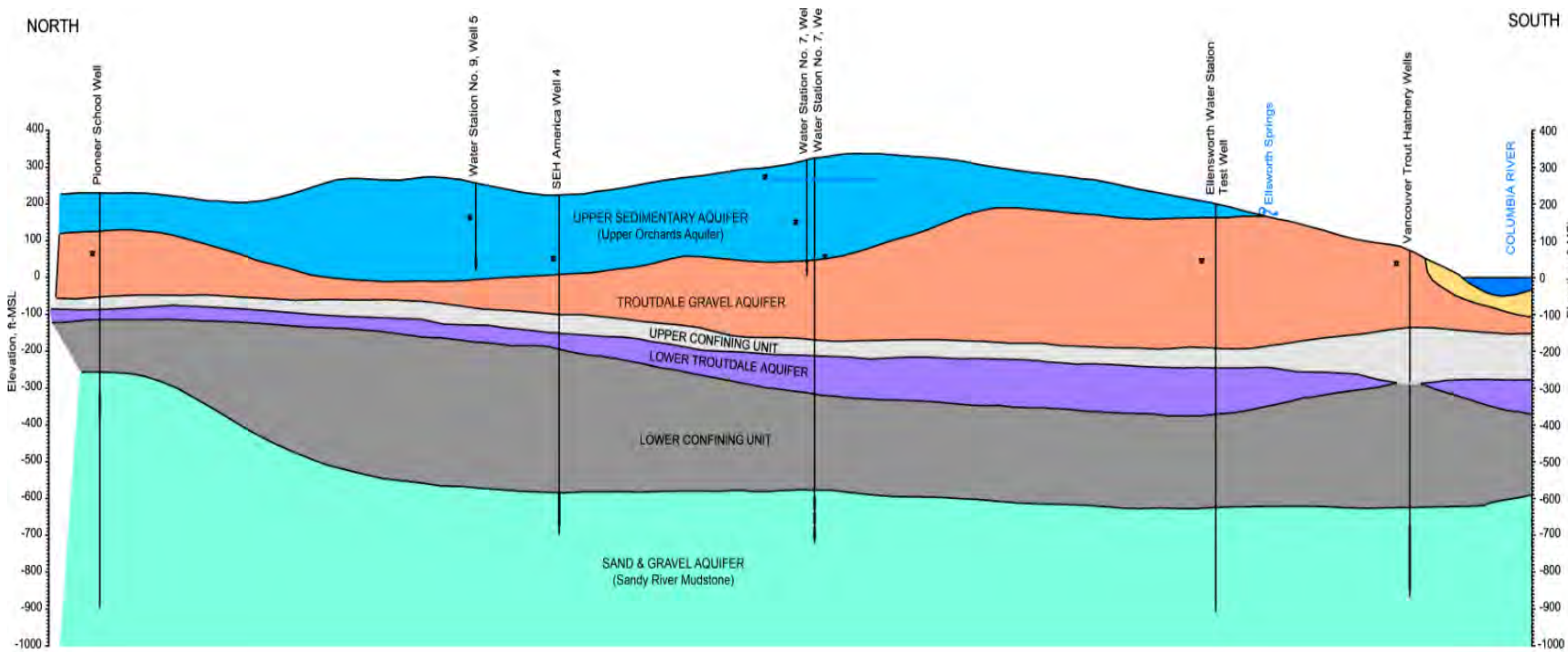


Modified from City of Vancouver Water System Plan (prepared by Robinson & Noble Inc. and presented in HDR 2007)

Figure PGG-4.
Hydrogeologic Cross-Section A-A'.

City of Vancouver
Watershed Health Assessment



Modified from City of Vancouver Water System Plan (prepared by Robinson & Noble Inc. and presented in HDR 2007)

Figure PGG-5.
Hydrogeologic Cross-Section B-B'.

City of Vancouver
Watershed Health Assessment

PGG

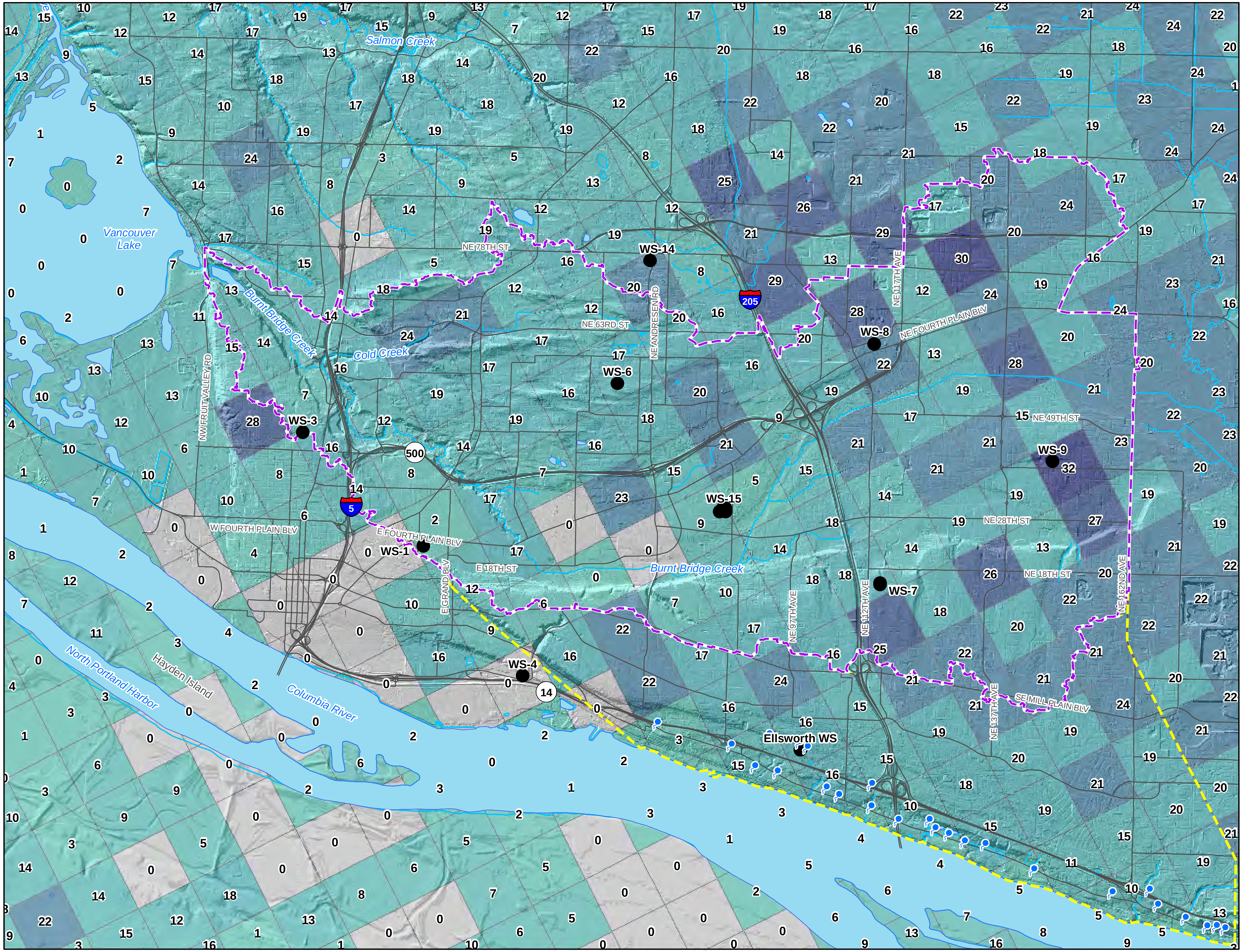


Figure PGG-6.
USGS Estimated
Groundwater Recharge

Legend

Precipitation + Dry-Well Recharge (inches/year)

- 0.0
- 0.1 - 5.0
- 5.1 - 10.0
- 10.1 - 15.0
- 15.1 - 20.0
- 20.1 - 25.0
- 25.1 - 30.0
- 30.1 - 35.0
- 35.1 - 40.0
- Springs (from WSP-1600)
- BBC Basin
- Columbia Slope Basin
- Vancouver Water Stations

0 2,500 5,000 10,000 Feet

HERRERA PgG

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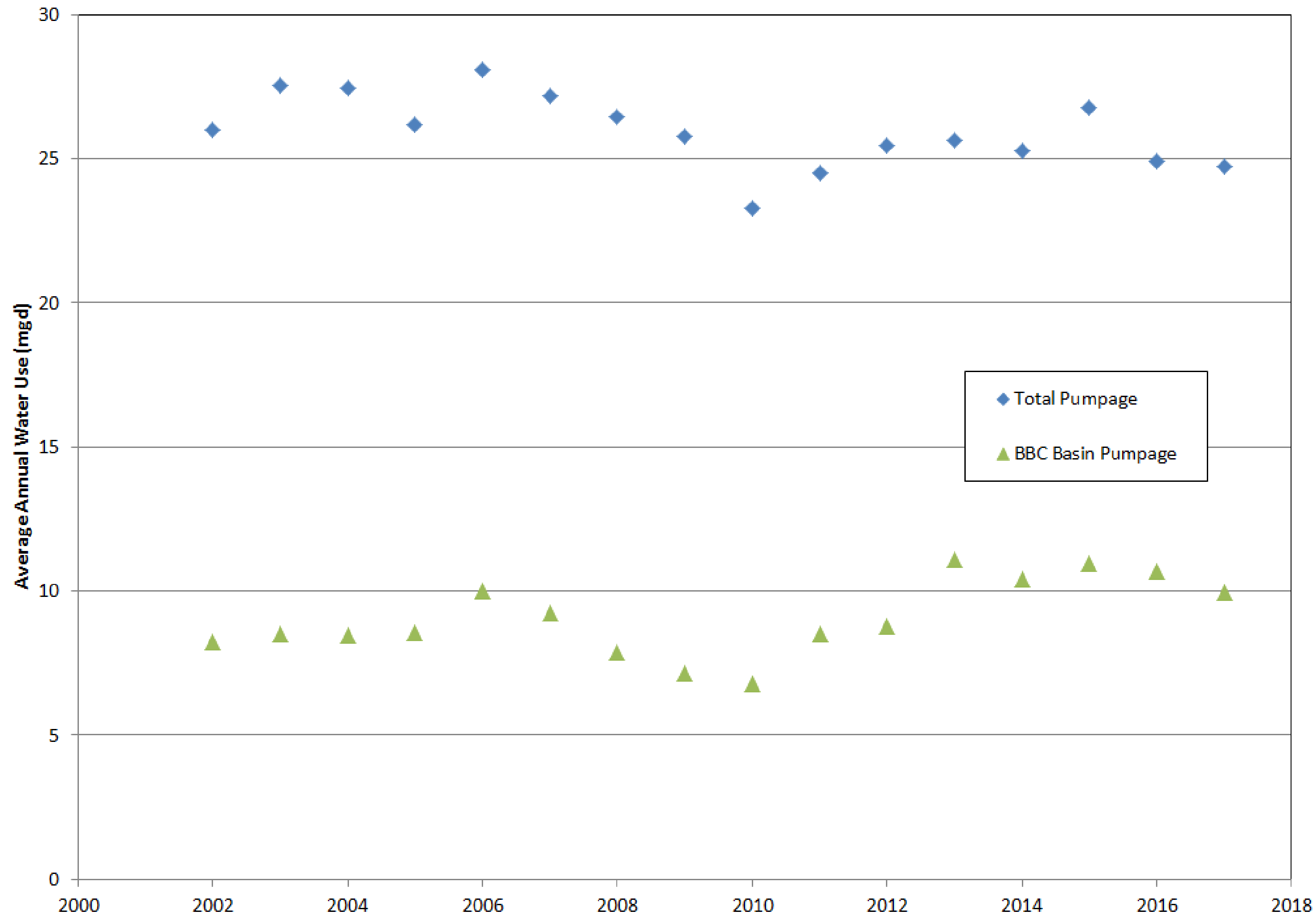
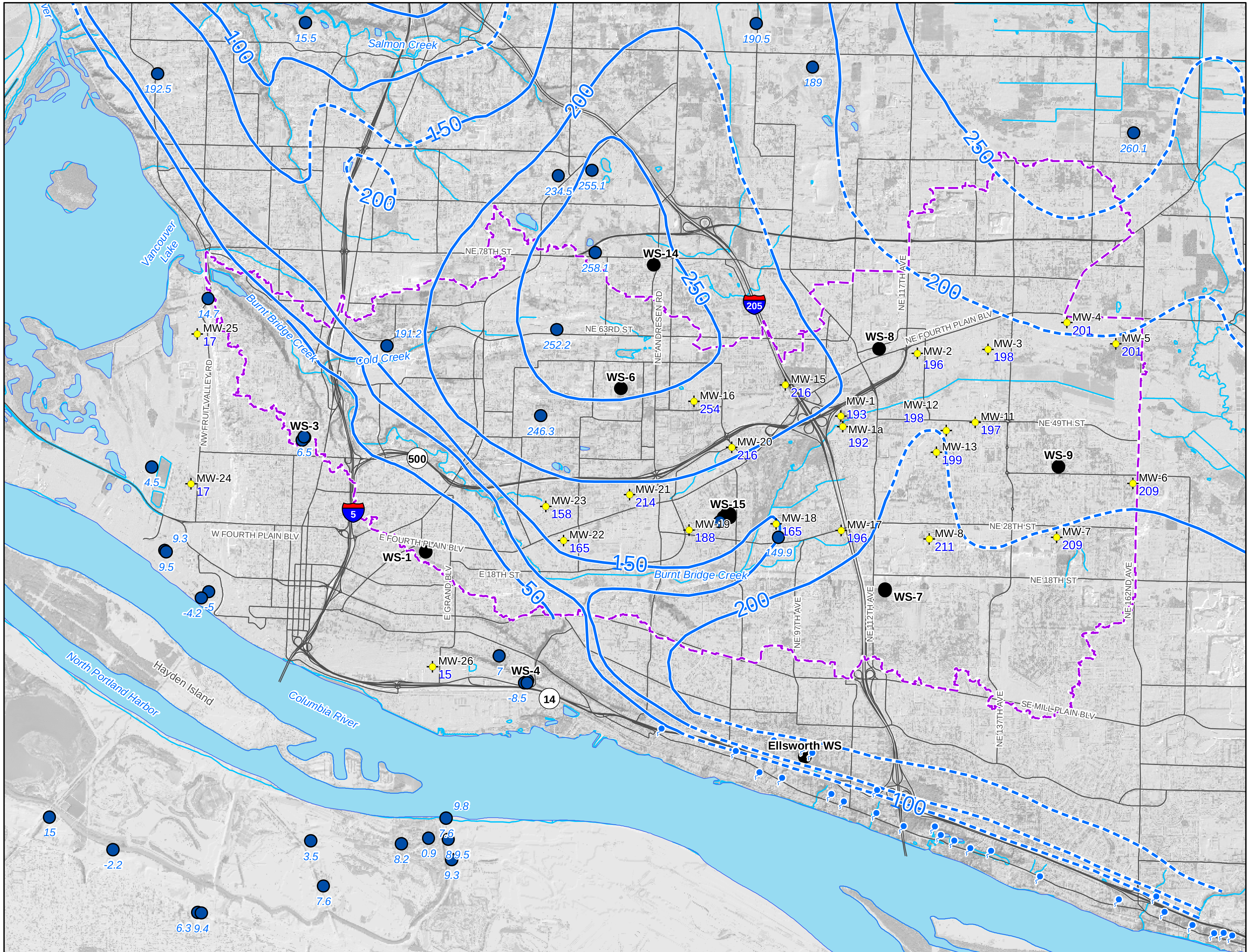


Figure PGG-7.
Annual Groundwater Withdrawals from City of Vancouver Water Stations.

City of Vancouver
Watershed Health Assessment

Figure PGG-8.
Groundwater Elevation Map for USA



Legend

- USGS Wells with Elevations*
- Springs (from USGS WSP-1600)
- City Monitoring Wells (2017 Average)
- USA Water Level Elevation Contours*
- BBC Basin
- Vancouver Water Stations

Elevation values in Feet NGVD29
* From USGS WSP-2470-A

0 2,500 5,000 10,000 Feet

HERRERA PgG

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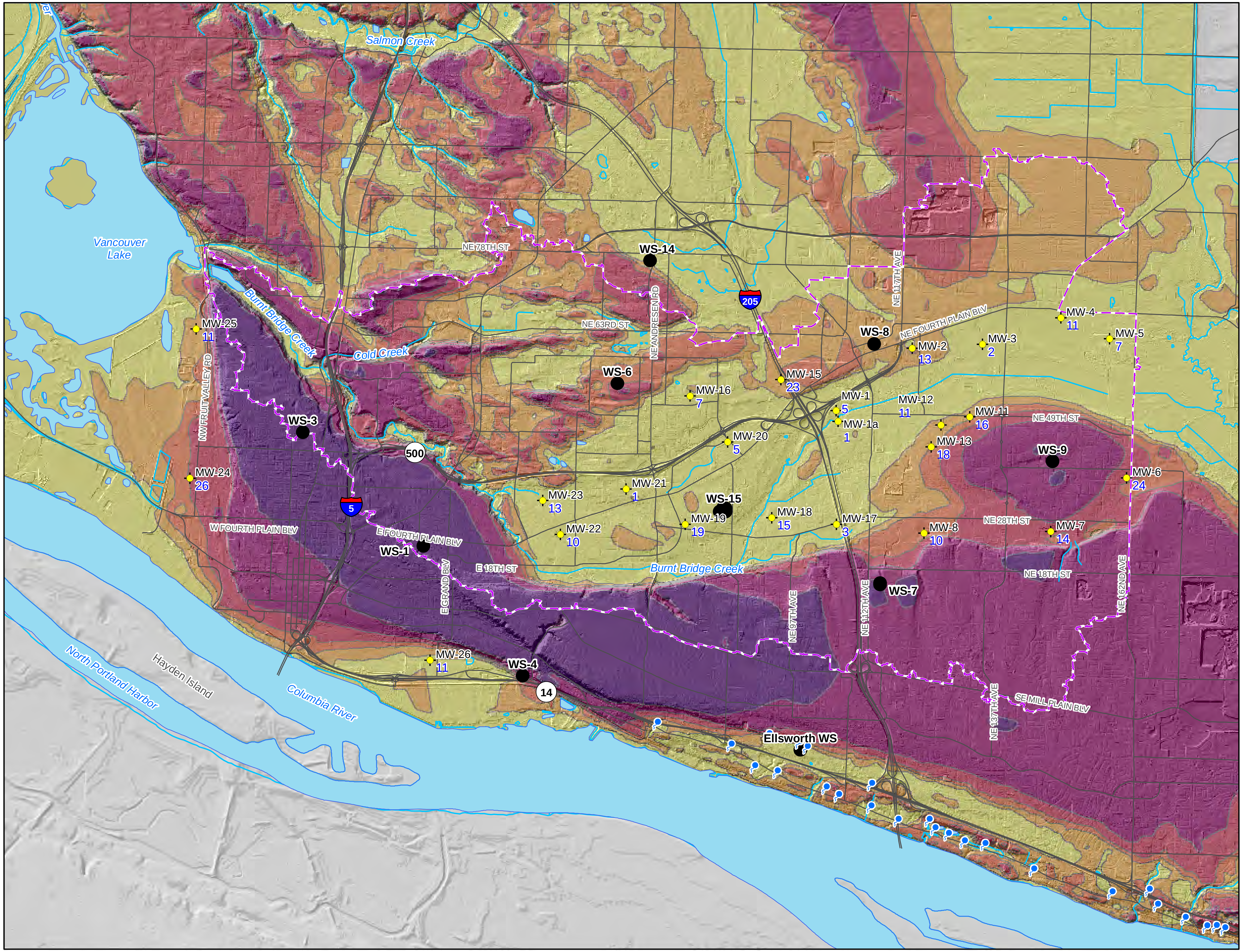
Figure PGG-9.
Depth to Groundwater in USA.



Legend

Depth to Water Table

- 0 - 10 Feet
- 10.01 - 20 Feet
- 20.01 - 30 Feet
- 30.01 - 50 Feet
- 50.01 - 100 Feet
- 100 - 279 Feet
- Springs (from USGS WSP-1600)
- City Monitoring Wells (2017 Minimum)
- BBC Basin
- Vancouver Water Stations

0 2,500 5,000 10,000 Feet

HERRERA PgG

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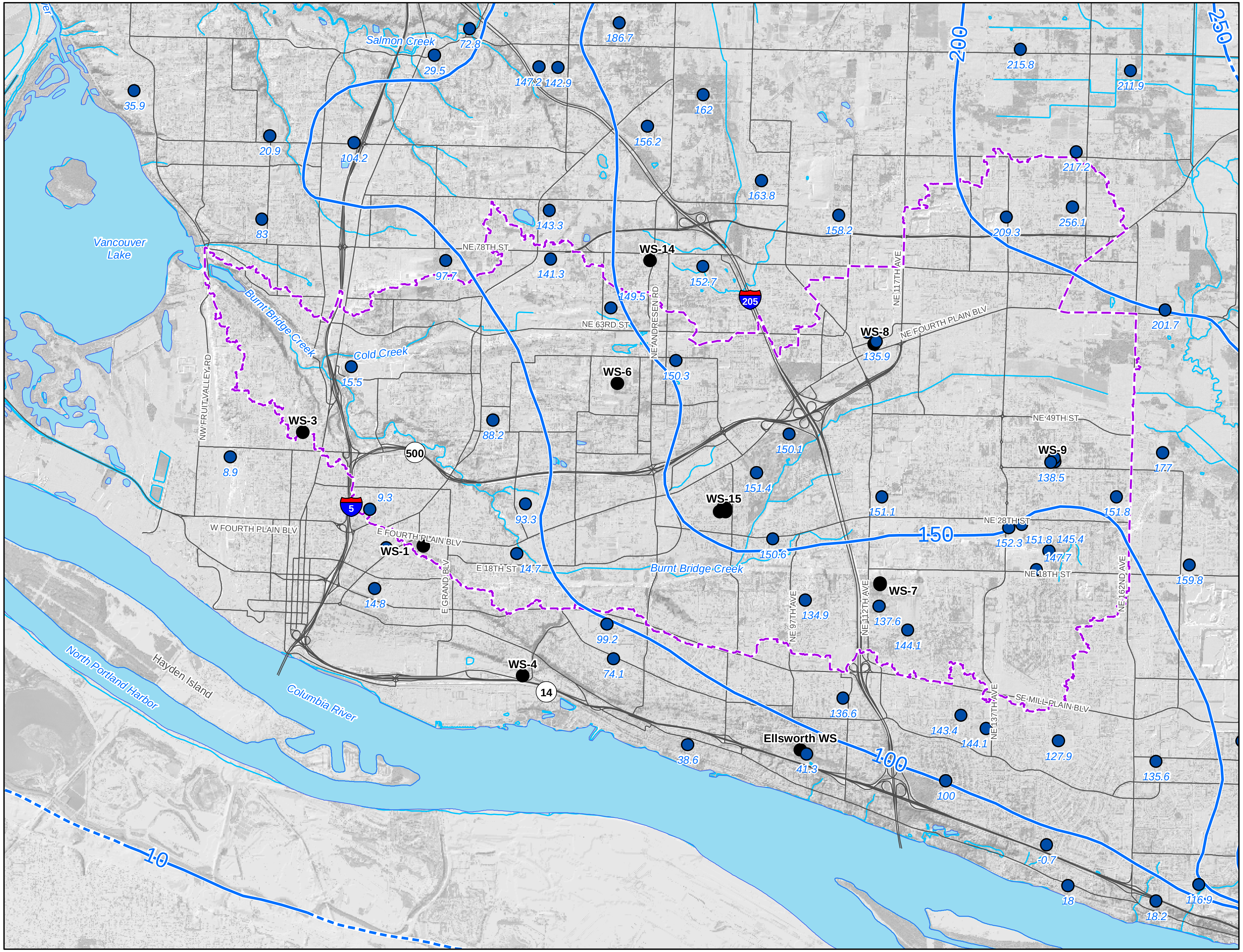
**Figure PGG-10.
Groundwater Elevation Map for
TGA**



Legend

- USGS Wells with Elevations*
- TGA Water Level Elevation Contours*
- BBC Basin
- Vancouver Water Stations

Elevation values in Feet NGVD29
* From USGS WSP-2470-A

N

0 2,500 5,000 10,000 Feet

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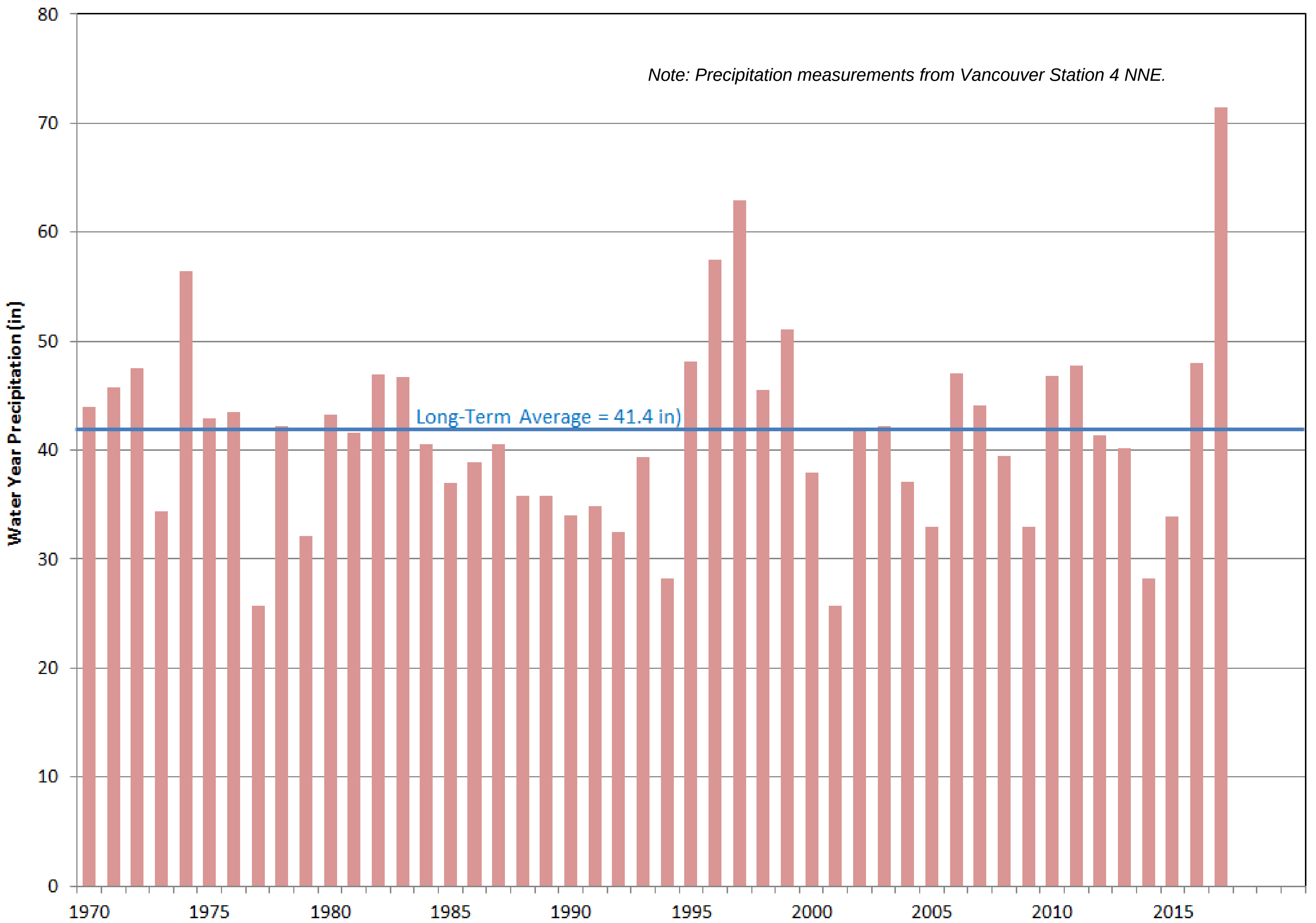

Figure PGG-11
Groundwater Level Trends in the Upper Orchards Area

City of Vancouver
Watershed Health Assessment

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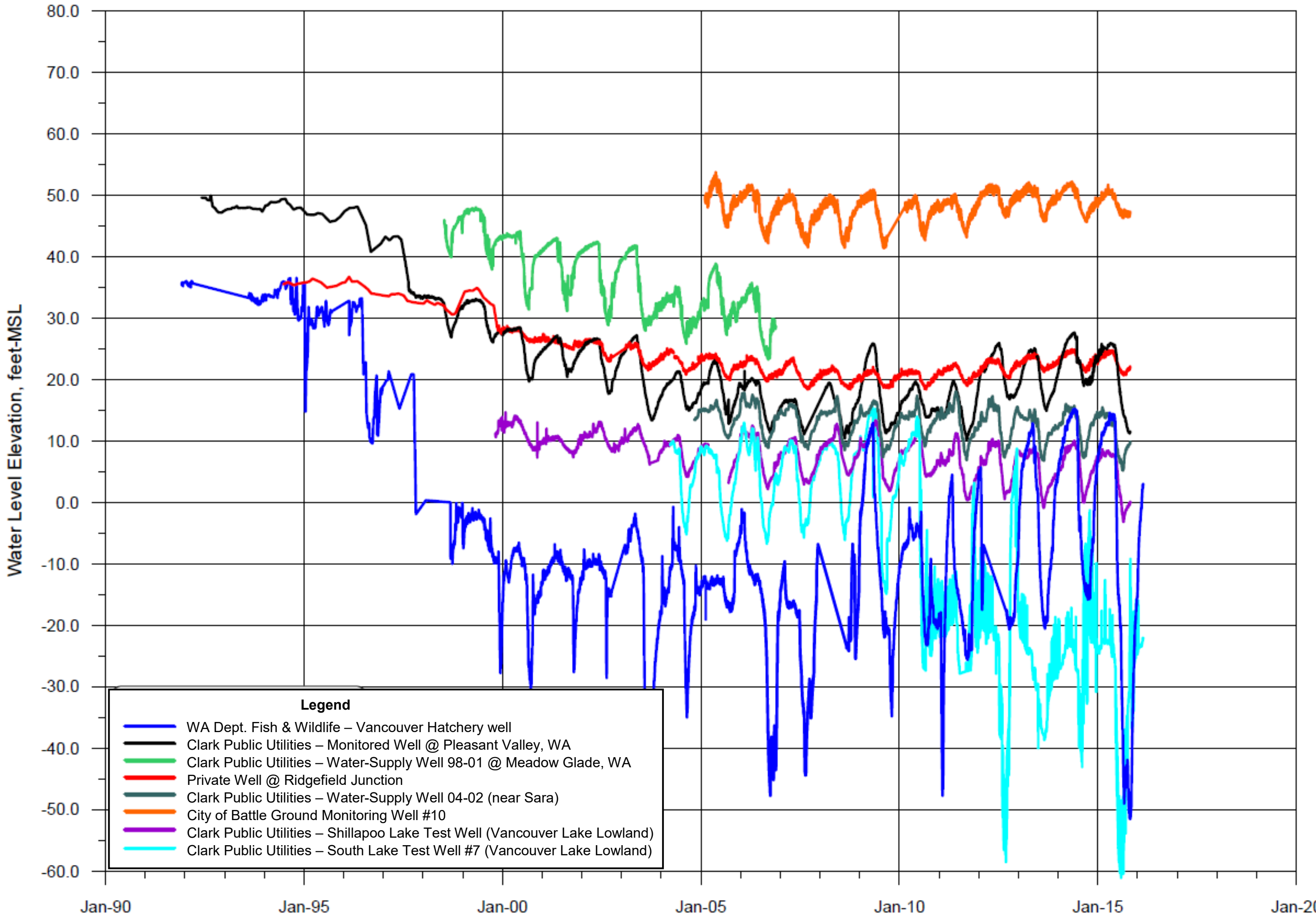

Figure PGG-12
Water-Level Trends in the SGA

City of Vancouver
Watershed Health Assessment

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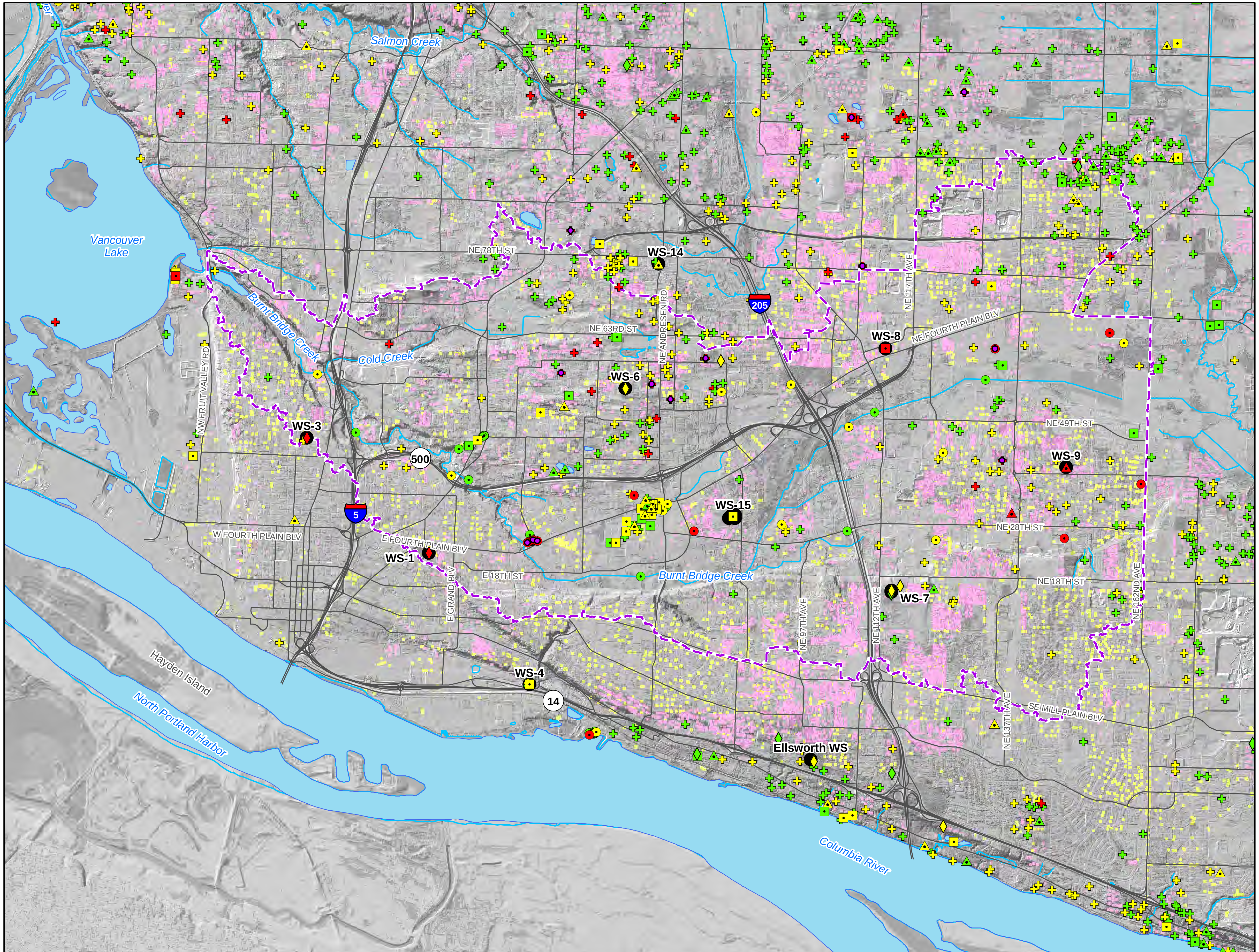
Figure PGG-13.
Maximum Nitrate
Observed in Groundwater



Legend

- Vancouver Water Stations
- BBC Basin
- Septic Systems
- Drywells

Well Depth (feet)

No Data | >200 | 100-200 | 50-100 | 0-50

- < 2.0 mg/l
- 2 - 5 mg/l
- 5 - 10 mg/l
- > 10 mg/l

N

0 | 2,500 | 5,000 | 10,000 Feet

HERRERA | PGG

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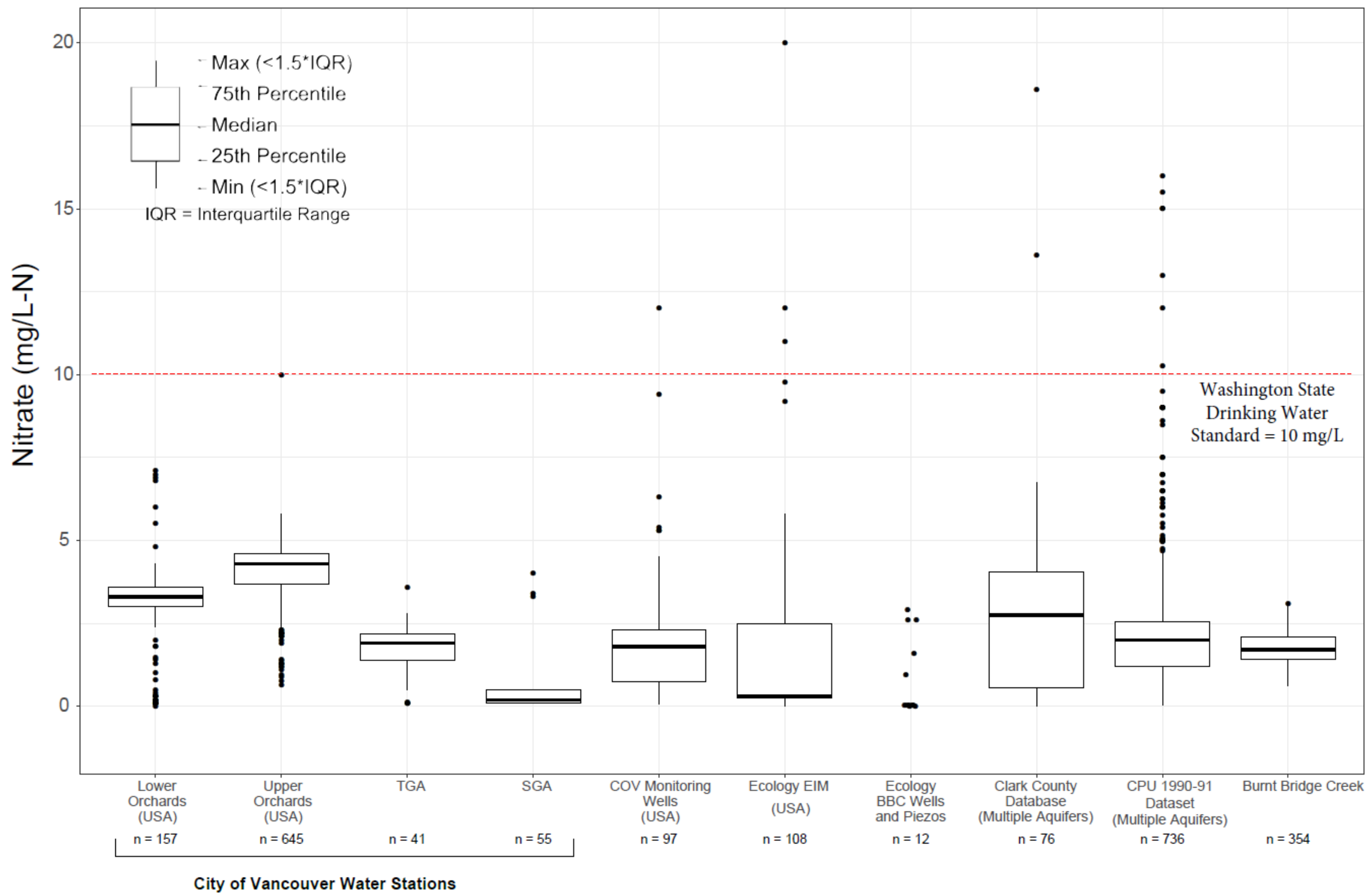

Figure PGG-14.
Nitrate Comparison by Aquifer.

City of Vancouver
Watershed Health Assessment

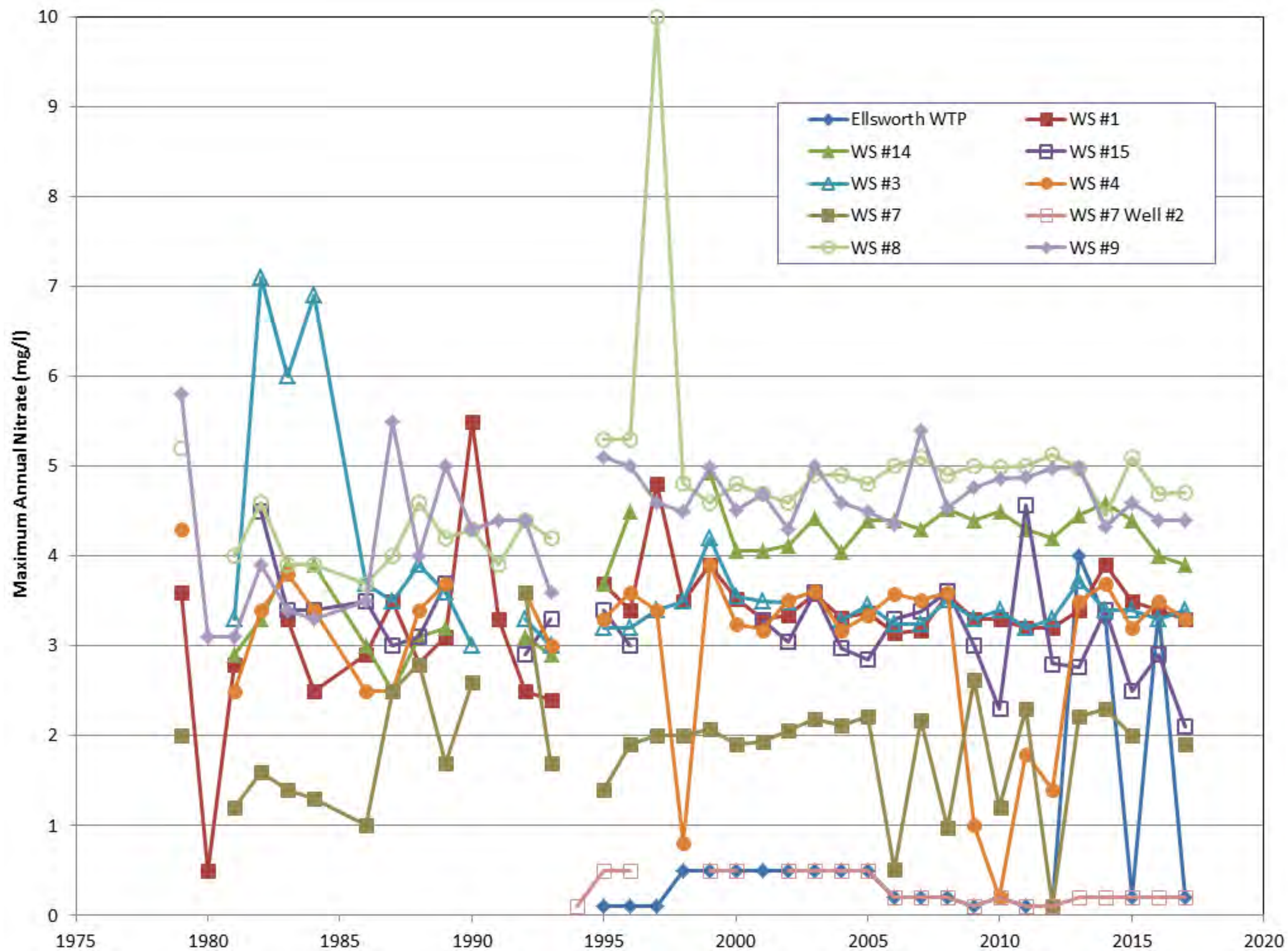

Figure PGG-15.
Nitrate Trends at City Water Stations.

City of Vancouver
Watershed Health Assessment

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PgG

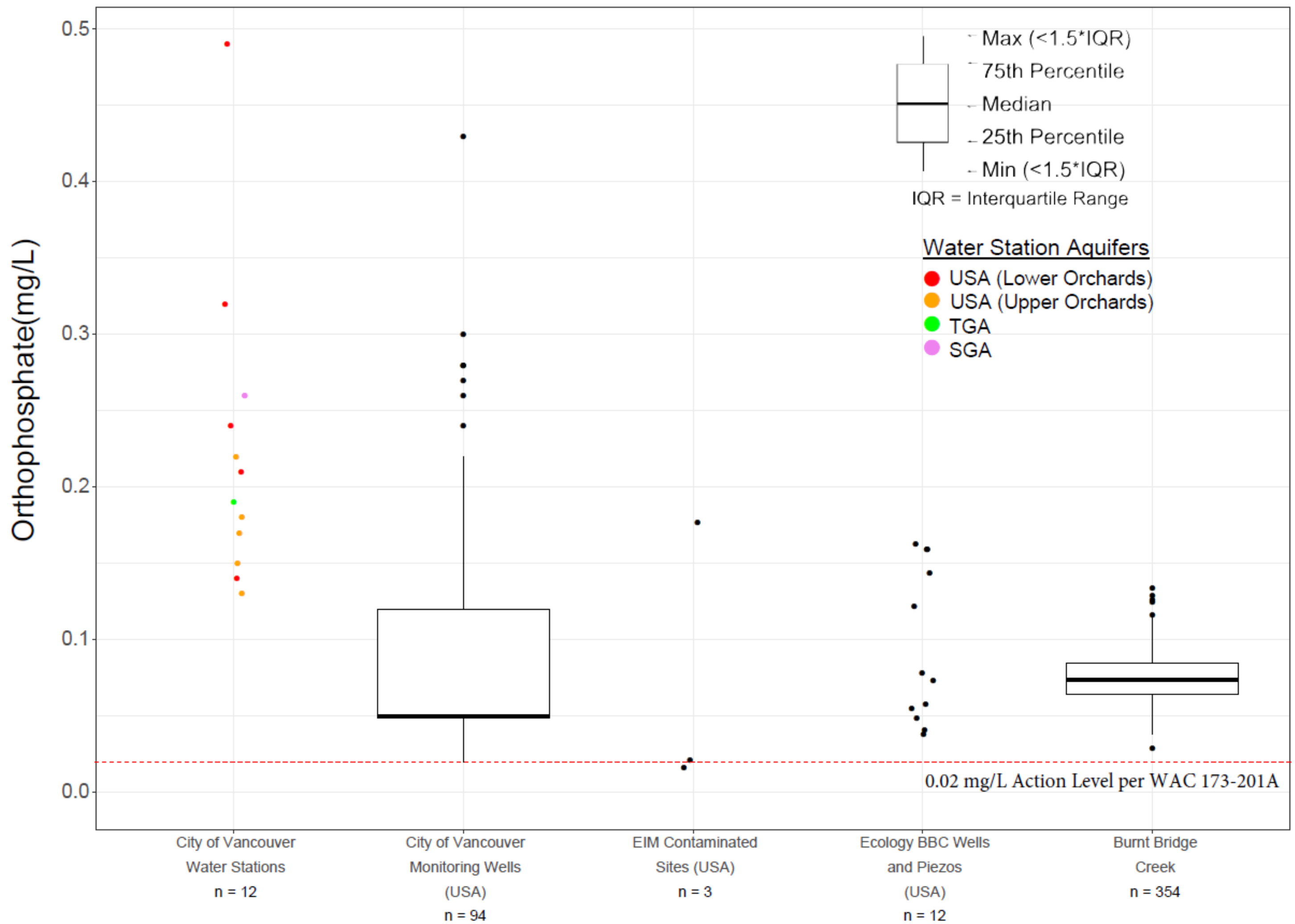

Figure PGG-16.
Phosphorus Comparison by Aquifer.

City of Vancouver
Watershed Health Assessment

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APPENDIX B

GIS Statistical Analysis for the Watershed Health Assessment

GIS STATISTICAL ANALYSIS FOR THE WATERSHED HEALTH ASSESSMENT

This appendix describes the geospatial statistical analyses performed for the City of Vancouver, Washington (City), by Herrera Environmental Consultants, Inc. (Herrera) to evaluate the relationships among land use practices, watershed management activities, and water quality in the Burnt Bridge Creek watershed. The goal of the analyses was to determine if there are statistical correlations between the data selected to represent watershed attributes and water quality. While the analysis described in this appendix was limited in scope, the approach has potential applicability for future efforts. Potential applications include:

- Helping to quantify and compare benefits of stormwater management and stream/wetland restoration activities
- Helping to target watershed activities, areas, and land covers most likely to generate specific pollutants as total maximum daily load (TMDL) plans are developed
- Helping to identify and develop environmental policies and programs that are most effective in protecting and improving surface water and groundwater quality
- Helping to develop strategies for long-term water quality monitoring and GIS data collection that are designed to produce datasets that can be used to analyze effects of watershed activities on water quality
- Characterizing whether water quality trends are due to natural variation or to human-caused changes in land use and watershed management strategies
- Predicting current water quality conditions in other unmonitored river systems

BACKGROUND

The City has a long-term data record on surface water quality in the Burnt Bridge Creek watershed, having monitored ambient water quality from 2011 through 2017 at 11 stations on Burnt Bridge Creek and its tributaries. In addition, the City has been collecting water quality data from its shallow groundwater monitoring network since 2015.

The City also has access to geographic information system (GIS) data, including LiDAR elevation data, the 2011 National Land Cover Database (NLCD), City of Vancouver datasets (septic system locations, stormwater infrastructure and treatment best management practices [BMPs], and riparian plantings), and Clark County datasets (stormwater infrastructure and treatment BMPs). The NLCD database includes land cover (20 classes), percent impervious area, and percent canopy grids with 30-meter pixels for the entire United States.

This combination of spatial (GIS) data and long-term data records on surface and groundwater quality presented an opportunity to assess whether watershed characteristics (landscape conditions such as land use, terrain, and septic system density) and watershed management activities (such as habitat restoration and stormwater treatment) were correlated with water quality. To capitalize on the available data, Herrera conducted statistical analyses of various watershed condition datasets, the City's watershed management efforts, and water quality. The results, indicating which watershed attributes are statistically correlated with improved water quality, can help the City understand those relationships, prioritize its watershed management activities, and improve and prioritize its data collection efforts.

METHODS AND RESULTS

Surface water quality in rivers and streams is highly influenced by nonpoint-source landscape characteristics like topography and land use. Understanding the relationship between stream water quality and land use practices is the important first step in prioritizing watershed management efforts to reduce impacts to the City's surface water. To help further this understanding, Herrera conducted a GIS-based statistical analysis that examined the interrelationships among watershed characteristics and surface water quality in the Burnt Bridge Creek watershed. The goal of this analysis was to test for statistically significant relationships between individual water quality parameters and watershed characteristics, including land use/cover characteristics, stormwater management practices, and restoration efforts.

This section outlines the methods and data used to conduct the analyses and presents the results. Statistical analysis is inherently iterative, and this section is organized to represent that process. First, there is a discussion of three different spatial scales considered. Then, the water quality data are described, followed by descriptions of the data representing watershed characteristics and watershed management practices. Next, the objectives, process, and results of the correlation analysis are presented, followed by a description of the multiple regression analysis and results.

Exploratory Analysis at Three Spatial Scales

Scale is an important consideration when assessing the relationship between watershed characteristics and water quality because potential effects of watershed characteristics on water quality are missed if the watershed scale does not coincide with the area draining to a water quality monitoring station. As a first step, to help determine the appropriate spatial scales for GIS-based statistical analysis, Herrera conducted an exploratory analysis using surface water and groundwater quality parameters at three different spatial scales in the Burnt Bridge Creek watershed. The extents of the three scales (two for surface water; one for groundwater) were selected based on differences in flow patterns and monitoring locations.

Surface Water Analyses

The Burnt Bridge Creek monitoring program includes eleven monitoring stations: eight stations along the main stem of the creek and one station on each of three tributaries near their confluence with the creek. The monitoring stations and their associated subbasin boundaries are shown on Figure B-1. Main stem subbasin boundaries are shown for the land draining between two stations (including a subbasin between the lowermost main stem station and the mouth of Burnt Bridge Creek that was not used in the analysis). The actual land area draining to each main stem station includes all upstream subbasins and tributaries combined.

Water quality data were analyzed at two spatial scales diagrammed in Table B-1:

1. Surface water basin scale: Water quality parameters at each of 11 surface water monitoring stations were analyzed for the entire upstream area draining to each monitoring station.

2. Stream reach scale: Changes in water quality values between the eight main stem monitoring stations were analyzed. Changes in water quality values were calculated as the difference between the parameter median values measured at the upstream monitoring station (considered to be the upstream extent of the reach for the analysis) and the next downstream monitoring station (considered to be the downstream extent of the reach) for the subbasins shown on Figure B-1. For the analysis, each subbasin was assumed to include only the area draining between two monitoring stations—not the entire area upstream.

Table B-1. Example Diagram of Water Quality Values and Subbasin Areas for Statistical Analysis.

Stream Station and Subbasin Number		Basin-Scale		Reach-Scale	
		Station Value	Subbasin Area	Station Value	Subbasin Area
â	❶	1	1	1	1
â	❷	2	1+2	2-1	2
â	❸	3	1+2+3	3-2	3
â	❹	4	1+2+3+4	4-3	4

The basin-scale analysis relates water quality at each monitoring station to watershed attributes for the entire area draining to that station. From upstream to downstream, watershed attributes change incrementally from station to station—in general, the amount and intensity of urban development and the amount of impervious surface increase as Burnt Bridge Creek flows towards Vancouver Lake.

The reach-scale analysis compares the watershed attributes of each drainage area between main stem stations to the *differences* in median water quality values between stations (downstream minus upstream). Between-station attributes were not compared to median values for the downstream station because main stem water quality is affected by the entire upstream subbasin area. The reach-scale analysis was initiated to evaluate potential impacts to stream water quality at a smaller scale from land activities within the immediate upstream area (reach) of each monitoring station.

Groundwater Analysis

The groundwater analysis used data from 11 shallow monitoring wells within the Burnt Bridge Creek watershed that have between 1 and 3 years of quarterly water quality monitoring data. Wells located outside of the watershed were not used because attributes were not assessed for those areas. Monitoring wells with less than 1 year of water quality data were not used because four quarterly samples per well were considered the minimum needed to represent groundwater quality conditions.

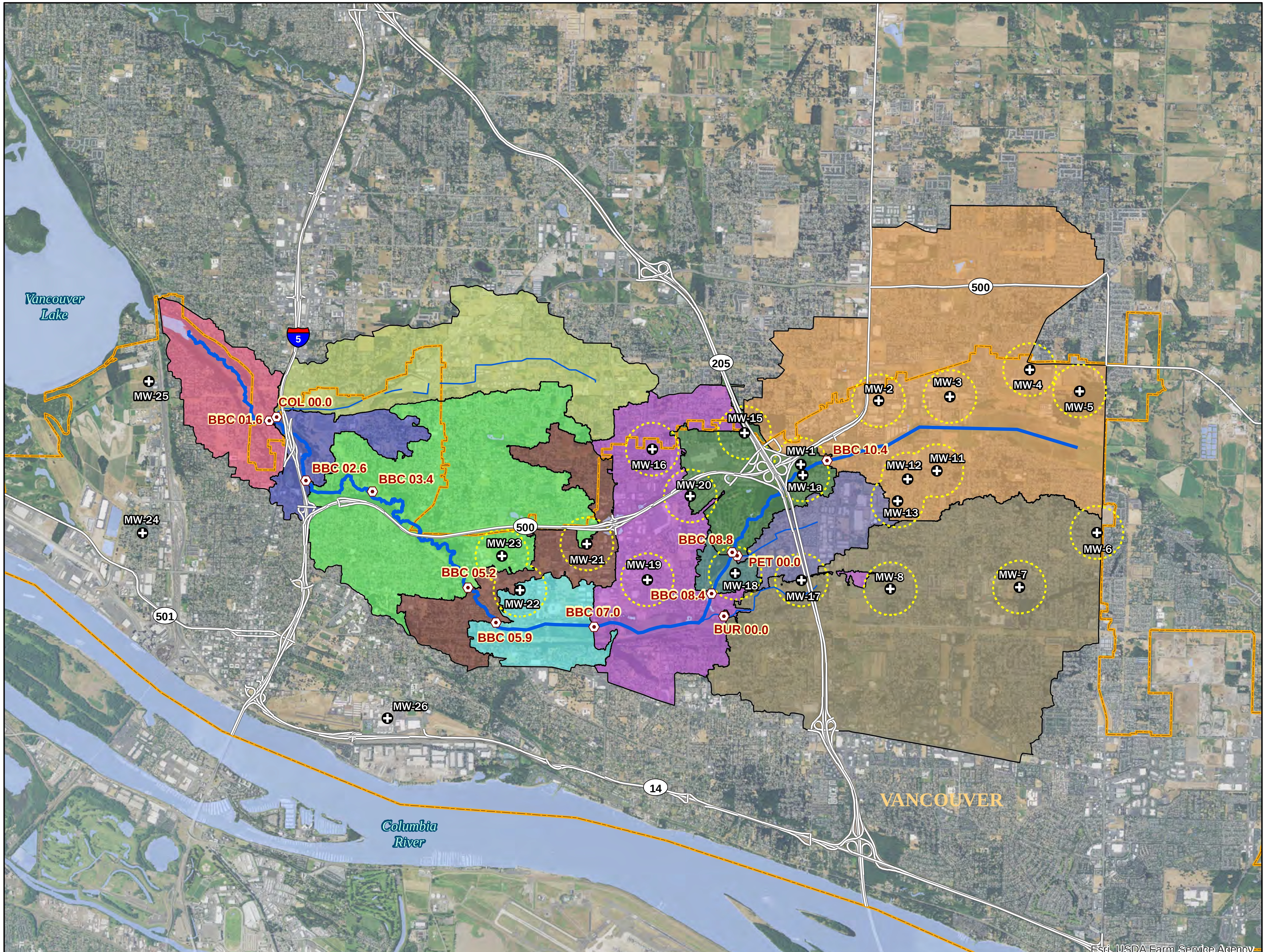
Groundwater basins do not follow surface topography; the limits of the aquifer systems have not been mapped in detail; and groundwater flow rates and directions are not well known. Therefore, Herrera defined a groundwater basin as the area within a reasonable distance from a monitoring well that most likely influences water quality and is large enough to include varied attributes within the well vicinity. Distances of 0.25 mile and 0.5 mile were considered large enough to include varied attributes within the well vicinity. Herrera and PGG selected the area within a 0.25-mile radius around each shallow monitoring well as the optimum area for the groundwater basin analysis because this smaller value would exclude more distant and less influential attributes in the analysis.

Water Quality Parameters

Surface water quality parameters used in the statistical analysis included:

- Base flow median values for 40 samples per station collected from 11 stations in 2011 through 2017 for 10 parameters (all monitoring parameters except conductivity):
  - Temperature (°C)
  - Dissolved oxygen (mg/L)
  - pH
  - Turbidity (nephelometric turbidity units [NTU])
  - Total suspended solids (mg/L)
  - Total phosphorus (mg/L)
  - Soluble reactive phosphorus (orthophosphate) (mg/L)
  - Total nitrogen (mg/L)
  - Nitrate+nitrite nitrogen (mg/L)
  - Fecal coliform bacteria (geometric mean colony-forming units per 100 milliliters [CFU/100 mL])

Figure B-1.
Surface Water and Groundwater Monitoring Stations.



Legend

- Groundwater monitoring well
- Water quality monitoring location
- Groundwater monitoring well 1/4-mile buffer

Subbasin boundary

- BBC 0.0
- BBC 1.6
- BBC 10.4
- BBC 2.6
- BBC 5.2
- BBC 5.9
- BBC 7.0
- BBC 8.4
- BBC 8.8
- BUR 0.0
- COL 0.0
- PET 0.0
- Burnt Bridge Creek
- BBC Tributary
- City limits

N

0 2,500 5,000 10,000 Feet

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- Mean number of days per year exceeding the water quality standard for the 7-day average of the daily maximum temperatures (7-DADMax) using continuous temperature data for eight stations from 2011 through 2017
- Minimum dissolved oxygen concentrations for 2011 through 2017
- Water quality index medians for 2011 through 2017 for eight parameters and the overall index using Ecology's index calculator
- Storm flow median values for five samples per station collected from 11 stations in water year 2013 for nine parameters (all base flow monitoring parameters except field parameters, plus dissolved copper and zinc)
- Base flow temporal trend analysis correlation coefficients for 11 stations in 2011 through 2017 for 10 parameters

All surface water quality parameters included in the Burnt Bridge Creek monitoring program were used in the statistical analysis, with a few exceptions. Conductivity was not used because there is no state standard for conductivity, and it is not a parameter of concern. Field parameters (temperature, dissolved oxygen, and pH) were not used for the storm flow analysis because they are of most concern during base flow, not storm flow. Dissolved copper and zinc were included in the storm flow analysis because they are important parameters and data were available for them in one water year. Median values for the entire monitoring period were used to best represent the central tendency for each monitoring station. The mean number of days exceeding the temperature standard was added because continuous temperature data were available for eight stations. Water quality index medians were added for all available parameters for comparison to analysis of median values. Finally, trend analysis coefficients were added to include a temporal component for each base flow monitoring parameter in the correlation with watershed attributes.

Groundwater quality parameters included:

- Temperature (°C)
- Turbidity (NTU)
- Total suspended solids (mg/L)
- Orthophosphate phosphorus (mg/L)
- Nitrate nitrogen (mg/L)
- Total copper (µg/L)
- Total zinc (µg/L)
- Diesel-range total petroleum hydrocarbons (mg/L)

Median values for between 4 and 12 samples collected from each well were used in the statistical analyses because median values (compared to average/mean values) better represent the central tendency for parameters when the data are skewed and not normally distributed.

Other metals (such as iron and manganese) and organic compounds were not used in the statistical analyses because they were not detected in the groundwater wells or are not a health concern. Data from the City's water supply testing were not included in the statistical analysis because land use impacts would be less evident in deep aquifers than in shallow ones. Data compiled from the Ecology EIM database were not included in the statistical analysis because they primarily include data collected occasionally at contaminated sites that do not necessarily represent typical aquifer conditions.

Watershed Attributes

Watershed attributes used in the statistical analysis included existing watershed characteristics and management efforts for which GIS data were available and which are expected to influence surface water and groundwater quality.

Watershed characteristics (and metrics for each) used in the analysis are listed in Table B-2. Land cover is shown on Figures B-2 and B-3. Septic system density is shown on Figure B-4.

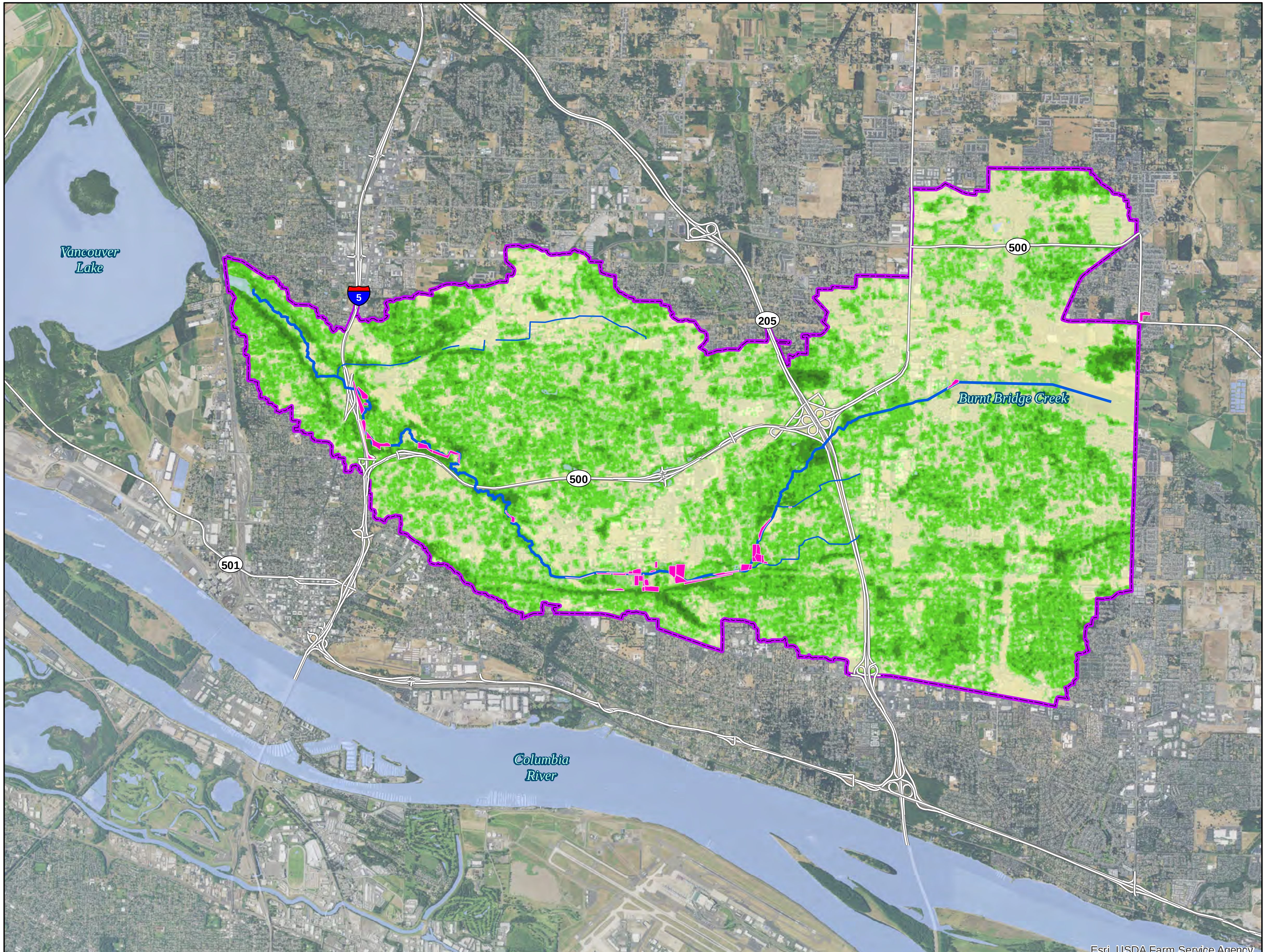
Table B-2. Watershed Characteristics Data Used in the GIS Statistical Analysis.

Watershed Characteristic	Metric
Parcel-based, designated land use in seven categories: · low-density/rural residential · medium-to-high density residential · commercial/business/public use · industrial · park/open space/water · forest · agriculture	Percent cover
Land cover in six categories: · residential · commercial/industrial · agriculture · forest/field/other · tree canopy · impervious	Percent cover
Wellhead protection areas	Percent cover
Average channel slope[a]	Feet per mile
Depth to shallow groundwater table[b]	Feet
Septic system density	Number per acre
Septic system age in three categories: · constructed before 1945 · constructed between 1945 and 1965 · constructed after 1965	Percent
Riparian canopy cover in the riparian buffer (100 feet wide) within 0.50 mile upstream of monitoring station [a]	Percent cover

[a] Used in surface water analysis only

[b] Used in groundwater analysis only

Figure B-2.
Canopy Cover and Riparian Planting Areas.



Legend

- Priority Planting Areas
- Burnt Bridge Creek
- BBC Tributary
- Watershed boundary

Percent Canopy Cover

- 5%
- 5 to 15%
- 15 to 25%
- 25 to 50%
- 50 to 75%
- > 75%

0 2,500 5,000 10,000 Feet

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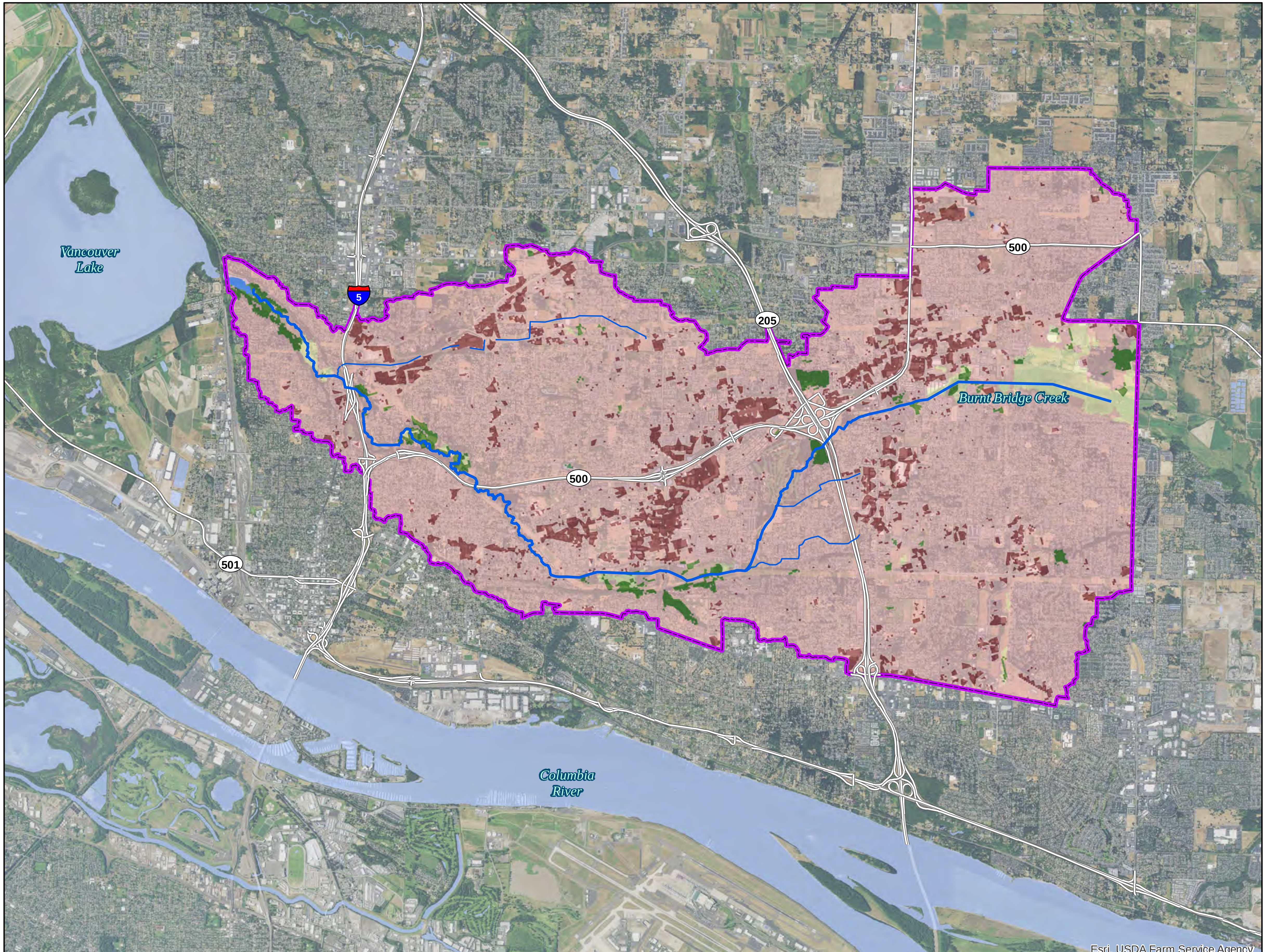
Figure B-3.
Land Cover.



Legend

- Burnt Bridge Creek
- BBC Tributary
- Watershed boundary

Land Cover

- Agriculture
- Commercial/Industrial
- Forest/Field/Other
- Residential
- Water

0 2,500 5,000 10,000 Feet

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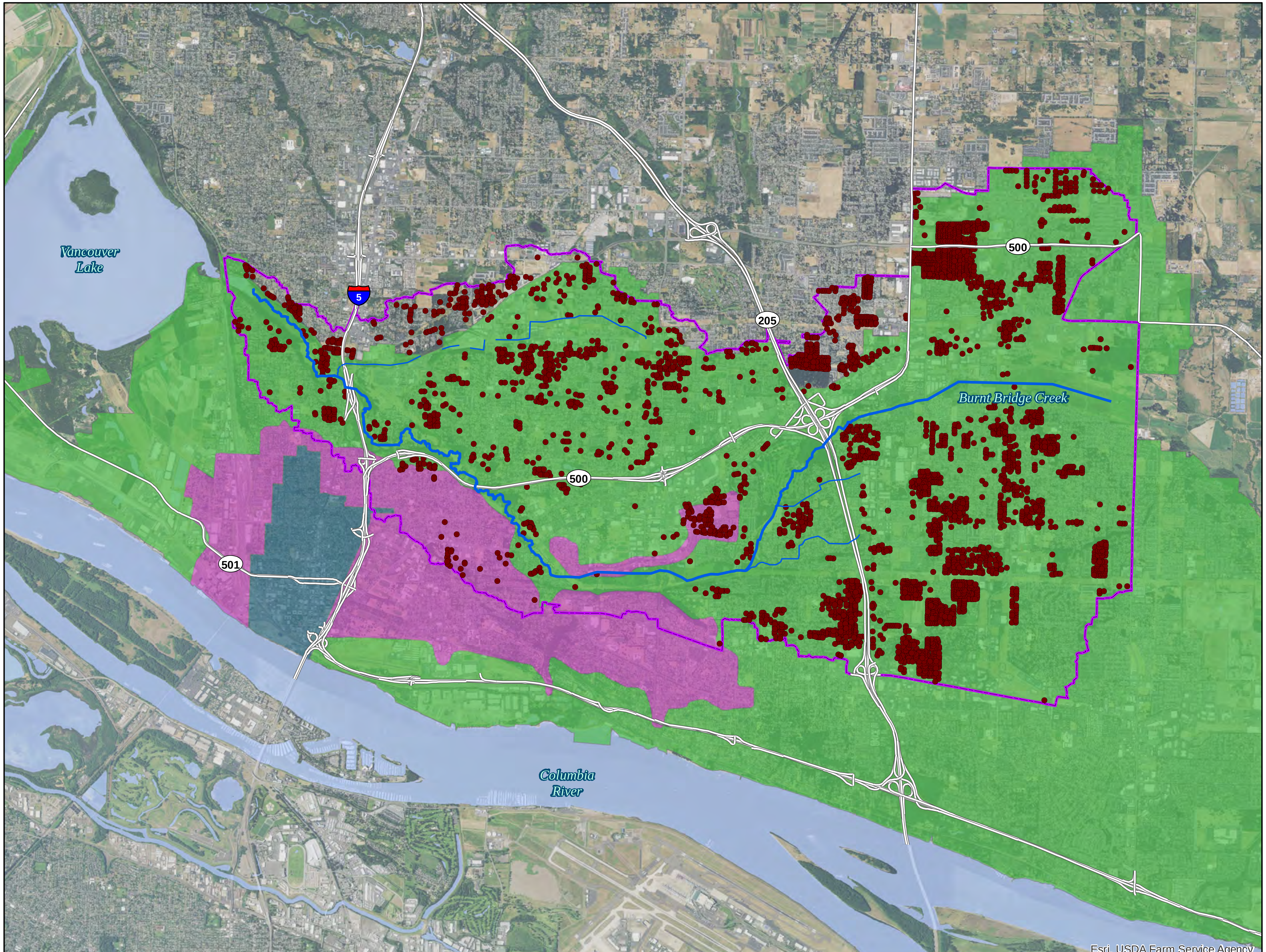
Figure B-4.
Mapped Septic Systems Locations and Approximate Sewer Age.



Legend

- Burnt Bridge Creek
- BBC Tributary
- Septic system
- Watershed boundary

Approximate sewer age

- 1890-1945
- 1945-1965
- After 1965

0 2,500 5,000 10,000 Feet

HERRERA PgG

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The available GIS data from the City and Clark County included 56 categories of land use, which Herrera grouped into the seven categories listed in Table B-2. Preliminary analysis to correlate water quality and land use produced spurious results that did not make sense, likely because the actual land cover did not necessarily reflect the land use category designated for each parcel. Therefore, Herrera replaced the designated land use data in the analysis with land cover data. The 20 classes of land cover in the NLCD database were grouped into the four categories used by Herrera to estimate loadings of toxic chemicals in surface runoff to Puget Sound for Ecology (Herrera 2011). Tree canopy and impervious surface were added as land cover categories because they are known to affect surface water quality.

Watershed restoration and stormwater management efforts (and metrics for each) used in the analysis are listed in Table B-3.

Table B-3. Watershed Restoration and Stormwater Management Efforts Data Used in the GIS Statistical Analysis.

Watershed Restoration/Management Effort	Metric
Stormwater facility density in six categories: · dry well · detention · sedimentation · filtration · infiltration · pond/wetland	Number per acre
Riparian planting density	Number of plantings (herbaceous, lie stakes, shrubs, transplanted, and trees) per acre
Riparian planting area	Acres

The available GIS data from Vancouver and Clark County included 33 categories of stormwater facilities that Herrera grouped into the six categories listed in Table B-3. Facility density was used as the metric, rather than percent of the subbasin served by each facility group, because data on the drainage area for each facility were not available.

Data for other City restoration and management efforts were not included because either there was minimal variability within the watershed (as was the case for catch basin/pipe cleaning and street sweeping) or GIS data were not available (as was the case for septic system failures/repairs, sanitary sewer leaks/repairs, septic-sewer connections, illicit discharges, eliminated, stormwater conveyance improvements, stream culvert replacements, recent capital projects, contributing area to stormwater BMPs, and riparian restoration/maintenance area).

Correlation Analysis

The two objectives of the correlation analysis were:

1. To determine whether there are statistically significant relationships between water quality (as indicated by the parameters specified above) and watershed attributes affecting water quality

2. If such relationships exist, to assess whether the relationships are positive (i.e., when the value of the watershed attribute increases, the value of the watershed quality parameter also increases) or negative (i.e., when the value of the watershed attribute increases, the value of the water quality parameter decreases, or vice versa)

Assessing the relationships between watershed attributes and water quality parameters was an iterative process for the three spatial scales (i.e., surface water basins, stream reaches, and groundwater basins). The correlation analysis consisted of three steps. Each step and its results are described below.

Step 1

For the first step of the analysis, Herrera generated a correlation matrix to determine if statistically significant relationships exist between individual watershed attributes and water quality parameters. The correlations could be either positive or negative. Relationships between attributes do not necessarily indicate cause and effect.

No statistically significant relationships were found at the stream reach or groundwater basin scales between any of the watershed attributes and water quality parameters considered. Therefore, no further analysis was completed for those datasets. As noted above, land use data were replaced with land cover data in this step to better represent existing conditions in the watershed.

Table B-4 presents values for each water quality parameter and watershed attribute used in the stream basin-scale correlation analysis. Table B-5 presents the Pearson's correlation coefficients (r) from this analysis with the significant correlations ($p < 0.05$) shown in red, where the r values represent the strength of the correlation up to a maximum value of 1.0 for positive correlations or a minimum value of -1.0 for negative correlations.

Table B-4. Water Quality and Watershed Attribute Values for the Basin-Scale Correlation Analysis.

	BBC10.4	BBC8.8	BBC8.4	BBC7.0	BBC5.9	BBC5.2	BBC2.6	BBC1.6	PET0.0	BUR0.0	COL0.0
Basin Area (acres)	4398	5784	9989	11870	12388	13177	15477	17566	483	4064	1795
Temp Median (°C)	13.9	15.7	16.0	17.1	16.3	16.5	16.6	16.5	16.7	14.6	13.5
DO Base Median (mg/L)	6.9	9.9	8.4	9.0	7.5	9.2	9.5	9.5	8.7	9.3	10.3
pH Base Median (Value)	6.7	7.5	7.4	7.5	7.5	7.7	7.9	8.0	7.4	7.5	8.0
Turb Base Median (NTU)	1.4	2.4	2.0	3.0	1.7	1.9	1.9	2.1	1.0	0.9	1.7
TSS Base Median (mg/L)	2.6	7.9	6.5	10.4	3.8	5	4.3	5.4	3.4	1.6	3.2
SRP Base Median (mg/L)	0.06	0.05	0.08	0.08	0.08	0.08	0.08	0.08	0.12	0.06	0.08
TP Base Median (mg/L)	0.07	0.08	0.11	0.12	0.1	0.1	0.1	0.11	0.15	0.07	0.1
NO3 Base Median (mg/L)	2.56	2.36	1.81	1.51	1.42	1.51	1.51	1.51	1.28	2.34	1.71
TN Base Median (mg/L)	3.08	2.85	2.2	1.86	1.63	1.72	1.78	1.75	1.47	2.79	1.81
Fecal BaseGeomean (CFU/100mL)	101	91	98	134	166	175	202	297	134	287	306
DO Base Minimum (mg/L)	4.9	8.2	6.8	5.4	4.9	5.3	5	4.9	7.5	8.1	5.8
Temp Index (Value)	87	79	78	67	74	74	74	73	77	85	89
DO Index (Value)	53	88	75	69	55	78	76	78	79	84	86
pH Index (Value)	72	94	97	94	97	96	92	91	95	95	90
Turb Index (Value)	95	91	93	88	93	93	92	90	97	95	89
TSS Index (Value)	95	79	83	75	90	87	87	83	91	90	89
TP Index (Value)	78	64	45	38	48	47	47	44	21	75	50
TN Index (Value)	1	2	10	37	49	44	44	44	64	1	39
Fecal Index (Value)	76	76	75	71	66	67	67	59	69	57	60
WQ Index (Value)	61	70	51	42	46	52	48	42	61	66	49
Turb StormMedian (NTU)	7.9	7.8	no data	no data	5.2	5.5	6.5	6.2	2.7	5.2	7.3
TSS StormMedian (mg/L)	14	11	no data	no data	14.5	18	39	40	6.3	9.5	42
SRP StormMedian (mg/L)	0.08	0.07	no data	no data	0.07	0	0.05	0.05	0.07	0.03	0.03
TP StormMedian (mg/L)	0.16	0.13	no data	no data	0.15	0.14	0.15	0.14	0.09	0.08	0.15
NO3 StormMedian (mg/L)	1.92	1.63	no data	no data	0.96	0.97	1	0.98	1.15	1.3	0.4
TN StormMedian (mg/L)	2.4	2.3	no data	no data	1.4	1.3	1.4	1.3	1.4	1.6	0.7
Fecal StormGeomean (CFU/100mL)	567	360	no data	no data	359	605	674	945	700	1472	531
DCu StormMedian (ug/L)	1.1	1.5	no data	no data	1.6	1.7	1.5	1.6	2	1.6	2
DZn StormMedian (ug/L)	5	14	no data	no data	9	15	8	10	15	23	23
Temp 11-17Trend (tau)	not sig.	not sig.	not sig.	-0.24	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.
DO 11-17Trend (tau)	not sig.	not sig.	not sig.	not sig.	-0.37	-0.24	not sig.	not sig.	not sig.	-0.23	-0.24
pH 11-17Trend (tau)	-0.44	-0.42	-0.28	not sig.	not sig.	not sig.	not sig.	not sig.	0.27	-0.31	not sig.
Turb 11-17Trend (tau)	not sig.	not sig.	not sig.	-0.23	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.
TSS 11-17Trend (tau)	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	0.27	not sig.	not sig.
SRP 11-17Trend (tau)	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.
TP 11-17Trend (tau)	-0.26	-0.30	not sig.	-0.24	-0.36	-0.34	-0.28	not sig.	0.33	not sig.	0.28
NO3 11-17Trend (tau)	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.
TN 11-17Trend (tau)	0.29	not sig.	not sig.	not sig.	-0.29	-0.25	-0.39	-0.25	-0.28	not sig.	not sig.
Fecal 11-17Trend (tau)	0.35	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	not sig.	0.21	not sig.	not sig.
Residential Land Use	80%	81%	87%	86%	85%	85%	87%	86%	83%	94%	86%
Commercial/ Industrial Land Use	9%	10%	8%	9%	9%	10%	9%	9%	17%	5%	13%
Agriculture Land Use	9.0%	7.0%	4.0%	3.0%	3.0%	3.0%	3.0%	3.0%	0.0%	0.3%	0.2%
Forest/ Field/Other Land Use	2.0%	2.0%	1.0%	2.0%	2.0%	2.0%	2.0%	2.0%	0.1%	1.0%	0.3%
Tree Canopy Cover	12%	13%	16%	16%	16%	16%	16%	16%	16%	19%	16%
Impervious Surface Cover	44%	45%	46%	47%	46%	47%	46%	46%	55%	47%	44%
Wellhead Protection Area (% Cover)	49%	47%	37%	35%	36%	37%	39%	38%	25%	21%	25%
Slope Total (feet/mile)	1.63	4.72	5.24	4.94	4.95	7.53	13.4	14.4	42.3	235	163
Upstream Riparian Canopy (0.5 mi.)	25%	52%	38%	53%	34%	40%	46%	56%	46%	28%	56%
Urban Development Cover	44%	45%	46%	47%	46%	47%	46%	46%	55%	47%	44%
Agricultural Land Cover	9.0%	7.0%	4.0%	3.0%	3.0%	3.0%	3.0%	3.0%	0.0%	0.3%	0.2%
Septic System Density (No./acre)	0.31	0.266	0.302	0.278	0.267	0.255	0.238	0.227	0.172	0.356	0.168
Sewer System Age: After 1965	89%	91%	95%	93%	91%	90%	88%	86%	100%	100%	64%
Sewer System Age: 1945 - 1965	0.00%	0.00%	0.00%	3.00%	4.00%	6.00%	8.00%	8.00%	0.00%	0.00%	0.00%
Sewer System Age: Before 1945	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.05%	0.04%	0.00%	0.00%	0.00%
Drywell (No./acre)	0.178	0.147	0.167	0.158	0.160	0.158	0.156	0.147	0.027	0.199	0.085
Detention (No./acre)	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Infiltration (No./acre)	0.020	0.017	0.011	0.010	0.009	0.009	0.009	0.011	0.012	0.002	0.023
Filtration (No./acre)	0.067	0.056	0.039	0.036	0.035	0.034	0.036	0.039	0.002	0.016	0.070
Sedimentation (No./acre)	0.033	0.026	0.026	0.025	0.025	0.024	0.025	0.025	0.001	0.027	0.027
Pond/Wetland (No./acre)	0.005	0.004	0.003	0.003	0.003	0.003	0.004	0.007	0.002	0.001	0.027
Riparian Planting Density (No./acre)	16.8	14.3	17.2	195.4	349	334	328	317	31.5	0.001	0.001
Riparian Planting Area (acres)	2.3	2.5	5.5	31.8	42.7	42.7	63	69	0.20	0.001	0.001

not sig. = no significant temporal trend observed from 2011-2017 using Kendall's Tau corrleation test (a = 0.05)

Table B-5. Pearson's r Correlation Coefficients from the Basin-Scale Correlation Analysis.

	Residential Land Use	Commercial/ Industrial Land Use	Agriculture Land Use	Forest/ Field/Other Land Use	Tree Canopy Cover	Impervious Surface Cover	Wellhead Protection Area (% Cover)	Slope Total (feet/mile)	Upstream Riparian Canopy (0.5 miles)*	Urban Development Cover*	Agricultural Land Cover*	Septic System Density (No./acre)*	Sewer System Age: After 1965*	Sewer System Age: 1945 - 1965*	Sewer System Age: Before 1945*	Drywell (No./acre)*	Detention (No./acre)*	Infiltration (No./acre)*	Filtration (No./acre)*	Sedimentation (No./acre)*	Pond/Wetland (No./acre)*	Riparian Planting Density (No./acre)*	Riparian Planting Area (acres)*
Temp Median (°C)	-0.056	0.166	-0.145	0.301	0.171	0.521	0.108	-0.574	0.742	0.610	-0.145	-0.226	0.495	0.651	0.433	-0.151	-0.504	-0.665	-0.680	-0.727	-0.597	0.696	0.652
DO Base Median (mg/L)	0.362	0.100	-0.457	-0.286	0.365	-0.046	-0.349	0.382	0.759	-0.299	-0.457	-0.384	-0.380	0.117	0.264	-0.234	-0.701	0.017	0.023	-0.075	0.433	-0.090	0.049
pH Base Median (Value)	0.448	0.059	-0.607	-0.117	0.543	-0.053	-0.376	0.190	0.751	-0.341	-0.667	-0.503	-0.447	0.547	0.513	-0.196	-0.818	-0.168	-0.080	-0.079	0.414	0.427	0.520
Turb Base Median (NTU)	-0.390	-0.090	0.438	0.625	-0.434	-0.520	0.645	-0.564	0.684	-0.323	0.438	-0.200	-0.395	0.481	0.368	0.170	-0.203	0.299	0.527	0.368	0.164	0.434	0.494
TSS Base Median (mg/L)	-0.472	0.107	0.388	0.469	-0.434	-0.146	0.570	-0.593	0.604	0.075	0.388	-0.226	-0.057	0.289	0.201	-0.035	-0.314	0.192	0.227	0.010	-0.091	0.256	0.294
SRP Base Median (mg/L)	-0.051	0.765	-0.671	-0.556	0.301	0.810	-0.481	-0.115	0.268	0.714	-0.611	-0.517	0.091	0.150	0.094	-0.800	-0.313	-0.093	-0.582	-0.864	0.021	0.190	0.134
TP Base Median (mg/L)	-0.159	0.812	-0.542	-0.481	0.207	0.794	-0.370	-0.233	0.478	0.838	-0.542	-0.803	0.071	0.195	0.154	-0.848	-0.427	-0.033	-0.536	-0.891	0.022	0.214	0.188
NO3 Base Median (mg/L)	-0.070	-0.504	0.603	0.194	-0.401	-0.495	0.342	0.251	-0.444	-0.305	0.603	0.699	0.091	-0.566	-0.338	0.541	0.591	0.226	0.450	0.592	-0.068	-0.733	-0.564
TN Base Median (mg/L)	-0.085	-0.525	0.637	0.249	-0.413	-0.455	0.386	0.191	-0.471	-0.233	0.747	0.735	0.181	-0.527	-0.301	0.566	0.595	0.167	0.393	0.564	-0.168	-0.593	-0.523
Fecal BaseGeomean (CFU/100mL)	0.761	-0.245	-0.659	-0.304	0.720	-0.185	-0.625	0.661	0.298	-0.570	-0.659	0.823	-0.431	0.258	0.328	0.052	-0.424	-0.219	-0.042	0.175	0.497	0.108	0.245
DO Base Minimum (mg/L)	0.196	0.096	-0.211	-0.465	0.189	0.390	-0.366	0.471	0.037	0.306	-0.211	0.153	0.417	-0.650	-0.434	-0.198	-0.304	-0.157	-0.361	-0.363	-0.194	-0.682	-0.672
Temp Index (Value)	0.058	-0.037	0.062	-0.464	-0.135	-0.322	-0.214	0.632	-0.245	-0.434	0.062	0.179	-0.375	-0.775	-0.498	0.009	0.472	0.506	0.473	0.336	0.534	-0.831	-0.789
DO Index (Value)	0.356	0.161	-0.471	-0.421	0.377	0.165	-0.432	0.460	0.635	-0.081	-0.471	-0.292	-0.143	-0.097	0.074	-0.298	-0.656	-0.055	-0.154	-0.243	0.268	-0.295	-0.175
pH Index (Value)	0.451	0.083	-0.653	-0.171	0.657	0.396	-0.498	0.164	0.345	0.176	-0.653	-0.215	0.212	0.242	0.016	-0.200	-0.952	-0.570	-0.593	-0.442	-0.164	0.338	0.236
Turb Index (Value)	-0.007	0.121	-0.029	-0.230	0.075	0.660	-0.181	0.020	-0.696	0.731	-0.029	0.321	0.788	-0.350	-0.362	-0.083	0.322	-0.381	-0.633	-0.481	-0.657	-0.240	-0.363
TSS Index (Value)	0.048	0.090	-0.096	-0.330	0.061	0.175	-0.264	0.220	-0.689	0.110	-0.096	0.146	0.078	-0.318	-0.321	-0.052	0.570	0.031	-0.099	-0.058	0.014	-0.208	-0.316
TP Index (Value)	0.123	-0.755	0.557	0.378	-0.244	-0.701	0.334	0.279	-0.549	-0.542	0.557	0.824	0.002	-0.331	-0.225	0.787	0.544	0.070	0.495	0.819	-0.050	-0.362	-0.321
TN Index (Value)	-0.032	0.616	-0.571	-0.270	0.314	0.544	-0.332	-0.275	0.423	0.365	-0.571	-0.759	-0.112	0.477	0.281	-0.637	-0.484	-0.117	-0.419	-0.647	0.108	0.547	0.475
Fecal Index (Value)	-0.848	0.242	0.779	0.342	-0.869	-0.005	0.746	-0.675	-0.179	0.401	0.779	0.065	0.218	-0.255	-0.237	-0.036	0.529	0.432	0.287	-0.018	-0.310	-0.174	-0.251
WQ Index (Value)	-0.114	-0.031	0.271	-0.195	-0.230	0.182	0.037	0.241	-0.329	0.304	0.271	0.427	0.477	-0.757	-0.557	0.048	0.231	0.034	-0.095	-0.098	-0.327	-0.763	-0.785
Turb StormMedian (NTU)	-0.281	-0.396	0.672	0.479	-0.584	-0.911	0.628	-0.108	0.092	-0.715	0.672	0.232	-0.562	-0.031	0.115	0.475	0.430	0.575	0.924	0.845	0.404	-0.141	-0.025
TSS StormMedian (mg/L)	0.161	-0.017	-0.187	0.069	0.111	-0.439	-0.004	0.020	0.603	-0.591	-0.187	-0.455	-0.759	0.565	0.695	-0.045	-0.197	0.258	0.418	0.307	0.644	0.365	0.549
SRP StormMedian (mg/L)	-0.558	0.190	0.484	0.096	-0.575	0.102	0.423	-0.410	-0.120	0.381	0.484	0.014	0.242	-0.292	0.000	-0.144	0.433	0.304	0.097	-0.135	-0.229	-0.236	-0.190
TP StormMedian (mg/L)	-0.497	-0.070	0.541	0.565	-0.577	-0.686	0.664	-0.556	0.130	-0.485	0.541	-0.156	-0.626	0.395	0.266	0.220	0.370	0.541	0.774	0.576	0.375	0.426	0.423
NO3 StormMedian (mg/L)	-0.397	-0.283	0.765	0.394	-0.583	-0.045	0.593	-0.295	-0.542	0.334	0.765	0.633	0.583	-0.338	-0.199	0.395	0.665	0.025	0.066	0.179	-0.609	-0.345	-0.322
TN StormMedian (mg/L)	-0.462	-0.299	0.837	0.476	-0.661	-0.158	0.688	-0.359	-0.462	0.251	0.837	0.609	0.498	-0.320	-0.191	0.422	0.620	0.098	0.181	0.257	-0.555	-0.312	-0.295
Fecal StormGeomean (CFU/100mL)	0.810	-0.453	-0.444	-0.240	0.695	0.184	-0.556	0.676	-0.252	-0.041	-0.444	0.429	0.364	0.007	0.171	0.280	-0.135	-0.627	-0.499	-0.009	-0.227	-0.162	-0.029
DCu StormMedian (ug/L)	0.255	0.636	-0.856	-0.764	0.545	0.534	-0.770	0.373	0.553	0.147	-0.856	-0.718	-0.242	-0.098	-0.160	-0.760	-0.718	-0.013	-0.378	-0.655	0.422	-0.075	-0.129
DZn StormMedian (ug/L)	0.574	0.081	-0.679	-0.696	0.603	0.129	-0.788	0.853	0.200	-0.260	-0.679	-0.103	-0.201	-0.450	-0.415	-0.237	-0.507	-0.083	-0.161	-0.147	0.421	-0.486	-0.502
Temp 11-17Trend (tau)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
DO 11-17Trend (tau)	-0.431	0.236	0.404	0.090	-0.492	0.186	0.432	-0.381	0.284	0.406	0.404	-0.156	0.181	0.047	0.456	-0.201	0.304	0.257	0.038	-0.203	-0.193	-0.212	0.019
pH 11-17Trend (tau)	0.098	0.637	-0.710	-0.436	0.444	0.640	-0.505	-0.097	0.419	0.389	-0.710	-0.756	-0.074	0.379	0.237	-0.695	-0.538	-0.173	-0.519	-0.725	0.129	0.419	0.364
Turb 11-17Trend (tau)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TSS 11-17Trend (tau)	-0.205	0.784	-0.386	-0.649	0.083	0.942	-0.392	-0.052	0.111	0.856	-0.386	-0.493	0.400	-0.299	-0.188	-0.809	-0.125	-0.026	-0.630	-0.955	-0.198	-0.273	-0.313
SRP 11-17Trend (tau)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TP 11-17Trend (tau)	0.204	0.589	-0.664	-0.919	0.355	0.495	-0.731	0.549	0.388	0.147	-0.664	-0.565	-0.220	-0.391	-0.110	-0.741	-0.220	0.206	-0.241	-0.559	0.485	-0.514	-0.411
NO3 11-17Trend (tau)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
TN 11-17Trend (tau)	-0.237	-0.209	0.523	-0.048	-0.486	-0.449	0.238	0.271	-0.382	-0.332	0.523	0.431	-0.167	-0.705	-0.516	0.266	0.731	0.526	0.587	0.504	0.235	-0.739	-0.698
Fecal 11-17Trend (tau)	-0.551	0.313	0.435	-0.137	-0.559	0.240	0.266	-0.239	-0.456	0.441	0.435	0.066	0.225	-0.435	-0.273	-0.191	0.841	0.383	0.078	-0.163	-0.160	-0.427	-0.431

Red values are significant at $p<0.05$.

NC = Not calculable due to less than two stations with significant temporal trends.

Step 2

In the second step of the analysis, Herrera generated a separate correlation matrix to determine if statistically significant relationships exist between two or more watershed attributes. This may indicate that more than one watershed attribute represents the same underlying landscape characteristic, such as the relationship between industrial land use and impervious area (both represent urban development).

Table B-6 presents results of the correlation analysis among the watershed characteristics and restoration/stormwater management efforts. In this table, arrows are used to show positive (↑) and negative (↓) correlations and only the significant relationships are highlighted in yellow. Relationships are considered statistically significant if the p value (i.e., the statistical significance of the model results) is less than 0.05.

Significant correlations observed include:

- Agriculture was positively correlated with forest/field/other and negatively correlated with residential and tree canopy. This means that as the percent of agriculture land cover in a watershed increases, the percent of forest/field/other land cover also increases and the percent of residential land cover and tree canopy decreases. (Agriculture often overlaps with field cover, but not with forest cover or tree canopy cover.)
- Commercial/industrial was positively correlated with impervious. This means that as the percent of commercial/industrial land cover increases, so does the percent of impervious surface.
- Forest/field/other was positively correlated with riparian planting density and negatively correlated with channel slope. This means that as the percent of forest/field/other land cover increases, the density of riparian planting increases and channel slope decreases.
- Tree canopy was positively correlated with residential and negatively correlated with dry wells and detention facilities. This means that as the percent of tree canopy increases, the percent of residential land cover also increases; and the density of dry wells and detention facilities decreases.
- Septic density was negatively correlated with riparian planting density. This means that as the density of septic systems increases the density of riparian plantings decreases.
- Channel slope was negatively correlated with septic age and positively correlated with pond/wetland density. This means that as channel slope increases, sewer age decreases and the density of pond/wetlands increases.
- Dry wells positively correlated with all other stormwater treatment devices. This means that as the density of dry wells increases, the density of all other stormwater treatment devices also increases.

Table B-6. Correlation of Watershed Attributes with Each Other.

Watershed Attributes	Watershed Characteristics									Restoration and Stormwater Management Efforts								
	Agriculture (percent)	Commercial/Industrial (percent)	Forest/Field/Other (percent)	Residential (percent)	Tree Canopy (percent)	Impervious (percent)	Septic System Density	Septic System Age	Channel Slope (feet/mile)	Wellhead Protection Area (percent)	Upstream Riparian Cover (percent)	Dry Wells	Detention	Sedimentation	Filtration	Infiltration	Pond/Wetland	Riparian Plantings
Agriculture Land Cover (percent)																		
Commercial/Industrial Land Cover (percent)	↓																	
Forest/Field/Other Land Cover (percent)	**↑**	↓																
Residential Land Cover (percent)	**↓**	↓	↓															
Tree Canopy Cover (percent)	**↓**	↓	↓	**↑**														
Impervious Land Cover (percent)	↓	**↑**	↓	↑	↓													
Septic System Density	↑	**↓**	↓	↑	↑	↓												
Sewer System Age Newer than 1965 (percent)	↑	↓	↑	↑	↑	↑	↑											
Average Channel Slope (feet/mile)	↓	↑	**↓**	↑	↑	↓	↑	**↓**										
Wellhead Protection Area (percent)	**↑**	↓	**↑**	**↓**	**↓**	↓	↓	↑	**↓**									
Upstream Riparian Canopy Cover (percent)	↓	↑	↓	↓	↓	↑	↓	↓	↑	↑								

Note: Highlighted correlations are significant at $p < 0.05$. The p value is the statistical significance of the model results and must be less than 0.05 to be considered statistically significant.

Table B-6 (continued). Correlation of Watershed Parameters with Each Other.

Watershed Attributes	Watershed Characteristics									Restoration and Stormwater Management Efforts								
	Agriculture (percent)	Commercial/Industrial (percent)	Forest/Field/Other (percent)	Residential (percent)	Tree Canopy (percent)	Impervious (percent)	Septic System Density	Septic System Age	Slope (feet/mile)	Wellhead Protection Area (percent)	Upstream Riparian Cover (percent)	Dry Wells	Detention	Sedimentation	Filtration	Infiltration	Pond/Wetland	Riparian Plantings
Dry Wells (no./acre)	↑	**↓**	**↑**	↓	↑	↓	↑	↓	↑	↓	↓							
Detention (no./acre)	**↑**	↓	↑	↓	**↓**	↓	↑	↓	↓	↑	↓	**↑**						
Sedimentation (no./acre)	↑	**↓**	↑	↓	↓	↓	↑	↓	↑	↓	↓	**↑**	**↑**					
Filtration (no./acre)	↑	↑	↓	↓	↓	↓	↑	↓	↑	↓	↓	**↑**	**↑**	**↑**				
Infiltration (no./acre)	↑	↑	↓	↓	↓	↓	↑	↓	↑	↓	↓	**↑**	**↑**	**↑**	**↑**			
Stormwater Pond/Wetland (no./acre)	↓	↑	↓	↑	↓	↓	↑	**↓**	**↑**	↓	↑	↑	↑	↑	**↑**	**↑**		
Riparian Planting Density (no./acre)	↓	↓	**↑**	↑	↑	↓	**↓**	↓	↓	↑	↑	↓	↓	↓	↓	↓	↓	

Note: Highlighted correlations are significant at $p < 0.05$. The p value is the statistical significance of the model results and must be less than 0.05 to be considered statistically significant.

The observed correlations and lack of correlations were used to identify a subset of potential watershed characteristics to include in regression analysis.

The results showed strong positive correlations (geographic overlaps) between the land cover categories of agriculture and forest/field/other, as well as between the categories of commercial/industrial and impervious. Therefore, for the third step of the correlation analysis, land cover was grouped into just two categories: urban development (representing areas consisting of commercial/industrial, residential, and impervious land cover) and agriculture (representing agriculture and forest/field/other). Tree canopy was eliminated as a land cover category because it is essentially the opposite of urban development.

Step 3

Based on the results of the first two steps, Herrera conducted a correlation analysis between water quality parameters and the watershed attributes (with just two land cover categories) at only the surface water basin scale. Table B-7 lists only those correlations that are statistically significant. Significant correlations observed include:

- Temperature increased (bad) with riparian canopy cover and riparian planting density, and decreased (good) with stormwater treatment facilities.
- Dissolved oxygen and pH increased (good) with riparian canopy cover and decreased (bad) with stormwater detention.
- Turbidity increased (bad) with riparian canopy.
- Total phosphorus and soluble reactive phosphorus increased (bad) with urban development.
- Total nitrogen, nitrate, and fecal coliform increased (bad) with septic density.

Results of the correlation analysis indicate that septic systems are increasing nitrogen and fecal bacteria concentrations and that urban development is increasing phosphorus concentrations in Burnt Bridge Creek. Riparian canopy cover showed a positive water quality effect by increasing dissolved oxygen concentrations, while its effect on pH is only positive at the furthest upstream station that occasionally has a low pH. However, riparian canopy cover showed unexpected negative effects of increasing temperature and turbidity in stream waters. Because tree canopy cover within riparian buffers should reduce stream temperatures from shade and possibly turbidity from erosion control, other upstream factors are likely increasing stream temperatures and turbidity.

No statistically significant correlations were found between any of the water quality parameters and wellhead protection areas, average channel slope, or sewer system age. Therefore, those watershed parameters were not considered in the multiple regression analysis.

Table B-7. Correlation of Watershed Attributes with Water Quality Parameters.				
	Watershed Characteristics		Restoration and Stormwater Management Efforts	
Water Quality Parameter	**Positive Correlations**	**Negative Correlations**	**Positive Correlations**	**Negative Correlations**
Median Temperature	Riparian canopy in upstream 0.5 mile	None	Riparian planting density	Sedimentation facility density Filtration facility density Infiltration facility density
Median Dissolved Oxygen	Riparian canopy in upstream 0.5 mile	None	None	Detention facility density
Median pH	Riparian canopy in upstream 0.5 mile	Agriculture		Detention facility density
Median Turbidity	Riparian canopy in upstream 0.5 mile	None	None	None
Median Total Suspended Solids	None	None	None	None
Median Soluble Reactive Phosphorus	Urban development	Agriculture	None	Dry well density Sedimentation facility density
Median Total Phosphorus	Urban development	Septic System Density	None	Dry well density Sedimentation facility density
Median Nitrate	Septic system density	None	None	Riparian planting density
Median Total Nitrogen	Septic system density Agriculture	None	None	None
Geomean Fecal Coliform	Septic system density	None	None	None

Multiple Regression Analysis

Multiple regression analysis was used to assess the relationship between multiple watershed attributes (including watershed characteristics and restoration and stormwater management efforts) and the water quality parameters. The analysis was conducted only at the surface water basin scale.

Eleven independent (predictor) variables were considered in the multiple regression analysis:

1. Percent upstream riparian cover
2. Percent agricultural land cover
3. Percent urban development cover
4. Septic system density
5. Riparian planting density
6. Dry well density

7. Detention facility density
8. Infiltration facility density
9. Filtration facility density
10. Sedimentation facility density
11. Stormwater pond/wetland density

Stepwise multiple regression was used to determine which combinations of the 11 independent (predictor) variables are best for predicting each of the 10 dependent (predicted) water quality parameters. Results are shown in Table B-8. As indicated in the table, statistically significant models (i.e., combinations of independent variables) were identified for four of the dependent water quality variables: pH, soluble reactive phosphorus, total phosphorus, and fecal coliform. Details for each model are provided in Table B-8 and include: the variables that were statistically significant in the model, the regression equation for the model, the model R^2 value, and the overall model p value. The model R^2 value is a metric of wellness-of-fit that measures how much of the variability seen in the monitoring stations for the dependent variables is explained by the watershed parameters included in the model; a value of 1 represents a perfect fit. The p value is the statistical significance of the model results and must be less than 0.05 to be considered statistically significant.

Table B-8. Multiple Regression Model Results.

Dependent Variable	Statistically Significant Independent Variables	Regression Equation	Model R^2 Value[a]	Overall Model P Value[b]
Temperature	None	N/A	N/A	N/A
Dissolved Oxygen	None	N/A	N/A	N/A
pH	Filtration ($p < 0.001$), Pond/wetland ($p < 0.001$), Riparian planting density ($p < 0.001$)	pH = (-10.246 x filtration) + (50.287 x ponds) + (0.0008*riparian planting) + 7.3875	0.9308	0.006
Turbidity	None	N/A	N/A	N/A
Total Suspended Solids	None	N/A	N/A	N/A
Soluble Reactive Phosphorus (SRP)	Urban development ($p = 0.046$)	SRP = (0.208 x urban development) - 0.023	0.3739	0.046
Total Phosphorus (TP)	Urban development ($p = 0.040$)	TP = (0.2455 x urban development) - 0.016	0.39019	0.034
Nitrate	None	N/A	N/A	N/A
Total Nitrogen	None	N/A	N/A	N/A
Fecal	Agriculture ($p = 0.017$), Urban development ($p = 0.004$)	Fecal = (-830.76 x urban development) - (2113.83*a griculture) + 645.18	0.7394	0.005

[a] The model R^2 value is a metric of wellness-of-fit that measures how much of the variability seen in the monitoring stations for the dependent variables is explained by the watershed parameters included in the model; a value of 1 represents a perfect fit.

[b] The p value is the statistical significance of the model results; a p value of less than 0.05 indicates statistical significance.

N/A = not applicable

There are two key limitations to the multiple regression analysis. First, the monitoring data collected for each main stem stream basin are dependent on all upstream monitoring stations. In the future, it may be appropriate to include an interaction factor in the regression equation to account for this spatial dependence. Second, the stormwater management predictor variables in the model are based solely on density and do not include the size of area treated; for example, the area treated by a dry well is typically much smaller than the area treated by an infiltration facility. Including the area treated in future analysis may improve predictions of water quality variables in Burnt Bridge Creek.

FINDINGS

Below are five hypotheses of relationships that one would expect to observe between water quality parameters and watershed attributes. Each hypothesis is followed by discussion of the actual results of the statistical analysis and recommendations for watershed management efforts.

Hypothesis No. 1: Septic systems impair surface water quality.

Based on the correlation analysis of watershed management effectiveness, it appears that septic system density is correlated with some water quality parameters in Burnt Bridge Creek. The analysis showed statistically significant positive correlations between septic system density and concentrations of fecal coliform, total nitrogen, and nitrate (see Table B-5). Concentrations of these parameters are high in septic system effluent, and these results suggest that water quality in Burnt Bridge Creek may be degraded by septic systems in the watershed.

Recommendations: The City should continue to invest in and expand the Sewer Connection Incentive Program (SCIP). The City should work with Clark County Public Health to implement and enforce septic system inspection and maintenance regulations. The City should use quantitative microbial source tracking methods to further investigate contamination of Burnt Bridge Creek by fecal bacteria and nutrients in areas of concern.

Hypothesis No. 2: Riparian buffers improve surface water quality.

The correlation analysis also showed statistically significant, positive correlations between riparian canopy cover and temperature, dissolved oxygen, pH, and turbidity (see Table B-5). Tree canopy cover within a riparian buffer, defined as within 50 feet of each stream bank and 0.5 mile upstream, was shown to improve (increase) dissolved oxygen and impair (increase) temperature and turbidity. It is expected that an increase in dissolved oxygen from riparian canopy cover would primarily be due to decreased temperature from more shade because cooler waters retain more oxygen from the air. However, temperature, pH, and turbidity also increased with riparian canopy cover and those increases were not likely caused by more canopy cover, suggesting that increases in dissolved oxygen in the stream also were not caused by riparian canopy cover.

Similarly, the analysis also unexpectedly showed that temperature increased with increased riparian planting density. Nitrate decreased with riparian planting density but not with riparian canopy cover. Some trees have been shown to uptake substantial amounts of nitrate from stream waters and should have more of an effect than young riparian plantings, suggesting that other unknown factors are cumulatively affecting nitrate concentrations in Burnt Bridge Creek.

Collectively, the correlation analysis results did not demonstrate that either riparian canopy or planting density affect water quality. Relationships may exist and could be identified by refining the data analysis methodology.

Recommendations: Because of the extensive riparian planting efforts expended by the City, potential effects of riparian cover and plantings on stream temperatures should be evaluated further using alternative riparian metrics (e.g., percent stream cover, total riparian vegetation cover, and plant height) and continuous temperature data (e.g., daily maximum and mean corrected for air temperature)

Hypothesis No. 3: Tree cover improves surface water quality.

Tree canopy cover within the subbasins draining to the stream monitoring stations was positively correlated with fecal coliform bacteria and not significantly correlated with any other water quality parameters (see Table B-5). Residential land use was also positively correlated with fecal coliform bacteria and tree canopy cover. Collectively, these results indicate that increased fecal coliform bacteria concentrations may be linked with residential land use and not tree canopy cover. Intuitively, tree canopy cover should reduce stormwater pollutant loadings to the stream and improve water quality by reducing pollutant concentrations in the stream. The increase in tree canopy cover with residential development in this watershed makes it difficult to discern potential benefits of efforts to increase tree canopy.

Recommendations: As Urban Forestry continues its efforts to increase tree canopy citywide, the City should continue to collect GIS data for comparing historical trends in tree canopy cover with water quality in key subbasins of Burnt Bridge Creek.

Hypothesis No. 4: Urban development impairs surface water quality.

The correlation analysis evaluated water quality relationships with residential land use, commercial/industrial land use, and impervious land cover—both separately and combined to represent urban development (see Table B-5). Urban development (along with commercial/industrial land use and impervious land cover but not residential land use) correlated positively with total and soluble reactive phosphorus concentrations in Burnt Bridge Creek. These findings indicate that urban development in the watershed is increasing phosphorus concentrations during summer base flow conditions.

Key sources of phosphorus in Burnt Bridge Creek were not identified in this analysis but may include stormwater runoff from impervious surfaces (presumably roads and parking lots more than roofs), improper phosphorus content or application of fertilizers, and sanitary wastewater inputs from septic systems or storm drain cross-connections.

Recommendations: The City should continue to implement phosphorus source control practices (e.g., street sweeping, fertilizer education, and sewer connections) and stormwater treatment targeting phosphorus removal within developed areas of the Burnt Bridge Creek watershed.

Hypothesis No. 5: Stormwater management facilities improve surface water quality.

Potential effects of stormwater management on stream water quality were evaluated by correlating base flow water quality with the density of dry well, detention, infiltration, filtration, sedimentation and pond/wetland facilities. Detention, filtration, and infiltration facilities were negatively correlated with (improving) stream temperatures (see Table B-5). Detention facilities were also negatively correlated with dissolved oxygen (impairing) and pH (generally no impact). Dry wells and sedimentation facilities were negatively correlated (improving) total and soluble phosphorus concentrations. These findings indicate that stormwater management facilities are improving temperatures and phosphorus concentrations in Burnt Bridge Creek.

Dry well and sedimentation facility density also correlated negatively with commercial/industrial land use (see Table B-6). The lower density of these facilities in commercial/industrial areas of the watershed, combined with the finding of increasing phosphorus in commercial/industrial areas, suggests that stormwater management facilities are improving phosphorus concentrations less in commercial/industrial areas than in other areas of the watershed.

Recommendations: The City should continue implementing stormwater management BMPs in the Burnt Bridge Creek watershed to improve stream temperatures and phosphorus concentrations with an emphasis in commercial/industrial areas. The City should collect more stormwater quality data to allow future analysis of stormwater management on water quality during storm flow conditions. The City should improve GIS data on stormwater facilities by combining stormwater facilities into functional groups and include the catchment area and other characteristics of each facility in the GIS database for evaluating potential effects of specific BMP types on water quality on a basin scale in the future.

REFERENCES

Herrera 2011. 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.