Appendix B Only

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

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Note:
Some pages in this document have been purposely skipped or blank pages inserted so this document will copy correctly when duplexed.

Appendix B Only
INTEGRATED SCIENTIFIC ASSESSMENT REPORT

VANCOUVER WATERSHED HEALTH ASSESSMENT

Prepared for
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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])

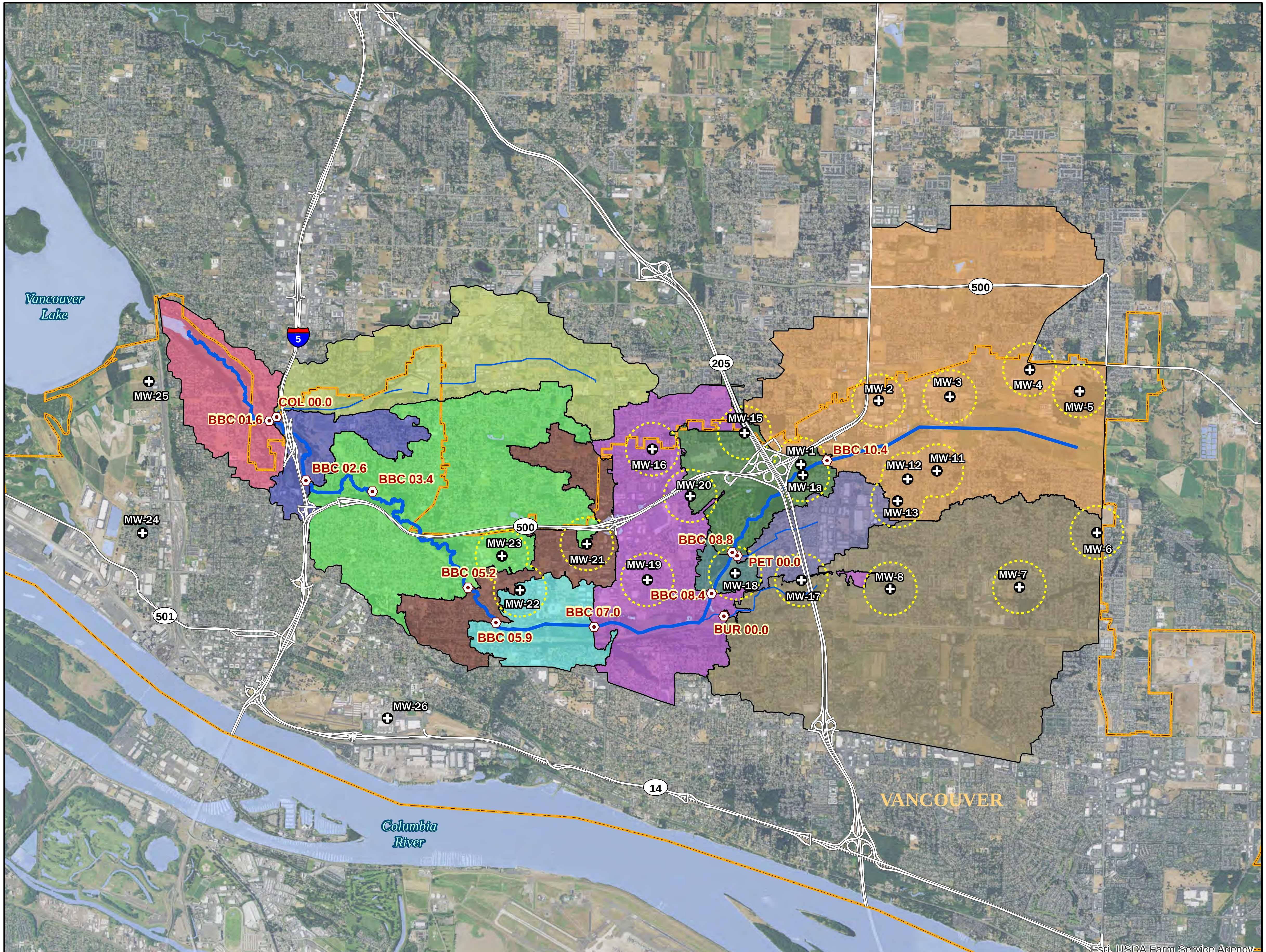

Figure B-1.
Surface Water and Groundwater Monitoring Stations.

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.

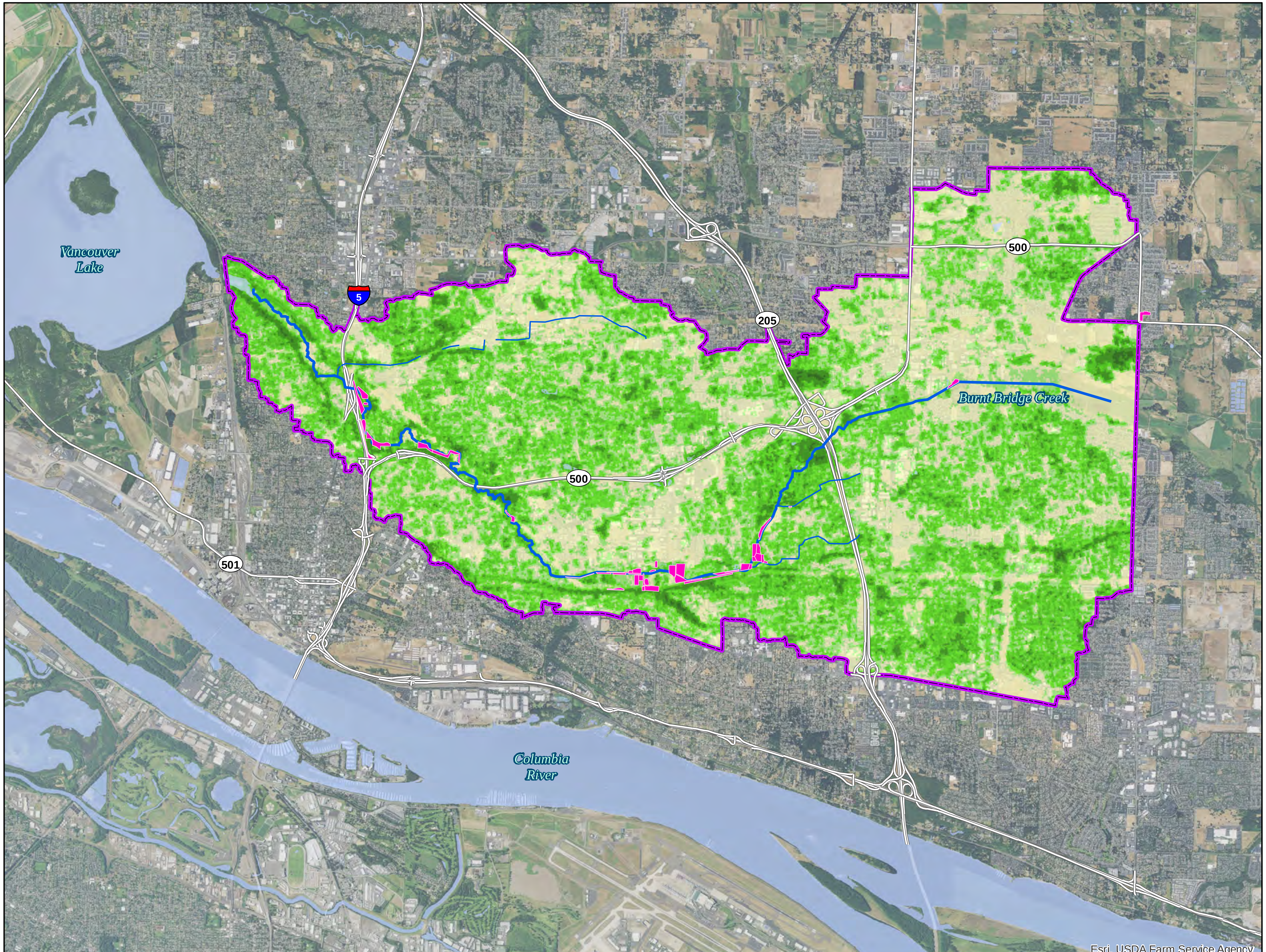
Table B-2. Watershed Characteristics Data Used in the GIS Statistical Analysis.

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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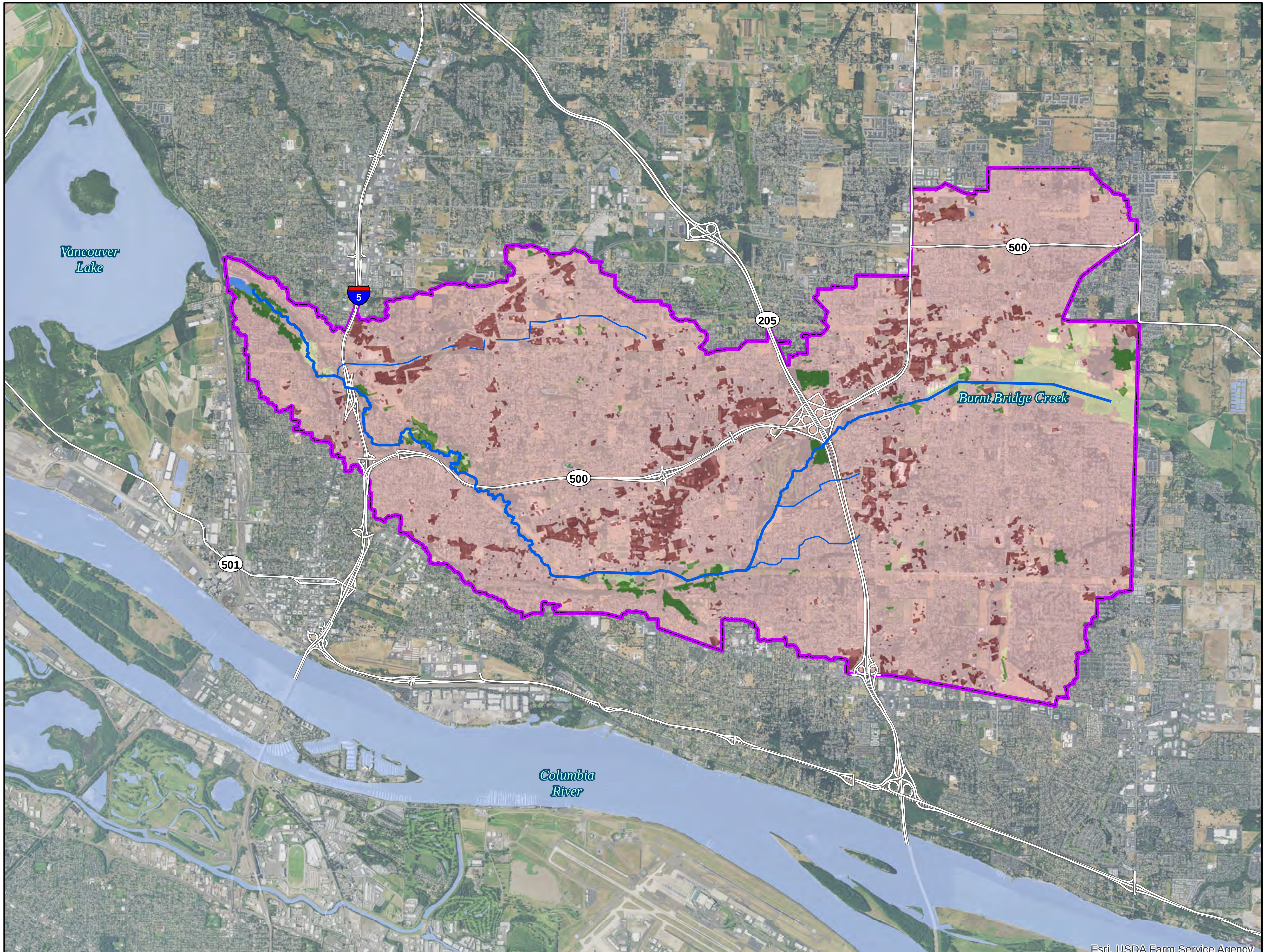
Figure B-3.
Land Cover.



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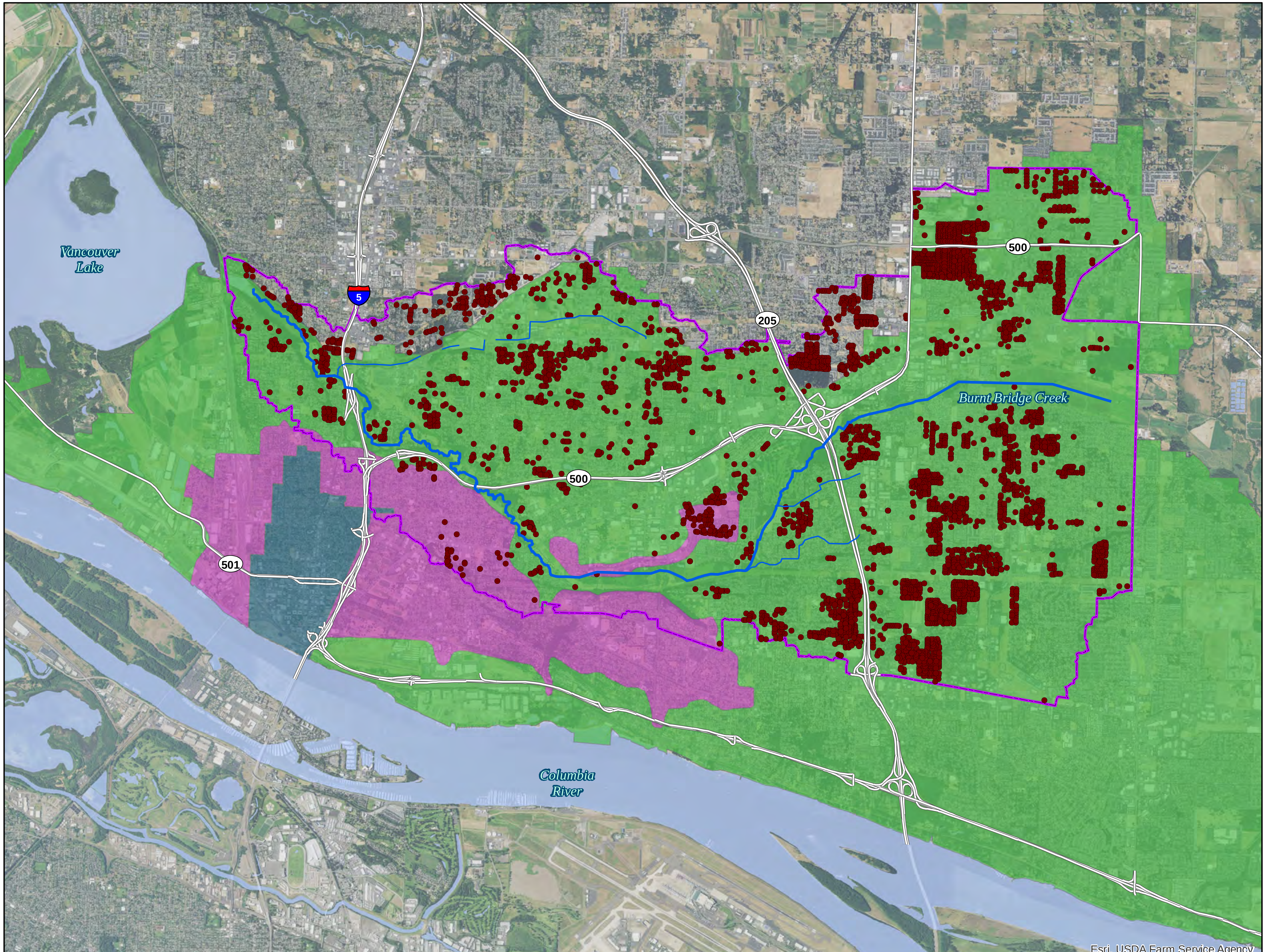
Figure B-4.
Mapped Septic Systems Locations and Approximate Sewer Age.



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

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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 Characteristics									Restoration and Stormwater Management Efforts								
Watershed Attributes	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.				
Water Quality Parameter	Watershed Characteristics		Restoration and Stormwater Management Efforts	
	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.