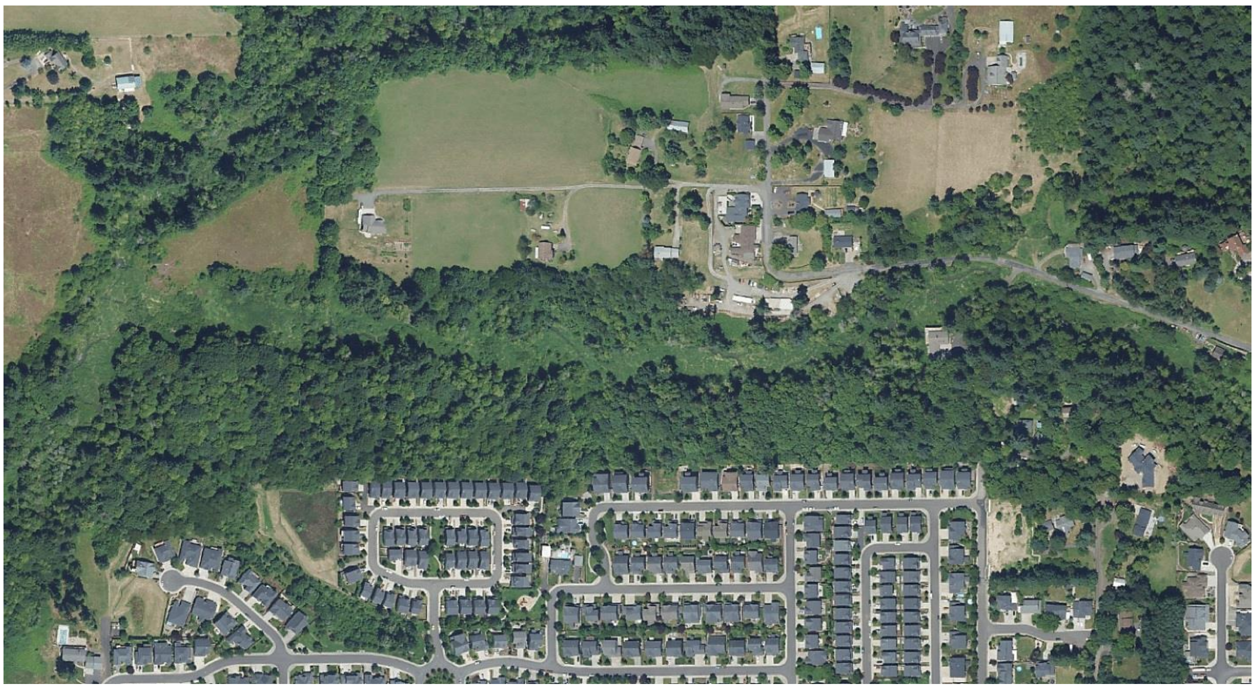
Clark County Whipple Creek Watershed-Scale Stormwater Plan Report

Submitted in Fulfillment of Municipal Stormwater Permit Condition S5.C.5.c

September 2017



Prepared by Clark County with Otak, Inc. and FSC Group

FCS GROUP
Solutions-Oriented Consulting

Foreword

Report Purpose and Budget Impacts

The actions listed in the Whipple Creek Watershed-Scale Stormwater Plan Report (Report) implementation plan are not part of the Clark County Stormwater Program Plan submitted under Permit condition S5.A., which is supported by the current County budget. The Report is created solely to meet Permit requirement S5.C.5.c.

No new actions in the Report are supported by the current County budget approved by the Clark County Board of County Councilors (BOCC). Implementation of any new action in this plan, not currently supported by the County budget, is subject to future budget approval by the BOCC. The Report may only be used to guide county planning for future actions to improve Whipple Creek stream health.

Submittal of this plan to Washington Department of Ecology has no budget impacts.

Submittal for S5.C.5.c: Whipple Creek Watershed-Scale Stormwater Plan Report

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Introduction

A. Summary

The Whipple Creek Watershed-Scale Stormwater Plan Report (Report) is presented to fulfill condition S5.C.5.c of Clark County's National Pollutant Discharge Elimination System (NPDES) Phase I Municipal Stormwater Permit (Permit), issued by the Washington Department of Ecology (Ecology).

The Report documents the results of a high-level conceptual exercise to estimate the magnitude of effort needed to meet state-established water quality standards and in-stream flow conditions for the Whipple Creek watershed. The watershed spans about 12 square miles in southwest Clark County, Washington. It is situated north of Salmon Creek and south of Gee and Flume Creeks. Nearly five square miles of the upper watershed is inside the Vancouver urban growth area (UGA).

The analyses in this Report relied on water quality and hydrology data in the watershed collected by Clark County over the past ten or more years. Observed conditions in the streams were used to calibrate computer models of the watershed, which allowed the County to estimate the effects of future planned land uses on Whipple Creek's water quality and in-stream conditions. Results generated by simulated future land use conditions did not meet some state water quality standards and did not result in in-stream flow conditions that would allow salmon and other aquatic life to thrive.

Numerous watershed-scale management strategies directly supportive of aquatic life were considered and some were simulated in the models. With full implementation throughout the watershed of strategies described in this plan, Whipple Creek would be predicted to meet state water quality standards for dissolved metals and temperature and to have improved (reduced) levels of fecal coliform bacteria. Modeled strategies did not appear capable of providing stream flow similar to a forested watershed that would fully support salmon and other aquatic life; although some improvements compared to current degraded conditions would be expected.

Full implementation could incur capital expenditures of $346 million and ongoing operational costs of $4 million annually.

B. Purpose and Background

Knowledge about the adverse impacts of stormwater runoff on water bodies is changing rapidly. Most stormwater mitigation is applied site-by-site as land is converted from forest or fields to roads, parking lots, buildings, and lawns.

To analyze approaches to protecting streams and lakes, King County studied the predicted effects of alternative strategies in a single watershed. Juanita Creek is an urbanized 6.8 square mile watershed in King County and the City of Kirkland which was developed before current water quality treatment and flow control standards were required in western Washington.

In 2012, King County and partners published the *Stormwater Retrofit Analysis and Recommendations for Juanita Creek Basin in the Lake Washington Watershed* under a grant from Ecology. The retrofit analysis studied numerous stormwater management scenarios in an attempt to find a strategy or combination of strategies that would improve flow and water quality conditions to support fish use and other aquatic life in the watershed's streams (King County, 2012).

The Juanita Creek study found that if small distributed on-site stormwater management facilities (called low impact development (LID)) were applied to nearly all impervious surfaces and if larger traditional end-of-pipe treatment and detention facilities were constructed to retrofit most impervious surfaces up to contemporary treatment and flow control standards, Juanita Creek's streams would achieve the goals at an estimated cost of $1.4 billion (King County, 2012).

On the heels of the Juanita Creek plan, Ecology began requiring each of the four Phase I western Washington counties – King, Snohomish, Pierce, and Clark – to conduct a similar study on an urban or urbanizing watershed. In its 2013-2018 Permit, Ecology required Clark County to select a watershed and perform watershed-scale stormwater planning as outlined in Permit section S5.C.5.c. The Permit-stated objective was to "identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support 'existing uses' and 'designated uses,' as those terms are defined in WAC 173-201A-020, throughout the stream system.[1]"

In June 2014, Clark County submitted a scope of work and schedule outlining its plan to complete the watershed-scale stormwater planning requirement in the Whipple Creek watershed. Ecology approved the County's scope in September 2014 and set a deadline of September 6, 2017 for submittal of a final report. Appendix R includes the approved scope of work.

Clark County's scope of work identified tasks necessary to meet specific sub-requirements of the watershed-scale stormwater planning requirement and to gather sufficient data to simulate Whipple Creek's hydrology and water quality in a computer model. The model, calibrated to Whipple Creek's observed current conditions, would then be used to simulate future development and stormwater management strategies in an attempt to find strategies that would attain designated uses.

Clark County, together with Otak, Inc., implemented the scope of work from 2014 to 2017.

The result is a conceptual watershed-scale stormwater plan report for Whipple Creek presented here to satisfy Permit requirement S5.C.5.c.

C. Regulation

The Clean Water Act (CWA) of 1972 is the principal federal law regulating discharge of pollutants into streams, rivers, and lakes. It controls discharges of pollutants by regulating both industries and government entities, such as cities and counties, which operate storm sewer systems that collect and discharge polluted stormwater runoff from urban and suburban areas. The National Pollutant Discharge Elimination System (NPDES) is the CWA's permitting program.

The CWA relies on the concept of designated uses to set goals for water quality. At a minimum, any existing use that the water body supported in 1974, such as fishing, swimming, or providing drinking water, must be maintained.

[1] WAC means Washington Administrative Code.

The Washington State Water Pollution Control Act (RCW 90.48) similarly protects surface waters of Washington State and ground water from discharge of contaminants, and it tasks Ecology with setting water quality standards.

In Washington, the CWA's NPDES permitting program is delegated by EPA and administered by Ecology. Ecology establishes designated uses, which may equal or exceed the CWA's existing uses, for Washington's surface waters. Ecology sets water quality standards that, if met, would theoretically sustain the designated uses. Ecology issues municipal stormwater permits and state waste discharge permits pursuant to the CWA and RCW 90.48. Clark County's Permit is issued under this program. The Clark County Permit authorizes the discharge of stormwater from the county storm drainage system to waters of the state.

D. Water Quality Goals

Washington Administrative Code (WAC) Chapter 173-201A establishes water quality standards for Waters of the State. Standards are set for each water body based on its existing uses and designated uses.

Ecology has not established individual designated uses for Whipple Creek, so default uses apply. The highest default uses are primary contact recreation and salmonid spawning, rearing, and migration.

This Report analyzes and models those water quality constituents required by the Permit, and provides a cursory analysis of parameters relating to Whipple Creek's designated uses that are not specifically required to be evaluated in this Report by the Permit. Water quality standards used as the basis for analysis are shown in Table 1.

Table 1: Designated Uses and Water Quality Standards for Whipple Creek Discussed in this Report

Parameter	Applicable Designated Use	State WQ Standard Criteria
Temperature	Aquatic Life: salmonid spawning, rearing, and migration	7-Day Average Daily Maximum (7-DADMax) of 17.5°C
Fecal Coliform	Primary contact recreation	< geometric mean of 100 colonies / 100 mL and <10% of samples: 200 colonies / 100 mL
Dissolved Copper	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Dissolved Zinc	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness

E. In-Stream Hydrology Goals

The ultimate goal of the state is to restore designated uses, chiefly to provide adequate habitat and in-stream flow conditions to ensure the survival and recovery of native salmon.

Hydrology and water quality models, however, do not directly estimate the ability of a stream to support fish populations. To account for this, the Permit requires in-stream flow conditions (hydrology) to be used as a surrogate for stream biologic integrity - a stream's ability to support aquatic life from the bottom of the food chain to the top.

Introduction

This Report uses four different methods to correlate modeled hydrology to stream biologic integrity, as described below.

i. Relationship of Flow Metrics to B-IBI Score

The Benthic Index of Biological Integrity (B-IBI) is a widely used indicator of stream biologic health in the Pacific Northwest. The index uses a multi-metric analysis of macroinvertebrate taxa (bugs) that are present in gravel riffles of wadeable streams.

The Permit requires the County to use a statistically valid relationship between one or more stream flow metrics reported by the hydrology model and B-IBI score.

The applicability to Whipple Creek of several hydrologic metrics that are commonly used in the Pacific Northwest were evaluated, emphasizing those from research done on Puget Sound lowland streams (DeGasperi *et al*. 2009). Metrics are calculated using daily average flows.

Using Clark County's long-term local monitoring data and statistical regression, three hydrologic metrics were evaluated for use in a correlation to B-IBI score: 1) T_{Qmean}; 2) High Pulse Count (HPC); and 3) High Pulse Range (HPR). Table 2 provides a definition for each metric and for high flow pulse, which is the base observation for two of the calculated metrics.

Table 2: Hydrologic Metric Definitions and Selection Status

Hydrologic Metric	Definition	Selection Status
TQmean *	Fraction of a year that the daily mean discharge rate exceeds the annual mean discharge rate	Selected for use in Report
High Flow Pulse ~	Occurrence of daily average flows that are equal to or greater than a threshold set at twice (two times) the long-term daily average flow rate	N/A – this is a base metric used to calculate HPC and HPR
High Pulse Count (HPC) ~	The number of days each water year that discrete high flow pulses occur	Selected for use in this Report
High Pulse Range (HPR) ~	The range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year	Not selected for use in this Report

Sources: Booth *et al.* (2001, pp. 19-20) * and DeGasperi *et al.* (2009, pp. 512 and 518) ~

Six Clark County watersheds were eligible for inclusion in the evaluation of a statistically valid relationship between flow metrics and B-IBI. The three criteria for inclusion in the study were similarity to Whipple Creek and presence of sufficient B-IBI and continuous flow monitoring data. Two metrics were selected for use in this Report – T_{Qmean} and HPC, described below. A detailed discussion of the analysis can be found in Appendix H.

T_{Qmean}

The T_{Qmean} metric has previously been used by Clark County and in the Puget Sound area (Booth *et al.*, 2001). All three metrics were used in a more recent Puget Sound lowland study (DeGasperi, *et al.*, 2009).

Linear regression showed that only T_{Qmean} using the equation below had a significant relationship to B-IBI based on local data:

$$\text{Avg B-IBI} = -16.7 + 154 \text{ Avg } T_{Qmean}$$

Further analysis during the effort to calibrate a hydrology model to observed conditions in Whipple Creek (see Chapter II) resulted in adjustments to the equation's coefficients. This Report uses a linear relationship between T_{Qmean} and B-IBI that best fits observed conditions to estimate future B-IBI scores under future planning scenarios in Whipple Creek.

The equation used in this Report for calculating B-IBI from T_{Qmean} is:

$$\text{Avg B-IBI} = -24.1 + 154 \text{ Avg } T_{Qmean}$$

High Pulse Count (HPC)

Although it was not found to have a statistically significant relationship to B-IBI score in Whipple Creek based on local data, this Report also uses the relationship between HPC and B-IBI published by King County in its Juanita Creek basin plan.

The equation used for calculating B-IBI from HPC is:

$$\text{Avg B-IBI} = 53.05 + -30.106 \log_{10} \text{Avg HPC (King County, 2012)}$$

ii. Using Flow Metrics to Estimate Salmonid Use Attainment

As required by the Permit, B-IBI scores are used to estimate future aquatic biologic integrity as described above. This Report also uses two other indicators of whether a stream can support salmonid uses (salmonid use attainment): direct correlations between HPC and salmonid use attainment and between T_{Qmean} and salmonid use attainment.

Context

In 2014, Ecology used B-IBI scores to list streams that did not meet narrative standards for salmonid uses. The criteria ranges Ecology used were: greater than 37 for fully supporting beneficial uses, less than 28 for non-supporting , and 28 through 37 for waters of concern (Ecology, 2014).The B-IBI metric has a top score of 50. Non-supporting streams were listed on the State 303(d) List, which officially records impaired waters under the CWA.

Table 3: Correlation of B-IBI to Salmonid Use Attainment for Ecology's 303(d) Listing

	Salmonid Uses		
	Non-supporting	Partially Supporting	Fully Supporting
B-IBI	<28	28-37	>37

Because sub-watershed-scale pool-riffle sites having both flow data and B-IBI scores are extremely rare in western Washington, statistical conclusions about relationships between flow and B-IBI as described above, are weak. There is scant data and a great deal of scatter in correlating flow metric to B-IBI scores.

Introduction

B-IBI itself is an indirect indicator of a stream's ability to support salmonid uses. B-IBI is a measure of the health of aquatic macroinvertebrates, not fish. Many stream and watershed conditions other than hydrologic regime influence B-IBI scores. These include channel substrate quality, temperature, and the presence of pollutants from urban runoff and other sources.

High Pulse Count (HPC) and T_{Qmean}

To account for the difficulties with B-IBI, this Report also uses HPC and T_{Qmean} to evaluate whether Whipple Creek will meet standards for salmonid uses under future scenarios.

A review of King County's analysis of flow and water quality targets for a Water Resource Inventory Area 9 planning project (Horner, 2013) reveals that flow metrics can be directly correlated to salmonid use attainment. A discussion of this analysis can be found in Appendix I.

King County recognized HPC as one of the more useful metrics for calculating the B-IBI score. Horner found that sites having HPCs between 3 and 7 generally supported salmon use (using B-IBI score range greater than 35). The report also found that very low B-IBI scores (< 16) were associated with HPCs above 15. B-IBI scores above 25 were associated with HPCs less than 11.

King County published a regression equation for HPC and B-IBI (King County, 2012). Clark County data also showed increasing B-IBI with lower HPC, making it a viable indicator based on local data and the Puget Sound results.

Table 4: Correlation of HPC to Salmonid Use Attainment

	Salmonid Uses		
	Non-supporting	Partially Supporting	Fully Supporting
HPC Range	>11	7-11	<7

The King County analysis also identified T_{Qmean} as a useful metric for calculating the B-IBI score. Evaluation of Clark County data for basins similar to Whipple Creek found a strong correlation. King County published a regression equation for T_{Qmean} and B-IBI (King County, 2012).

Clark County data suggest that a T_{Qmean} of about 25% to 27% is equivalent to the threshold for streams that do not support salmonid uses (non-supporting) and that about 37% is the lower threshold for streams that fully support salmonid uses (fully supporting).

Table 5: Correlation of TQmean to Salmonid Use Attainment

	Salmonid Uses		
	Non-supporting	Partially supporting	Fully Supporting
TQmean	10-27 %	28-37 %	>37 %

High Pulse Range was not used because it was not appropriate for the short time period modeled in Whipple Creek. It would be more appropriate to model results for decades.

Introduction

This Report describes the results of modeled future scenarios in terms of all three indicator metrics: B-IBI, HPC, and T_{Qmean} and correlates each metric to salmonid use attainment as described above.

I. Existing Conditions

A. Watershed Setting

The Whipple Creek Watershed spans about 12 square miles in southwest Clark County, Washington. It is situated north of Salmon Creek and south of Gee and Flume Creeks. Nearly five square miles of the upper watershed is inside the Vancouver urban growth area (UGA).

Whipple Creek flows generally west from headwaters east of Interstate-5 (I-5) between Vancouver and Ridgefield to Lake River. The confluence with Lake River is just six miles upstream of the Columbia River. The watershed includes an area draining directly to Green Lake on the Columbia River floodplain.

Currently, the watershed is moderately developed with rural and agricultural areas in the western portion. The Vancouver UGA in the east is rapidly urbanizing. Suburban and large-lot rural residences are common in the lower watershed outside of the UGA. I-5, a major interstate transportation corridor, traverses nearly two miles of the upper watershed.

The creek is thought to be degraded in terms of hydrology, water quality, and salmon habitat compared to its historic condition.

Data about existing conditions in the watershed were collected and described following Tasks 1 and 2 of The Whipple Creek Watershed-Scale Stormwater Planning Scope of Work and Schedule, June 2014.

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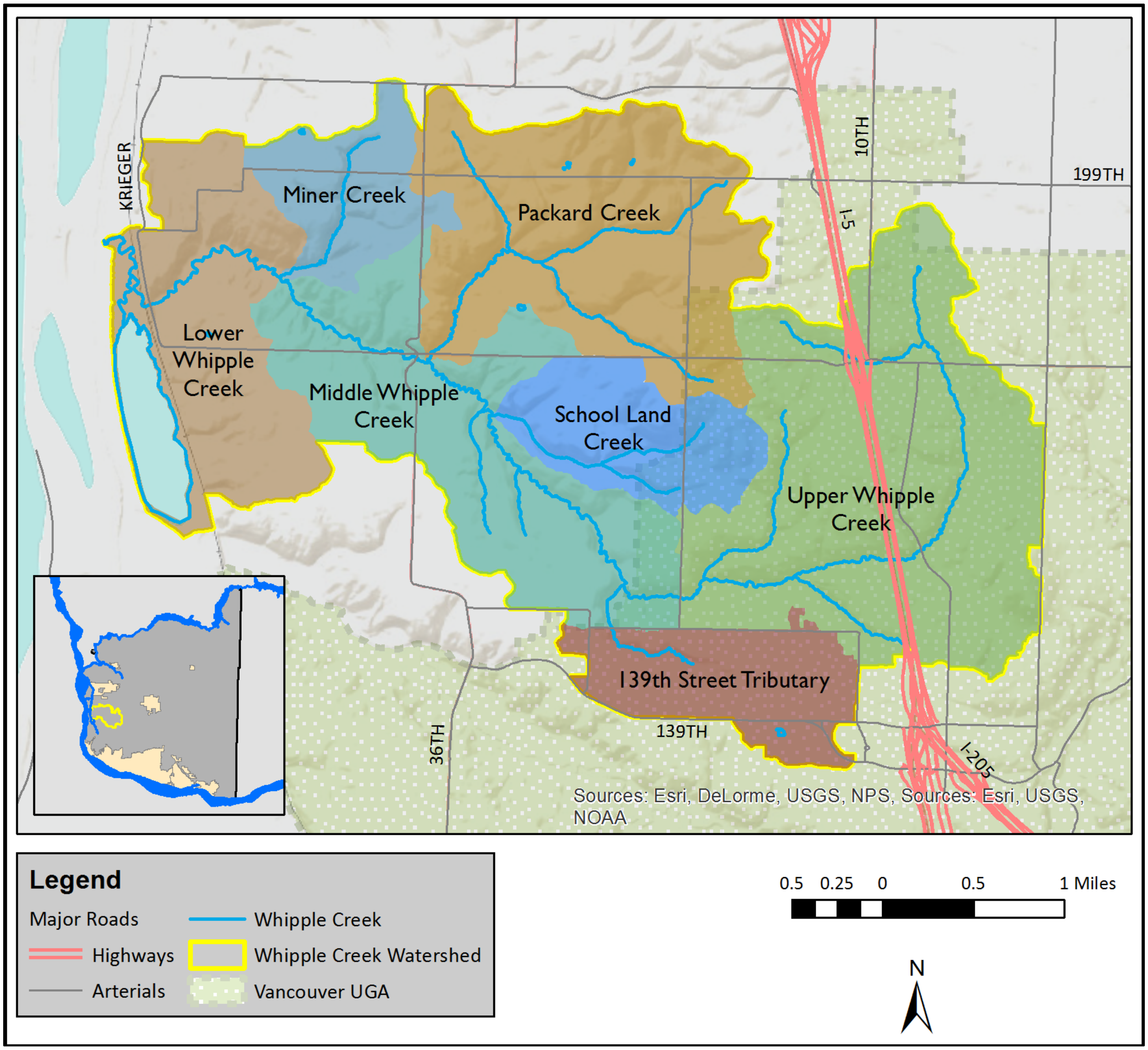
i. Basins

Whipple Creek has several important tributaries and about nine miles of main stem, divided into upper, middle, and lower. See Figure 1.

Existing Conditions

Figure 1: Whipple Creek Study Area



Lower Whipple Creek

Lower Whipple Creek begins where the creek meets Lake River a few miles upstream of the Columbia River. It includes Green Lake. The lowermost portion of this basin has a broad floodplain and is tidally influenced by the Columbia River. It also includes an area where small streams drain directly to Green Lake on the Columbia River Flood Plain. Further upstream, the creek also flows through a broad floodplain and contains potential salmon spawning habitat. Just below Packard Creek, large trees and good riparian corridors remain. The creek is nearly flat here. The area is characterized by agricultural uses.

Middle Whipple Creek

Middle Whipple Creek has some potential salmon habitat and pool-riffle sequences that have potential for salmon habitat restoration in its lower reaches. An important long-term water quality and stream flow monitoring site is located on the main stem downstream of the confluence with Packard Creek. Near the School Land Creek tributary, beaver ponds are numerous. The creek is nearly flat here. The area is characterized by rural and agricultural uses.

Upper Whipple Creek

The lower reaches of Upper Whipple Creek also have some low gradients and beaver ponds. Most headwater streams in Upper Whipple Creek have high gradients and flow through narrow canyons. All of Upper Whipple Creek is in the Vancouver Urban Growth Area (UGA). The I-5 corridor and the southeast portion of this basin are urbanized already while other areas of future growth are still characterized by open agricultural tracts. There is a full fish passage barrier at I-5.

Miner Creek Tributary

Miner Creek has salmon spawning gravel and the best water quality conditions in the watershed. The stream has good riparian corridors. The area is characterized by agricultural uses.

Packard Creek Tributary

Packard Creek is the largest tributary to Whipple Creek. The creek has gravel channel substrate providing salmon habitat. Stream conditions and water quality are degraded as a result of rural land uses and urbanization in headwaters along I-5. The stream has good riparian corridors. Packard Creek provides an opportunity for salmon habitat restoration. The area is characterized by agricultural uses.

School Land Creek Tributary

The School Land Creek tributary is an area where Clark County has significant land holdings. It has potential salmon habitat that is likely blocked by a culvert. The tributary has good riparian corridors, particularly within Whipple Creek Park.

139 St Tributary

The tributary to Whipple Creek at NW 139th Street drains an urbanized area in the UGA. Stream hydrology is greatly altered due to urban runoff. The area developed over the last 30 years.

ii. Topography

Whipple Creek is a part of the Columbia Slope watershed, which generally falls to the west toward the Columbia River. Upper reaches of the main stem and tributaries originate in rolling hills with a maximum elevation of about 350 feet. The creek ends in a broad wetland floodplain where it meets Lake River at 10 feet above sea level.

Headwater streams tend to flow through deep valleys with little or no room for a floodplain. The lower main stem flows through a broad floodplain as wide at 800 feet in the lowest reaches. Packard Creek also has a wide floodplain in its lower reaches. Floodplains tend to be bounded by deep, steep valleys (Inter-Fluve, 2006).

iii. Geology and Soils

The basin is covered mostly with deposits of sands and silts from the Late Ice Age Missoula Floods or Cataclysmic Floods. These deposits are moderately to poorly drained and have moderate to high erodibility. In some areas of the basin, weathered deposits of the Troutdale Formation gravels are at or near the surface. The weathered Troutdale Formation deposits are rich in clay and have very slow infiltration rates.

Most stream channels are characterized by highly erodible fine sediments, with only a few reaches characterized by coarse sediments (Inter-Fluve, 2006), such as the cobbles and gravels favored for spawning by many species of native fish.

iv. Wildlife

Beaver are known to live and to build dams in the main stem and some tributaries. Extensive sediment deposits can accumulate behind beaver dams and may contribute to filling incised stream channels. Ponds behind beaver dams may suffer from high nutrients, sediment, and high temperatures (Clark County, 2006).

The watershed is also home to deer, raccoon, song-birds, waterfowl, amphibians, and mussels (Clark County, 2006). Invertebrates found in streams form the base of the food chain for native fish.

Clark County staff found no anadromous fish (fish that migrate from freshwater to the ocean and back to spawn, including salmon and steelhead), no crayfish, and few resident fish while conducting fieldwork for the 2006 assessment of Whipple Creek (Clark County, 2006).

v. Vegetation

The Whipple Creek watershed, like most of western Washington, was once mostly forested.

Today, few large tracts of forest remain, and half of the land cover in the watershed is field, meadow, and pasture (Inter-Fluve, 2006). Invasive Himalayan blackberry are common, occurring on stream banks, in floodplains, and at times spanning the channel itself. In its assessment, Clark County staff noted that blackberries encroach to varying degrees from nearly every road crossing and stormwater outfall (2006).

Where riparian coniferous forest cover has been removed along the streams in many locations, fast-growing alders, succeeded by invasive species, now dominate (Inter-Fluve, 2006).

vi. County Storm Sewer Drainage

Clark County operates a municipal separate storm sewer system (MS4) throughout unincorporated Clark County and in the Whipple Creek watershed. The MS4 is a network of pipes and ditches along with water quality treatment and detention facilities.

The MS4 discharges to Whipple Creek and its tributaries through numerous outfalls. In its 2006 assessment, Clark County identified maintenance needs and significant impacts downstream of many of the county’s outfalls. Common impacts described include erosion, invasive plant colonization, and trash accumulation (Clark County, 2006).

Many large agricultural lots drain directly to Whipple Creek or a tributary without first passing through the county's storm sewer.

vii. Land Use, Land Cover, and History

The watershed is a moderately developed rural and agricultural area, which is rapidly urbanizing in the UGA. Large-lot rural residences are interspersed with agriculture in the lower watershed outside of the UGA.

Historic dense coniferous forests were cleared by the early 1900s for building materials and agriculture, and the watershed has been home to a saw mill and shingle mill.

In 1978, *The Columbian* characterized Whipple Creek near the intersection of NW 179th Street and NW 41st Avenue as a "lazy, quiet stream" flowing through a traditional farming area (Sara) that was transitioning to rural large-lot development of 5-acre tracts (Columbian Archives, 2006).

Clark County's 2006 assessment records anecdotal accounts of the creek from longtime streamside landowners, which suggest the creek has changed over the past 50 years:

> Several landowners reminisced about the historical presence of steelhead and sea-run cutthroat trout on their properties. Others noted the disappearance of once-abundant crayfish populations…A number of residents commented they had not been near the creek on their property for years, citing impenetrable blackberry thickets as the reason (Clark County, 2006).

Changes in land use are continuing to impact Whipple Creek. In portions of the watershed that have been urbanizing since the 1980s, County staff observed several cases of downstream impacts such as incision and headcuts that appear to have occurred as a result of recent development projects (Clark County, 2006).

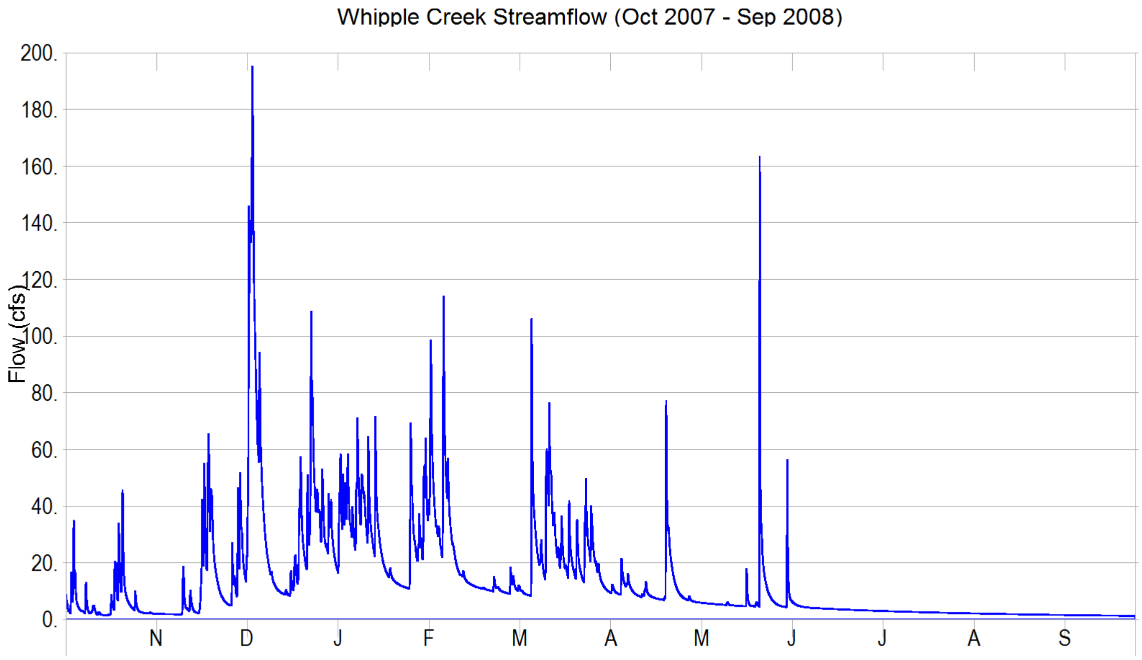
The percentages of land covers include 34% forested, 12% impervious, 51% non-canopy (fields/meadows), and 2% water (Inter-Fluve, 2006). Loss of historic forests has implications for channel stability, stream temperature, and stream habitat complexity. The county's 2006 assessment concluded that Whipple Creek has been heavily impacted by human activity in both rural and urban portions, and degraded areas far outnumber intact areas.

B. Hydrology

Whipple Creek can be described as a flashy stream, which means that the amount of flow in the creek changes quickly in response to rainfall from major storm events. Peak flows rise quickly in the stream channel during storm events and then once the rain stops the flows return to normal or low flow conditions. A graph of stream flow (hydrograph) illustrates these sharp peaks at a stream gage in the lower middle watershed in Figure 2, below.

Existing Conditions

Figure 2: Whipple Creek Observed Stream Flow at WPL050 Gage (in cubic feet per second (cfs))



This quick response to rainfall is the result of a number of factors.

Many of the soils in the watershed have low infiltration rates. Heavy rainfall does not soak into the ground but instead quickly runs off into the nearest stream. This surface runoff produces high peak flows, and the lack of infiltration produces low base flows. The replacement of forest with impervious surfaces intensifies this pattern.

Another major factor is that the upper portions of the main stem of Whipple Creek and headwater tributaries are relatively steep, as shown in Table 6.

Table 6: Whipple Creek Main Stem Channel Slopes

Channel	Reach	Length (mi)	Elev Change (ft)	Slope (%)
Upper	195	0.283	17.03	1.1%
Upper	190	0.832	20.77	0.5%
Upper	180	1.167	60.58	1.0%
Upper	175	0.194	12.86	1.3%
Upper	170	0.578	19.60	0.6%
Upper	160	0.733	18.40	0.5%
Middle	150	0.608	13.53	0.4%
Middle	140	1.080	14.72	0.3%
Middle	130	1.045	17.43	0.3%
Middle	120	1.095	35.12	0.6%
Lower	110	1.264	10.47	0.2%
Lower	100	0.773	4.08	0.1%
Total/Average		**9.652**	**244.59**	**0.5%**

These steep stream channel slopes produce high stream channel velocities and high peak flows. This, in turn, results in channel erosion through downcutting (also known as incision). Downcutting deepens the channel and prevents flood flows from overtopping the channel banks and spreading out onto the adjacent floodplain.

The stream channel slopes decrease in the middle portion of the main stem of Whipple Creek. This is a section of the stream channel where sediment deposition can occur and where beaver dams further encourage sediment deposition. Erosion that does occur in this section is mainly from the stream channel banks rather than the channel bottom.

The lower portion of Whipple Creek is in the Columbia River floodplain and the stream's bottom slopes are very low (0.1 to 0.2%). In this portion of the channel the stream velocities are lower than in the upper sections and the potential for sediment deposition is greater.

The total distance from the headwaters of Whipple Creek to its downstream confluence with Lake River is approximately 9.6 miles. During major storms the travel time for flood flows to reach the mouth of the creek is less than 24 hours.

Packard Creek, the main tributary to Whipple Creek, presents many of the same hydrologic characteristics. The upper section of Packard Creek's stream channel is steep and the slope flattens out near the confluence with Whipple Creek, as shown in Table 7.

Table 7: Packard Creek Main Stem Channel Bottom Slopes

Channel	Reach	Length (mi)	Elev Change (ft)	Slope (%)
Upper	225	1.266	171.66	2.6%
Middle	219	0.206	13.41	1.2%
Lower	210	1.030	43.66	0.8%
Total/Average		**2.502**	**228.73**	**1.7%**

Overall Packard Creek's stream channel is significantly steeper than Whipple Creek's channel.

In 2006, Clark County's 2006 assessment confirmed the presence of erosion in the watershed, noting that stream scour, incision, and channel instability were common. The county found that deliberate modifications to the channel (e.g. channel straightening, in-line ponds) were relatively infrequent. However, channel crossings from past agricultural activities and driveways are fairly common in tributaries.

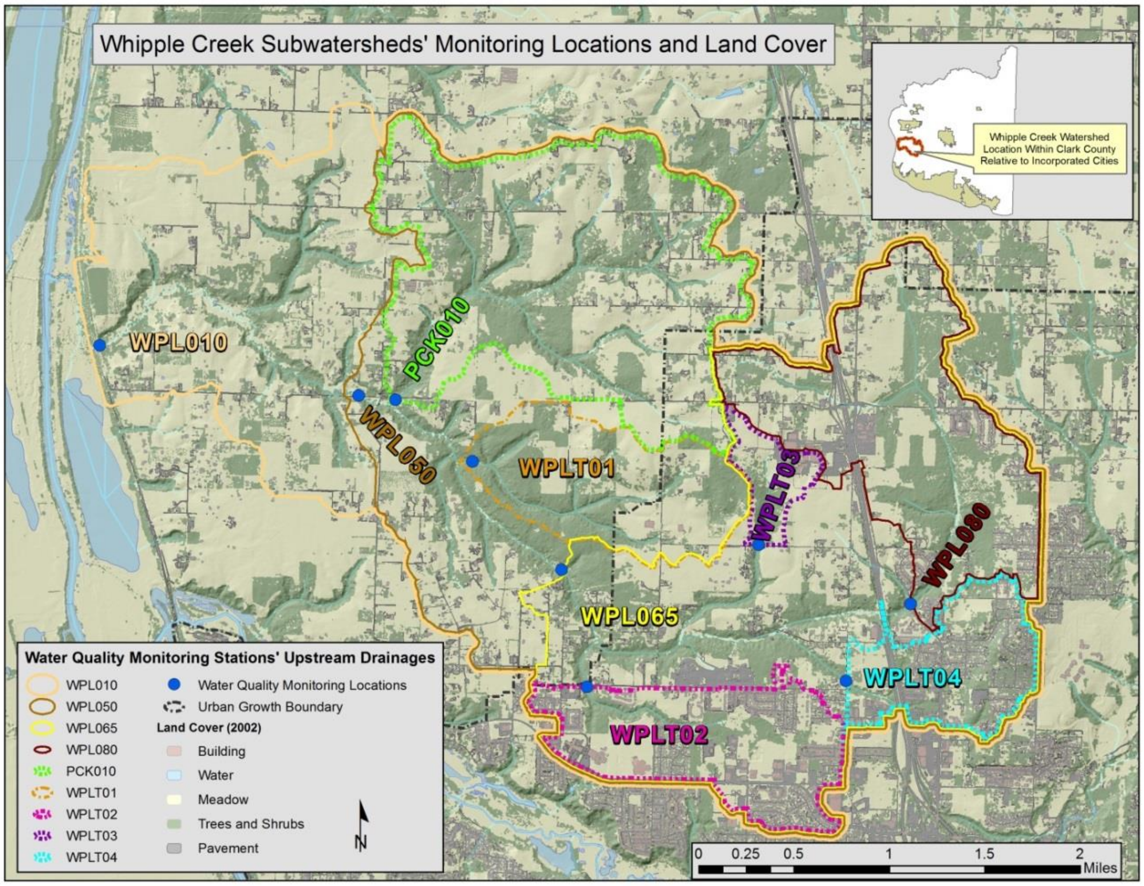
Stream hydrology has been altered as a result of development that occurred over many decades without stormwater detention. In addition, Inter-Fluve noted in its technical memo (2006) that because most development is occurring in the upper watershed, peak flows in the lower main stem could continue to increase significantly.

C. Water Quality

Information about water quality was gathered from several assessments and studies conducted between 2001 and 2015. Figure 3 shows nine stations where water quality data were collected at various times.

Appendix B contains a detailed assessment of Whipple Creek's water quality.

Figure 3: Monitoring Stations and Contributing Basins to Each Station



Water quality in the Whipple Creek watershed is often poor and is impacted by urban and rural development, which channels polluted runoff to the creeks. Ecology includes the lower main stem of Whipple Creek on its 303(d) Category 5 List of polluted waters for fecal coliform bacteria and temperature (Ecology, 2016).

High fecal coliform levels are a watershed-wide issue. The creek frequently exceeds the state's standards for primary contact recreation. Monitoring results suggest there are multiple sources of bacteria in the watershed. Typical sources are urban runoff carrying pet waste; rural non-point pollution from livestock; failing septic systems; and natural contributions from beaver, waterfowl, and other wildlife. Non-stormwater sources of bacteria such as these do not enter streams through the county's storm sewer system.

Existing Conditions

Long-term monitoring results show that Whipple Creek rarely exceeds state standards for either dissolved copper or dissolved zinc, suggesting that these urban pollutants are not limiting water quality in the watershed.

Table 8 summarizes the water quality parameters considered in the assessment of existing conditions and describes whether Whipple Creek meets state standards based on data collected in 2014 and 2015.

Table 8: Summary Comparison of Whipple Creek Water Quality to State Standards

Water Quality Parameter	State Designated Use Protection: Water Quality Standard Criteria & As Applicable Exceedance Frequency Limit	Met Water Quality Standard	Comments on 2014-2015 Watershed-wide Monitoring Results Exceedance of State Water Quality Standards Criteria
Temperature	Aquatic Life Use: 7-Day Average Daily Maximum (7-DADMax) of 17.5°C (63.5°F) once every 10 years on average	No	Most lower main stem and some tributary sub-watersheds commonly exceeded criteria especially during July & August, up to 87 and 77 times / year, respectively
Fecal Coliform	Primary Contact Recreation Use: < geom. mean of 100 cols./100 mL & < 10% of samples: 200 cols./100 mL Preferable to average by season of < 12 months	No	Except for WPL065 and WPL080 wet season, all of the other sub-watersheds exceeded the state's geometric mean criterion during both seasons. All the stations also exceeded the 10% criterion during both the wet and dry seasons.
Dissolved Copper	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 & WPLT04 exceed chronic and acute criteria and for both stations' criteria in only 6% of their respective samples. PCK010 exceeds chronic in 11% and acute in 6% of samples
Dissolved Zinc	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 exceeded either criterion but did so for both in only 6% of its samples

Three additional water quality parameters are of concern to Clark County. Dissolved oxygen, turbidity, and pH have standards established in state law to support the designated use of salmonid spawning, rearing, and migration. Whipple Creek is listed as a Category 2 water of concern for dissolved oxygen on the state's 303(d) List.

The Permit does not require consideration of these parameters. They are discussed in Appendix B but are not otherwise discussed in this Report.

D. Temperature

Information on existing conditions for temperature was gathered from the County's long-term temperature monitoring station at WPL050 and from watershed-wide temperature monitoring during the summers of 2014 and 2015.

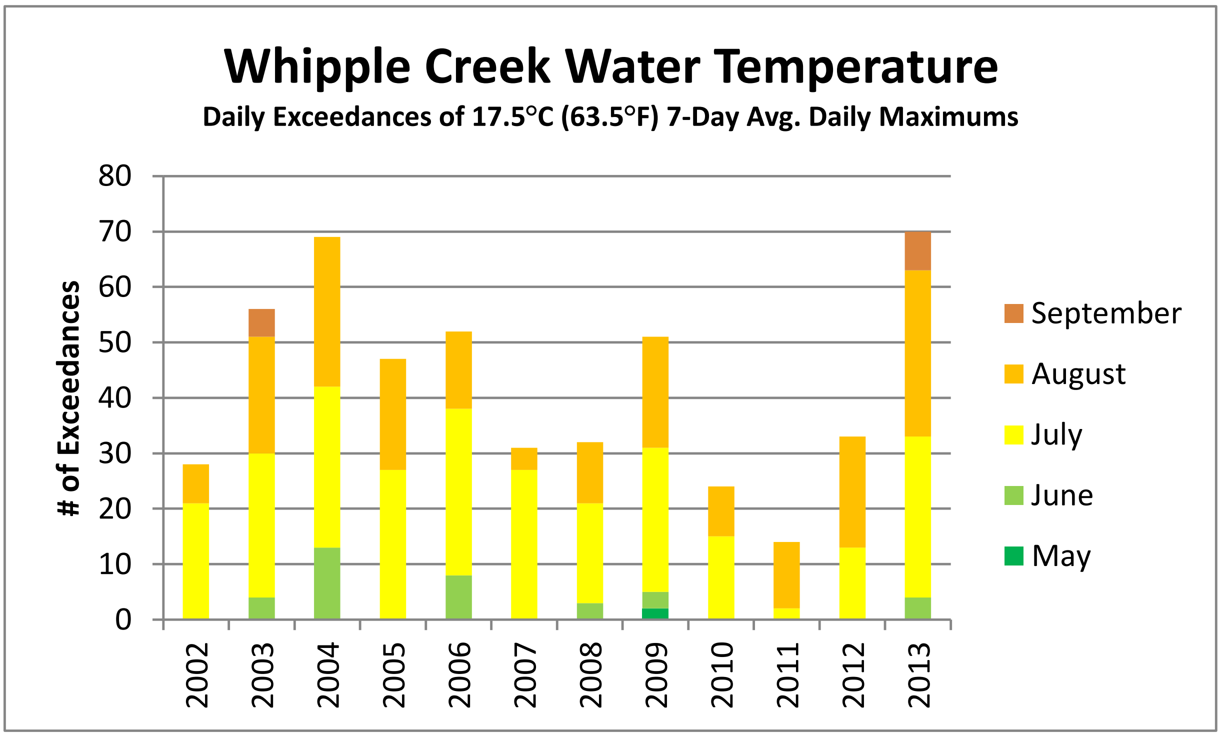
A detailed discussion of Whipple Creek's temperature is in Appendix B.

Whipple Creek is known to be warm and often exceeds temperatures known to kill or stress salmon and steelhead. High summer stream temperatures are frequent, peaking in July and August. Whipple Creek is on the state's 303(d) Category 5 List of polluted waters for temperature.

Long-term monitoring shows that the lower main stem has exceeded the 7-Day Average Daily Maximum temperature of 63.5°F established by the state between 13 and 70 times a year since 2002.

See Figure 4 for long-term exceedances at the WPL050 monitoring station in Middle Whipple Creek.

Figure 4: Lower Whipple Creek WPL050 Main Stem Exceedances of Temperature Criterion



E. Benthic Macroinvertebrates - Biologic Health

Information about existing conditions for biologic integrity was gathered from Clark County's long-term sampling site in the mid-watershed main stem as well as from sampling at four locations during 2014 and 2015.

A more detailed discussion of the macroinvertebrate sampling is in Appendix C.

Existing Conditions

In the summers of 2014 and 2015, the County sampled four locations to assess stream health based on the B-IBI score.

Whipple Creek appears to have poor biologic health. Low B-IBI scores consistent with streams not supporting salmonid uses were found in the rural Middle Whipple Creek, near the mouth of the rural Packard Creek tributary, and in the urbanized Upper Whipple Creek east of I-5. Miner Creek had B-IBI scores consistent with streams that partially support salmonid uses. Lower Whipple Creek is on the 303(d) Category 5 List of polluted waters for bioassessment.

Table 9: 2014 and 2015 Salmonid Use Attainment Based on B-IBI (Based on Observed Conditions)

Location	2014	2015	Key	
Lower Main Stem (WPL050)	Non-Supporting	Non-Supporting	(blue)	Fully Supporting
Upper Main Stem (WPL080)	Non-Supporting	Non-Supporting	(green)	Partially Supporting
Miner Creek (MCT010)	Partially Supporting	Partially Supporting	(orange)	Non-Supporting
Packard Creek (PCK010)	Non-Supporting	Non-Supporting		

F. Fish Distribution and Habitat

Data on fish distribution were gathered from the Statewide Washington Integrated Fish Distribution geodatabase (Washington State Department of Fish and Wildlife [WDFW], 2014) and the SalmonScape web page (WDFW, 2014).

A detailed discussion of fish presence and distribution is in Appendix D.

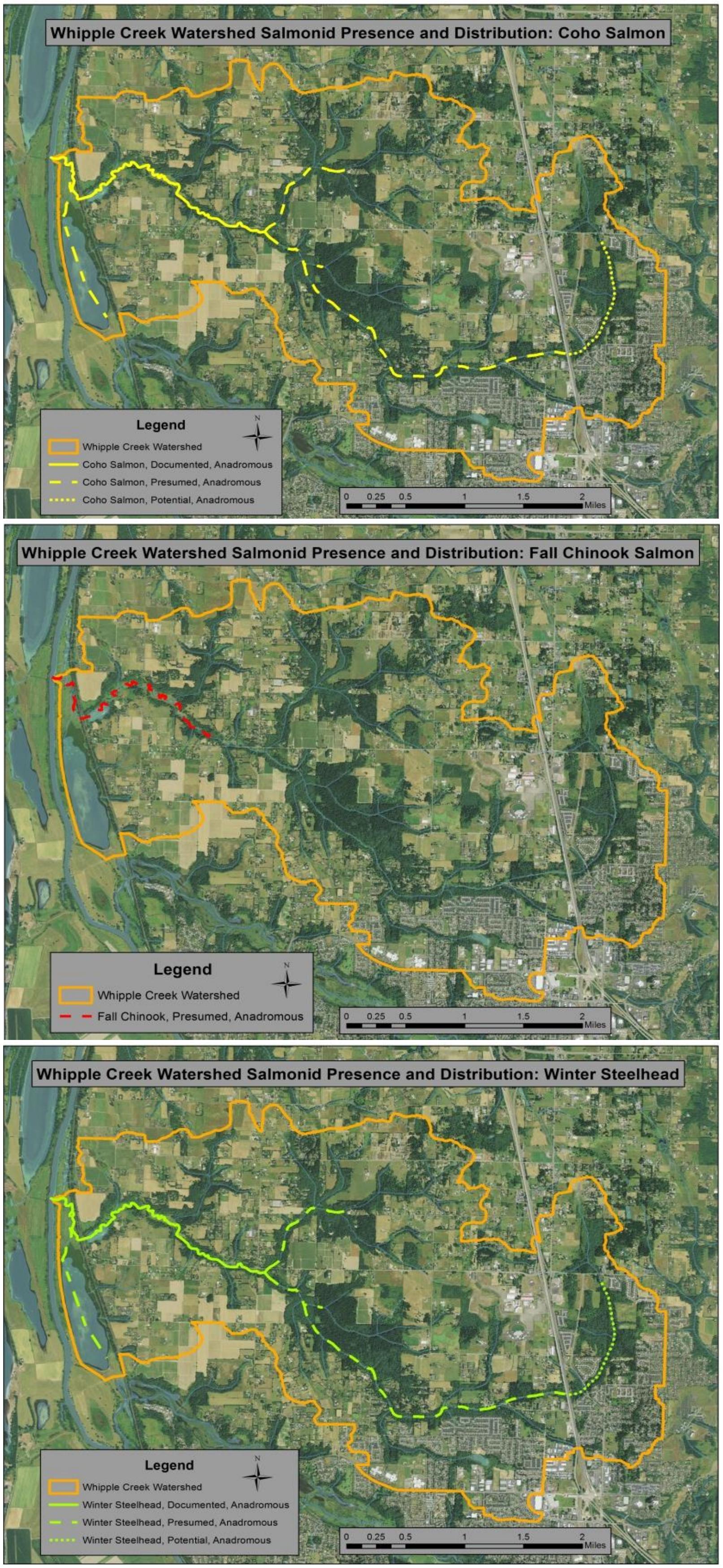
Figure 5 (next page) shows WDFW fish distribution maps for coho salmon, fall chinook salmon, and winter steelhead.

Field observations suggest a lack of spawning habitat for salmonids in the watershed. Low gradient channels are mostly bedded with sand and silt that is unsuitable for spawning, and fish passage barriers limit access to potentially good quality habitat (Inter-Fluve, 2006). The most suitable habitat has been identified in the lower watershed (Inter-Fluve, 2006).

Several partial fish passage barriers exist in the main stem, and there is a complete barrier at I-5. The barrier at I-5 would prevent anadromous fish from using any portion of Whipple Creek upstream of there. There are also barriers in lower Miner Creek and School Land Creek.

Overall, the status of the Whipple Creek watershed's fish community appears degraded. Good quality salmonid habitat is very limited due to small stream sizes, substrate conditions, and passage barriers. Whipple Creek's anadromous fish are listed as Threatened under the Endangered Species Act, including fall Chinook, coho salmon, and winter steelhead.

Figure 5: WDFW Fish Distribution Maps



G. Areas of Special Attention

Information about areas of special attention in Whipple Creek was gather from historic field observations, existing reports, and geographic information system (GIS) data analyses. Such areas include riparian buffers, wetlands, hydric soils, floodplains, steep slopes, forests, valuable habitat zones, and other sensitive resource areas.

A detailed discussion of areas of special attention is in Appendix E.

II. Creating Models of Whipple Creek

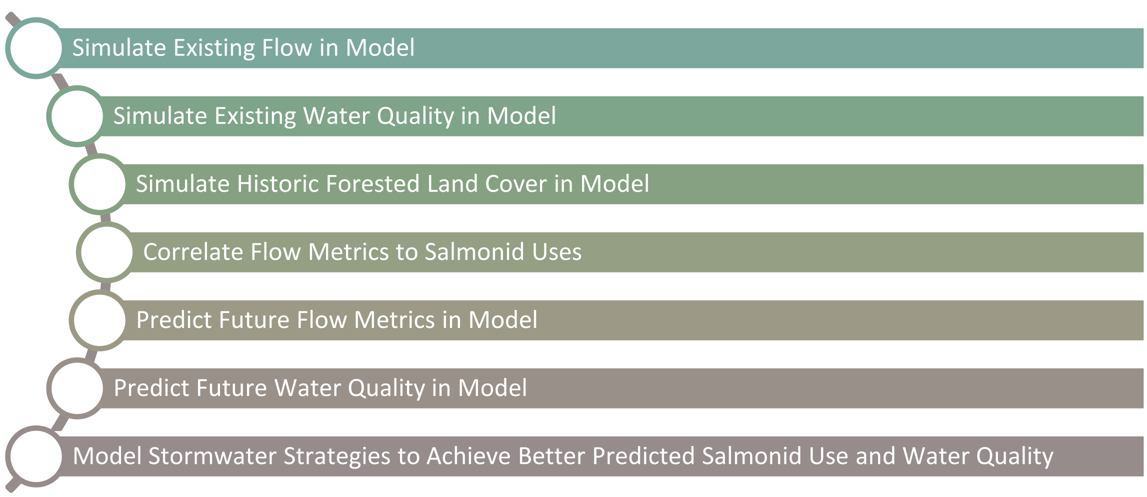
Models were calibrated following Task 3 of The Whipple Creek Watershed-Scale Stormwater Planning Scope of Work and Schedule, June 2014.

A. Purpose of Models

Stream hydrology and water quality change when land cover changes. Modification from forest to agriculture or to urban areas increases runoff and pollutants directed to creeks. As the Whipple Creek watershed develops over time, stream flow, the shape of the stream channel and banks, water quality, and temperature all change as a result of the impacts of stormwater runoff.

Using predictions of future land uses and land covers, this Report estimates future water quality and hydrologic conditions of Whipple Creek and its tributaries. Once the magnitude of potential impact is understood, the models can be used to test the effectiveness of stormwater management strategies and other strategies the County might use to mitigate the impacts of future development.

Figure 6: Purpose of Computer Models of Whipple Creek's Hydrology and Water Quality



Detailed discussions of hydrology model calibration and water quality model calibration are found in Appendices F and G.

B. Calibration Period and Data

Model calibration uses available data about precipitation, land cover, stream flow, pollutant concentrations, and air and stream temperatures in Whipple Creek from the recent past to match observed conditions as much as possible. Once calibrated, the models can be used to estimate hydrology, pollutant concentrations, and stream temperature under different future scenarios of land cover and stormwater management strategies.

Creating Models of Whipple Creek

The calibration period for both the hydrology and the water quality models was selected based on availability of the best quality stream flow data. The calibration period was for a five-year span beginning October 2003 and continuing through September 2008 (water years 2004 through 2008).

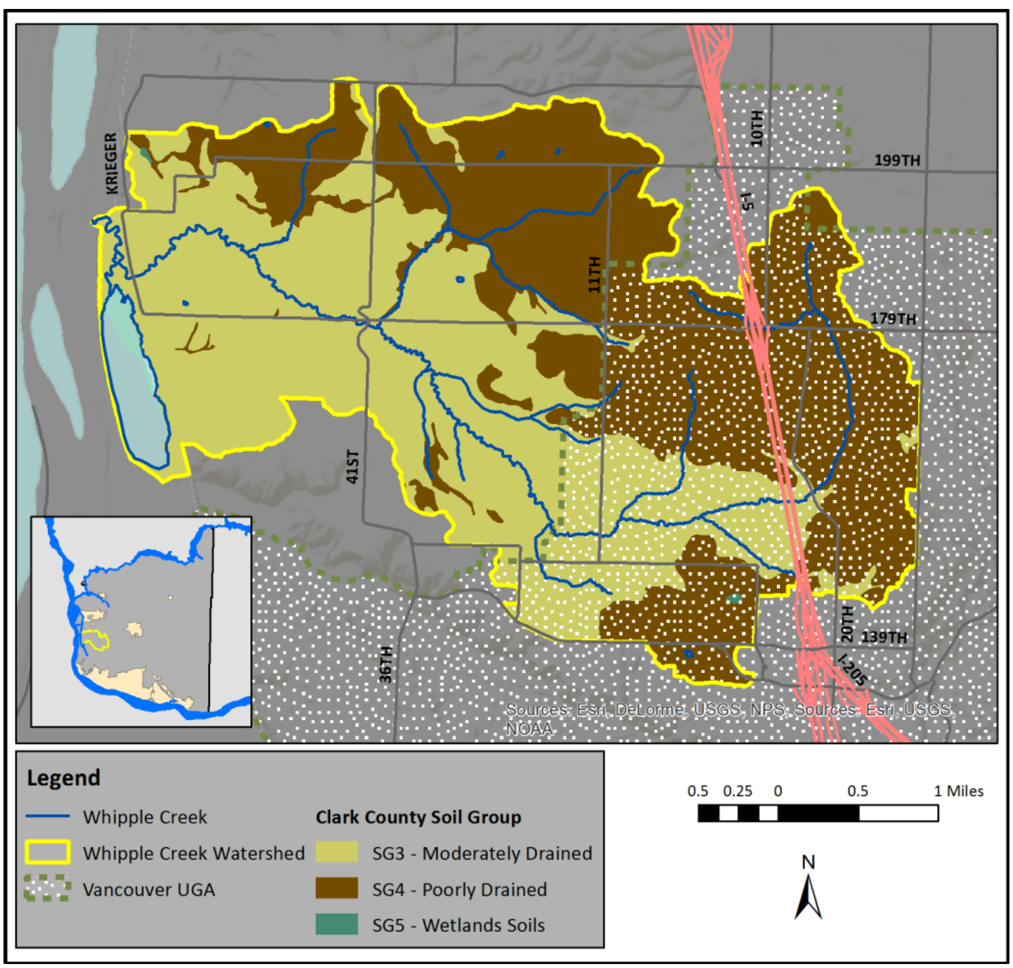
Data included continuous flow monitoring from Clark County's monitoring stations, stream temperature data, pollutant concentrations, and B-IBI collected and calculated as described in the assessment of Whipple Creek's existing conditions in Appendices B and C. The calibration for flow and water quality was at the WPL050 site.

Meteorological data (rainfall, evaporation, air temperature, cloud cover, dew point, temperature, wind speed, and solar radiation) were assembled from local sources for the calibration period.

Using infiltration capacity, soils in Clark County were grouped into five generalized categories. Underlying soils in the Whipple Creek watershed are a mix of moderately drained soils, poorly drained soils, and wetland soils. The following three soil groups were used in the model calibration:

1. SG3: Moderately Drained soils (hydrologic soil groups B & C)
2. SG4: Poorly Drained soils (slowly infiltrating C soils, as well as D soils)
3. SG5: Wetlands soils (mucks)

Figure 7: Whipple Creek Soil Groups

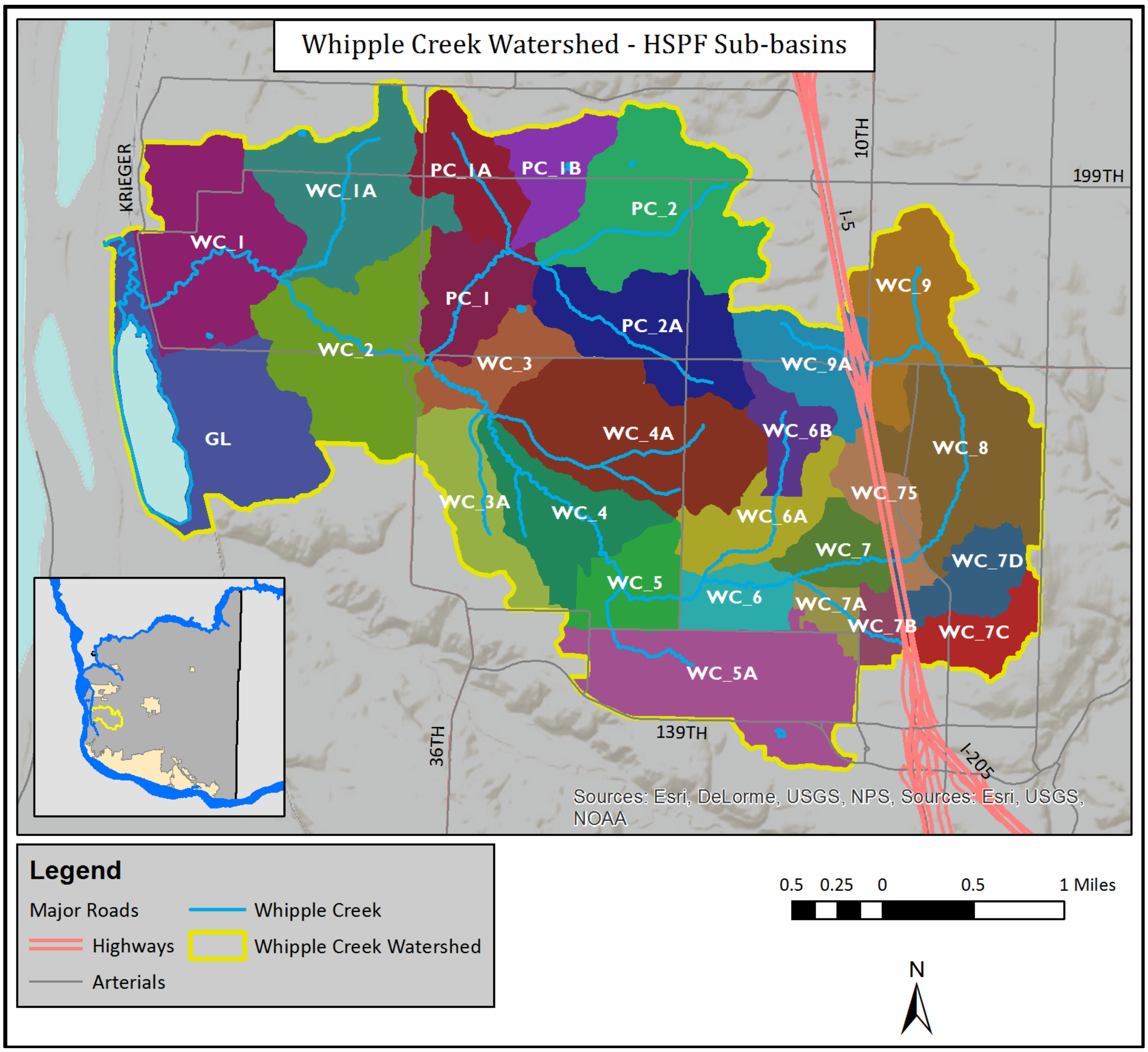


C. Hydrology Model Creation and Calibration

The Whipple Creek watershed hydrology model calibration produced a computer model of the contributing land area rainfall-runoff processes and stream flow routing from the upper end of Whipple Creek and its tributaries.

The hydrology model calibration required first dividing the Whipple Creek watershed into 27 sub-basins. The land area for each sub-basin was divided into bare soil, forest, grass, paved urban, and water land covers. The stream reach boundaries were selected based on topography, confluence with other major reaches, and flow travel time in the stream channel.

Figure 8: Modeled Sub-basin Boundaries



The calibration process is iterative and requires the input and adjustment of hydrologic parameter values and the comparison of simulated and recorded streamflow. Different hydrologic parameters and their values impact or change the timing and distribution of runoff. Some parameters represent different soil and vegetation characteristics while other parameters represent different runoff processes.

Based on experience in calibrating other hydrology models in western Washington, appropriate hydrologic parameter values were selected for the calibration. The hydrology model computed the simulated stream flow using these values. The results were compared with the recorded (observed) stream flow at the WPL050 gage located on the main stem in Middle Whipple Creek below Packard Creek. The results were compared in terms of hydrograph shape and size for multiple major flood events, annual total runoff volume, and flow duration. Flow duration is the percent of time different size flows occur at the gage site.

After each comparison, the hydrologic parameter values were adjusted with the goal of producing a better fit or comparison with the recorded stream flow data. The calibration process ended when it was decided that the hydrologic parameter values produced the best results and no further adjustment of these parameters would improve the calibration.

Table 10 shows the model performance for each of four comparative measures.

Table 10: Hydrology Model Performance

Calibration Period (WY 2004-2008)	Whipple Creek	Overall Model Performance
Annual Volume Error	Very Good	Very Good
Daily Flow R Squared	Very Good	Very Good
Flow Duration Curves	Excellent	Very Good
Hydrographs	Good to Very Good	Very Good

The calibration provided a sound hydrologic model of Whipple Creek. The resulting model parameters were appropriate for evaluating the impact of hydromodification management strategies and calibrating a water quality model. The calibration results demonstrate a good representation of the observed data.

The specifics of the hydrology calibration, the final selection of hydrologic parameter values, and the comparison of the simulated and recorded streamflow data are described in detail in the hydrology model calibration report in Appendix F.

D. Water Quality Model Creation and Calibration

The Whipple Creek watershed water quality model calibration produced a computer model of the contributing land area pollutant-producing processes and transport of these pollutants from the upper end of Whipple Creek and its tributaries. This water quality model was used to model water quality for both existing land use and future development conditions.

The water quality model calibration followed the completion of the hydrology model calibration. After the hydrology model calibration was finished, then water quality inputs were added for the simulation of copper, zinc, fecal coliform, and water temperature.

Creating Models of Whipple Creek

The same sub-basins and stream reaches used in the hydrology model calibration were used to calibrate the water quality model. Pollutant loading rates were based on sub-basin impervious area, soil group, and vegetation category. Soil temperature was correlated to air temperature. The movement of the pollutants (copper, zinc, and fecal coliform) and the calculation of water temperature were based on the stream channel characteristics.

The calibration process was iterative and required the input and adjustment of water quality model parameter values and the comparison of simulated and recorded water quality constituents (copper, zinc, fecal coliform, and water temperature). Different water quality parameters and their values impact or change the timing and distribution of each individual constituent. Some parameters represent different soil and vegetation-related pollutant loading rates while other parameters represent different interactions with the meteorological input.

Based on experience in calibrating other water quality models in western Washington, appropriate model parameter values were selected for the calibration of copper, zinc, fecal coliform, and water temperature. The water quality model computed the simulated water quality results in Whipple Creek using these parameter values. The results were compared with the recorded (observed) copper, zinc, and fecal coliform concentrations and water temperature at the WPL050 gage. The results were compared in terms of seasonal and annual values.

After each comparison, the model calibration parameter values were adjusted with the goal of producing a better fit or comparison with the recorded data. The calibration process ended when it was decided that the final selection of model calibration parameter values produced the best results and no further adjustments would improve the calibration.

Table 11 shows the model performance for each constituent.

Table 11: Water Quality Model Performance

Parameter	Model Performance
Temperature	Very Good to Excellent
Dissolved Metals	Appears Good
Fecal Coliform	Good
Overall Performance	**Good to Very Good**

Overall, the water quality calibration is considered good to very good. The water quality calibration model can be used to model water quality for both existing land use and future development conditions and scenarios.

The specifics of the water quality calibration are described in detail in Appendix G.

E. Reporting Model Results

The calibrated models produce simulated conditions for stream reaches in 27 sub-basins. To simplify presentation of model results, flow metrics and B-IBI scores are reported for a set of eight stream reaches.

Reaches were selected to represent the full range of conditions in the watershed and to demonstrate whether strategies will meet the Permit goal of restoring designated uses. Criteria for selection included:

- Presence of actual or potential salmon habitat
- Contribution of a significant part of the watershed
- Importance for modeling future conditions
- Represent areas to preserve/restore or retrofit
- Not subject to Columbia River backwater conditions

Reporting reaches are described below and are represented as sub-basins in Figure 9.

WC-2 – Lowermost Whipple Creek

This reach has a broad floodplain and potential for salmon spawning habitat restoration. It is the lowest Whipple Creek reach not subject to backwater conditions from the Columbia River floodplain. Temperature is a concern here. See Map A in Figure 9.

WC-3 – Whipple Creek at Sara

This reach includes significant potential salmon habitat and pool-riffle channel sequences that have potential for salmon habitat restoration. The lower end of the reach includes the mouth of Packard Creek, and it is the closest point to the county's long-term monitoring site at the Sara gage (WPL050). Temperature is a concern here. See Map B in Figure 9.

WC-5 – Whipple Creek above Whipple Creek Park

This point represents the main stem between I-5 and Whipple Creek Park. This reach has a fairly low gradient and extensive beaver ponds. Temperature is a concern here. See Map C in Figure 9.

WC-7.5 – Whipple Creek above I-5

There is a full fish passage barrier at I-5 making the area above I-5 a single area of interest for delivering flow and pollutants to downstream salmon habitat. See Map D in Figure 9.

WC-1A – Miner Creek Tributary

Miner Creek has spawning gravel and the best water quality conditions in the watershed. It is of interest for preservation and restoration. See Map D in Figure 9.

PC-1 – Packard Creek Tributary

Packard Creek is the largest tributary to Whipple Creek. The creek has gravel channel substrate providing salmon habitat. While it is significantly degraded due to hydrologic modification and rural land uses, Packard Creek provides an opportunity for salmon habitat restoration. See Map D in Figure 9.

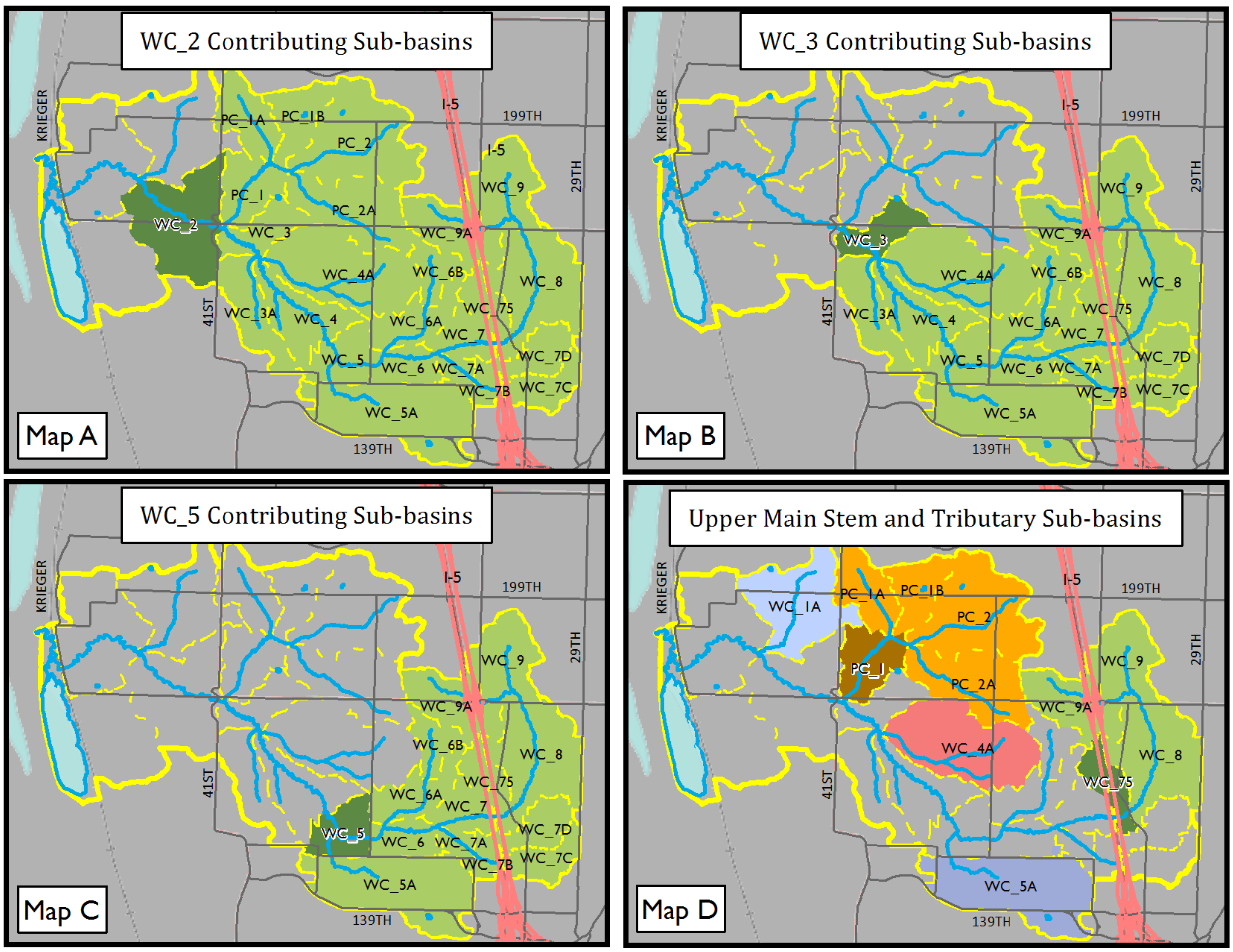
WC-4A – School Land Creek Tributary

School Land Creek drains an area that has potential as salmon habitat and is a sub-basin where Clark County has extensive land holdings as parks and open space. See Map D in Figure 9.

WC-5A – 139 St Tributary

WC-5A is a completely developed urban area built out over the last 30 years. Stream hydrology is greatly altered due to urban runoff and will require extensive retrofitting to restore the tributary's lower reach as salmon habitat. See Map D in Figure 9.

Figure 9: Model Results Reporting Reaches (Shown as Sub-basins) and Contributing Sub-basins



Darker sub-basins = Reporting sub-basins
Lighter sub-basins = Contributing flow to reporting sub-basin

III. Predicting the Future in Whipple Creek

A. Future Development in Whipple Creek

In 2016, Clark County adopted a *Comprehensive Growth Management Plan 2015-2035* (Comp Plan) to guide growth and development for the next 20 years. The Comp Plan's Community Framework Plan describes a vision in which land outside of urban growth areas is predominantly rural with farms, forests, open space, and large lot residences while urban growth areas are targeted for higher densities and a mix of more urban land uses (Clark County, 2016).

i. Land Use

The Whipple Creek watershed contains both the unincorporated Vancouver UGA (nearly 5 sq. mi. in the upper and middle watershed) and rural land throughout the watershed (approximately 7 sq. mi.).

Broadly, the Comp Plan describes a Whipple Creek watershed in which the I-5 corridor will become even more densely developed with industrial and commercial uses, as well as single-family and multi-family homes. The remainder of the UGA will be filled in with lower and medium density residential uses and mixed use. Open spaces will also be present in the UGA outside of the I-5 corridor.

Outside of the UGA, the Comp Plan describes a Whipple Creek watershed that will remain predominantly rural in character, with designations for rural, agriculture, parks/open space, and a small rural commercial area in the traditional unincorporated center of Sara.

Assumptions about future land uses based on Comp Plan designations were used to calculate future land covers. Future land covers form the basis for models that predict water quality and hydrologic conditions in Whipple Creek and its tributaries as the area develops. If all lands in the Whipple Creek watershed were developed to the full densities allowed under the Comp Plan and zoning designations, the watershed would contain the quantities of land covers shown in Table 12.

Table 12: Future Land Cover in Whipple Creek

Land Cover	Residential Impervious	Non-residential Impervious	Forest	Pasture	Lawn	Water
Acres	695	603	1,824	2,284	2,132	185

Land cover from allowed future build-out of the watershed was used to model future development scenarios to predict the effects on water quality and hydrology.

A full discussion of land use assumptions is given in Appendix J.

ii. Development and Engineering Standards

Modeled future scenarios assume that development in Whipple Creek will meet a number of County code chapters and standards that are pertinent to modeling hydrology and water quality. Assumptions are described below. For a chronology of past stormwater-related engineering standards enforced by Clark County, see Appendix N.

Stormwater Code and Manual

Future scenarios assume development will manage stormwater in accordance with Clark County's current Clark County Code Chapter 40.386, Stormwater and Erosion Control, which adopts the *2015 Clark County Stormwater Manual* (CCSM). This code is intended to protect water quality of surface and ground waters for drinking water supply, recreation, fishing, and other beneficial uses. The county manual is equivalent to the Ecology Stormwater Management Manual for Western Washington.

The adopted code and manual meet the requirement to use "all known, available, and reasonable methods of prevention, control, and treatment (AKART)" under the Washington Water Pollution Control Act (RCW 90.48) and reduces discharges to the "maximum extent practicable (MEP)" as required under the Clean Water Act (USC, Title 13, Section 1251 *et seq.*).

LID and County Code

In 2012 and 2015, Clark County revised road standards and development standards in Title 40 to remove barriers to Low Impact Development (LID).

LID is required in the CCSM, and modeled future scenarios assume that the bioretention LID best management practice will be used in development whenever feasible.

Use of other LID techniques such as lot clustering to reduce impervious surfaces could impact future development. County Code allows new subdivisions to cluster lots to preserve open space such as pasture and forest in rural zoned areas. Use of optional lot clustering provisions is difficult to predict and to model at the watershed scale. Considering this, future scenarios assume forested critical areas including both habitat and geologic hazard areas will remain forested.

Areas of Special Concern and County Code

Areas of Special Concern include critical areas where development is regulated under Title 40 to protect the environment, public safety, and public health. These are:

- Critical aquifer recharge areas
- Flood hazard areas
- Geologic hazard areas
- Habitat conservation areas
- Wetland protection areas
- Shorelines of the state

Several critical areas are assumed to remain forested in modeled future scenarios, including:

- Geologic hazards, which are mapped primarily as steep slopes and potential landslide areas;
- Habitat conservation areas; and
- Wetlands that are forested in the existing condition.

Modeled future scenarios do not consider critical aquifer recharge areas (CARAs) or flood hazard areas because they do not influence stream conditions. The entire watershed is a CARA to protect the regional gravel aquifer.

Whipple Creek is a shoreline water body, having regulated shoreline and floodplain from the Columbia River floodplain upstream to near the confluence with Packard Creek. Shorelines are often redundant with wetlands and riparian buffers, which were assumed to remain forested in the future scenarios.

B. Baseline Scenarios

Two baseline scenarios were modeled following Task 4 of The Whipple Creek Watershed-Scale Stormwater Planning Scope of Work and Schedule, June 2014.

i. Forested Land Cover Baseline Scenario

To form a baseline of hydrology for comparing future scenarios, the calibrated hydrology model was used to predict the hydrology of Whipple Creek with simulated historic forest land cover (Baseline Forested Scenario).

Using the modeled flow metrics with the established correlation of flow to B-IBI scores and salmonid uses, the model predicted the ability of the watershed to support salmon and steelhead under forested conditions.

Model Description

The Baseline Forested Scenario assumes a fully forested land cover in each of the modeled sub-basins. A limitation of the model is the inability to recreate pre-disturbance stream structure and drainage patterns, so the Baseline Forested Scenario assumes the forested land cover is applied to the watershed's current stream morphology.

Model Results

The Baseline Forested Scenario simulated stream flow for five water years (2004-2008). Flow metrics including T_{Qmean} and HPC were estimated using reported meteorological data from those years.

Predicted B-IBI scores were calculated from simulated flow metrics as the average annual scores for five years, estimated using the relationships established each for T_{Qmean} and HPC, as described in the Introduction.

Table 13: Predicted B-IBI Under Simulated Forested Land Cover

Sub-basin	Average B-IBI	Standard Salmonid Use Range (B-IBI)
WC-1A	34	Partially Supporting
WC-2	34	Partially Supporting
WC-3	34	Partially Supporting
WC-4A	33	Partially Supporting
WC-5	34	Partially Supporting
WC-5A	35	Partially Supporting
WC-7.5	34	Partially Supporting
PC-1	33	Partially Supporting

Under simulated forested conditions with the watershed's current stream morphology, a B-IBI score of 39 was the highest single score achieved in any reporting sub-basin. This score was calculated from T_{Qmean} and was achieved at WC-2 and at WC-4A in 2007.

Salmonid use attainment ranges were also estimated based on the correlations described in the Introduction for T_{Qmean} and HPC. The metrics and associated ranges are shown in Table 14.

Table 14: Simulated Flow Metrics and Salmonid Use Attainment Under Simulated Forest Land Cover

Sub-basin	Average T_{Qmean}	T_{Qmean} Salmonid Use Range	Average HPC	HPC Salmonid Use Range
WC-1A	34%	Partially Supporting	3	Fully Supporting
WC-2	35%	Partially Supporting	4	Fully Supporting
WC-3	35%	Partially Supporting	3	Fully Supporting
WC-4A	35%	Partially Supporting	4	Fully Supporting
WC-5	35%	Partially Supporting	4	Fully Supporting
WC-5A	36%	Partially Supporting	3	Fully Supporting
WC-7.5	34%	Partially Supporting	3	Fully Supporting
PC-1	34%	Partially Supporting	3	Fully Supporting

Average B-IBI scores and T_{Qmean} calculations suggest that all reporting sub-basins would partially support salmonid uses under forested land cover, while the average of the HPC metric suggests that all reporting sub-basins would fully support salmonid uses under forested land cover.

Adjusting the Fully Supporting B-IBI Score

Ecology's written guidance on watershed planning recommends using the lower of either a B-IBI score of 38 or 90% of the B-IBI score modeled for forested land cover as the threshold for fully supporting salmonid uses in future scenarios (Ecology, March 29, 2016). Following this guidance, the range of B-IBI scores for fully supporting salmonid uses in future scenarios was adjusted as shown in Table 15.

Table 15: Adjusted Salmonid Fully Supporting Use Range (B-IBI) by Reporting Sub-basin

Sub-basin	Average Forested Baseline B-IBI	Adjusted Fully Supporting Range (B-IBI)
WC-1A	34	>31
WC-2	34	>30
WC-3	34	>31
WC-4A	33	>30
WC-5	34	>30
WC-5A	35	>32
WC-7.5	34	>31
PC-1	33	>30

Conclusions

The simulated Forested Baseline Scenario does not unambiguously show that Whipple Creek would fully support salmonid uses even under forested land cover.

Clark County's investigations of the watershed suggest that some of the reasons for these limitations are inherent in the watershed's stream sizes, topography, and natural substrate (see Chapter I, Section F).

For determining fish use attainment predicted for modeled future scenarios, the lower threshold for attaining fully supporting salmonid uses based on B-IBI is adjusted to 90% of the B-IBI attained in the Forested Baseline Scenario.

ii. Full Build-out Baseline Scenario (Future Scenario 1)

Future Scenario 1 (FS1) is the future full build-out of the urban portion of the watershed. FS1 forms the baseline for decision-making in this Report. If the results of FS1 show that the Whipple Creek watershed will not meet water quality standards or attain designated salmonid uses, then the Permit requires Clark County to analyze management strategies it could implement to meet those requirements.

Description of Full Build-out Baseline Scenario

FS1 assumes that the UGA in the watershed will develop under existing land use designations to full densities allowed under the current Comprehensive Plan, which plans for county growth through 2035.

Using the build-out assumptions stated above, FS1 models the impact of land cover changes and the required stormwater controls under the 2015 Title 40 and the CCSM.

Stormwater facilities for full build-out were modeled as a single bioretention facility and a single stormwater detention pond for each sub-basin within the UGA. The bioretention facility included infiltration for Soil Group 3 (SG3), but no infiltration for Soil Group 4 (SG4).

The modeled stormwater facilities were sized using the Western Washington Hydrology Model version 2012 (WWHM2012). The bioretention facilities were sized to meet the water quality treatment standard (Minimum Requirement #6 of the CCSM). Bioretention facilities in sub-basins with SG3 soils were also sized to meet the LID Performance Standard (Minimum Requirement #5 of the CCSM). Stormwater detention ponds were sized to meet the western Washington Flow Control Standard (Minimum Requirement #7 of the CCSM).

Appendix K describes modeling stormwater facilities in FS1 using WWHM2012.

Bioretention facilities and stormwater detention ponds were modeled to reduce copper, zinc, and fecal coliform concentrations in stormwater runoff based on Ecology's watershed planning assumptions guidance (March 29, 2016).

Ecology's recommended pollutant removal rates are shown in Table 16.

Table 16: Pollutant Removal Rates

Runoff Flow Route	Copper	Zinc	Fecal Coliform
Bioretention flow through riser	0%	0%	0%
Bioretention flow through media to underdrain	0%	60%	50%
Bioretention flow to groundwater	100%	100%	100%
Stormwater Detention Pond discharge to stream	0%	0%	50%

These pollutant removal rates were incorporated into all subsequent future scenario water quality models.

Model Results

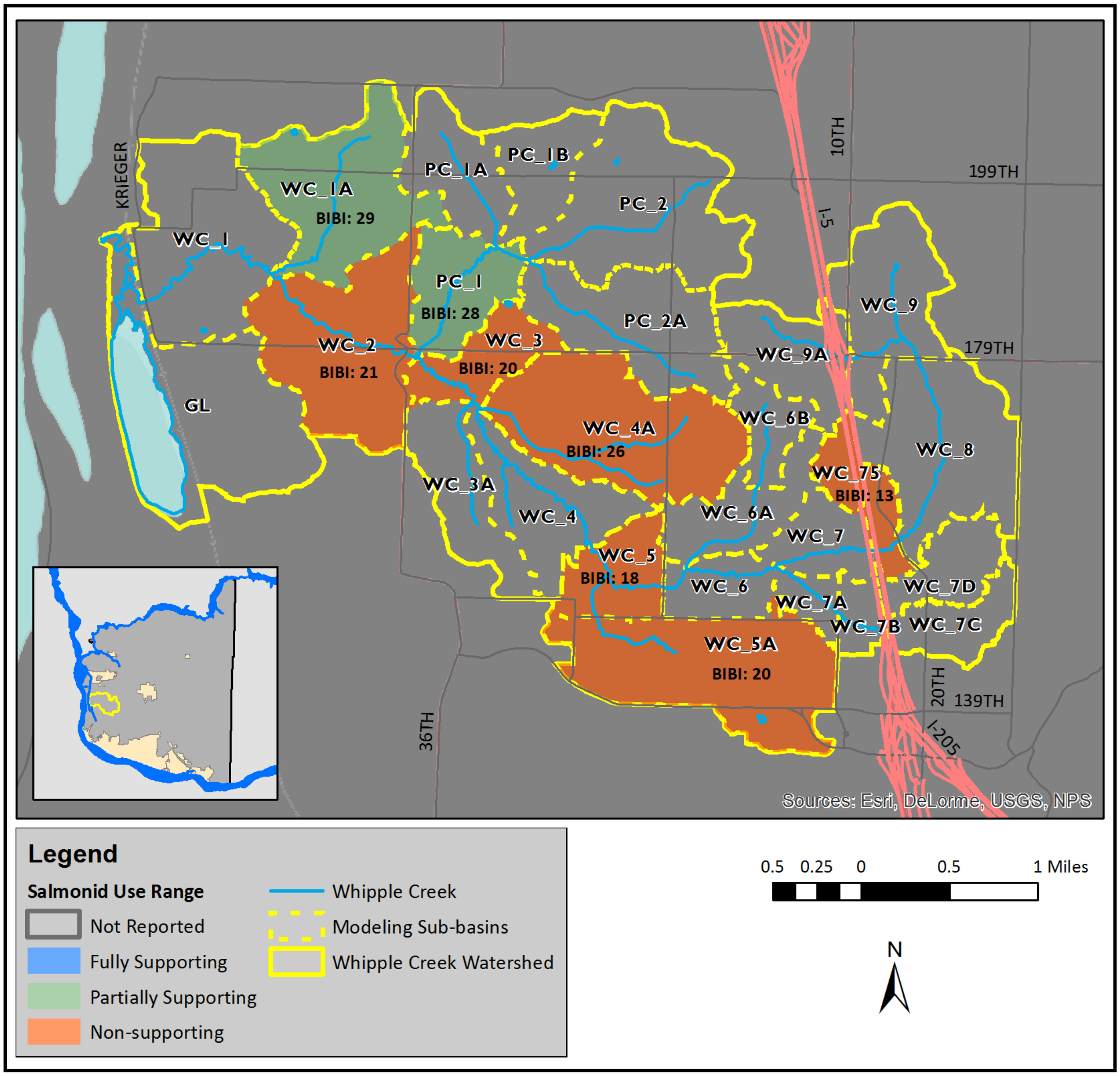
FS1 model results simulated stream flow and water quality parameters for five water years (2004-2008).

Predicted B-IBI scores were calculated from simulated flow metrics as the average annual score for five years, estimated using the relationships established each for T_{Qmean} and HPC. Predicted flow metrics were also directly reported. The B-IBI scores, flow metrics, and related salmonid use ranges are shown in Table 17. Figure 10 is a map of B-IBI scores.

Table 17: Predicted B-IBI, Flow Metrics, and Salmonid Use Ranges for Full Build-out Baseline (FS1)

	B-IBI			T_{Qmean}		HPC	
Sub-basin	Average B-IBI	Adjusted Salmonid Use Range	Adjusted Fully Supporting B-IBI	Average T_{Qmean}	Salmonid Use Range	Average HPC	Salmonid Use Range
WC-1A	29	Partially Supporting	>31	34%	Partially Supporting	6	Fully Supporting
WC-2	21	Non-supporting	>30	32%	Partially Supporting	14	Non-supporting
WC-3	20	Non-supporting	>31	30%	Partially Supporting	15	Non-supporting
WC-4A	26	Non-supporting	>30	33%	Partially Supporting	9	Partially Supporting
WC-5	18	Non-supporting	>30	29%	Partially Supporting	18	Non-supporting
WC-5A	20	Non-supporting	>32	31%	Partially Supporting	17	Non-supporting
WC-7.5	13	Non-supporting	>31	26%	Non-supporting	29	Non-supporting
PC-1	29	Partially Supporting	>30	33%	Partially Supporting	6	Fully Supporting

Figure 10: Map of Predicted B-IBI Scores and Adjusted Salmonid Uses - Full Build-out (FS1)



Based on B-IBI scores, the main stem of Whipple Creek (sub-basins WC-2, WC-3, WC-5, and WC-7.5) likely would not support salmonid use at full build-out. However, based on T_{Qmean}, most main stem and tributaries may partially support salmonid uses. HPC is less optimistic than T_{Qmean} and more optimistic than B-IBI; HPC shows a majority of reaches not supporting salmonid uses under full build-out and two that may fully support.

The water quality results are presented in terms of violations of the state water quality standards for copper, zinc, fecal coliform, and water temperature. The number of violations that occurred in reporting sub-basins during the five-year simulation period are shown below.

Table 18: Predicted Water Quality Violations, Full Build-out Baseline (FS1)

Sub-basin	Copper - Acute	Copper - Chronic	Zinc - Acute	Zinc - Chronic	Fecal Coliform	Water Temperature
WC-1A	0	0	0	0	1263	9
WC-2	0	0	0	0	1352	494
WC-3	0	0	0	0	1365	407
WC-4A	0	0	0	0	1266	2
WC-5	0	0	0	0	1384	413
WC-5A	0	0	0	0	1358	20
WC-75	0	0	0	0	1440	295
PC-1	0	0	0	0	1268	6

Copper and zinc concentrations in Whipple Creek are not predicted to exceed state water quality standards under full build-out. Predicted number of fecal coliform and water temperature violations are quite high in this scenario in all reporting sub-basins.

Estimated Costs

Full build-out is implemented primarily by private developers and has no estimated capital costs for the county.

Conclusions

The full build-out of the Whipple Creek watershed under current land use assumptions and stormwater control standards mitigates some of the stormwater runoff impacts from expected future development in the UGA, but still results in high fecal coliform and high water temperatures due in large part to the adverse impacts of stormwater runoff from existing development.

Predictions of fish use appear to lean to non-supporting based on B-IBI and HPC, with perhaps some basins partially supporting salmonid uses.

Modeled results of FS1 show that Whipple Creek will achieve neither state water quality standards nor salmonid beneficial uses as the watershed develops under the County's current zoning, development regulations, and stormwater regulations.

Recognizing this, Clark County considered numerous strategies, as described in Section C, that might allow Whipple Creek to achieve the required water quality standards and support salmonid uses as it develops.

C. Strategies to Meet Water Quality Goals

The Permit requires the county to consider several types of strategies to restore or protect designated uses if the full build-out scenario predicts that water quality standards will not be met or salmonid uses will not be attained. The Permit also allows other types of management actions to be considered. This Report contemplates a number of these.

i. Modeled Strategies Required by the Permit

The Permit requires Clark County to model the following stormwater management strategies:

- Future structural stormwater control projects; and
- Changes to development-related codes, rules, standards and plans.

Structural Stormwater Retrofits

The Permit requires Clark County to evaluate the potential effect of a structural retrofit program to add detention and water quality treatment to areas of existing development that do not currently have these controls.

Accordingly, structural stormwater retrofits were modeled for urbanized sub-basins in Future Scenario 2. Additional structural retrofits were modeled for the watershed's rural area in Future Scenario 4. See Section D for a discussion of modeled future scenarios.

Changes to Development-related Codes, Rules, Standards, and Plans

The Permit requires the county to evaluate the potential effect of changes to development-related codes, rules, standards, and plans. Because the county's current development and stormwater codes were updated in recent years to remove barriers to LID and to adopt an equivalent version of Ecology's stormwater manual that is considered AKART, this Report does not suggest any additional development-related code changes.

A brief discussion of each item category and its relevance to Clark County is below.

County Stormwater Code

Clark County development code meets the standards of the current Permit and is unlikely to be changed to the point where potential model scenarios could be created. The Clark County Stormwater Manual (CCSM) is considered to be AKART, and it is the standard for the full build-out scenario.

Rules

Clark County does not use administrative rules; all "rules" are adopted as County Code through legislative process.

Standards

Clark County does not use standards separate from County Code; all standards such as those of the CCSM are adopted as County Code through legislative process.

Comprehensive Growth Management Plan

The Clark County Comp Plan is adopted by the Clark County Board of County Councilors pursuant to state law. This Report does not consider updates to the Comp Plan. Future Comp Plan updates may consider actions for managing stormwater impacts related to growth.

ii. Optional Strategies

In addition to the two required strategies, the Permit allows other stormwater management strategies to be modeled, such as:

- Basin-specific stormwater control requirements for new development and redevelopment (per a basin plan); or
- Strategies to encourage redevelopment and infill.

The Permit also allows evaluating other strategies that influence maintenance of existing and designated uses of the stream, including, but not limited to:

- Channel restoration
- In-stream culvert replacement
- Quality of the riparian zone
- Gravel disturbance regime
- Presence and distribution of large woody debris

Consideration of Optional Strategies

During the planning process, optional strategies were evaluated and selected for inclusion in this Report. Selection criteria included benefits to flow, water quality, or other environmental benefits; whether the strategy applied in developed or undeveloped areas; and whether the benefit could be modeled or estimated. Some selected strategies were modeled in future scenarios and some were included as management options although their benefits were not modeled.

Table 19: Optional Management Strategies Considered

Management Strategy	Water Quality	Flow	Other Env Benefits	Notes	Selection Status
Floodplain reconnection to improve hydrology		X	X	Benefit cannot be modeled. Included in Channel Restoration strategy.	Selected
Stream channel and floodplain repair	X		X	Benefit cannot be modeled. Included in Channel Restoration strategy.	Selected
Stream channel restoration to improve hydrology		X	X	Could be a practical and cost effective alternative to improve hydrology, in the absence of space outside stream corridors to build flow control facilities. Benefit cannot be modeled. Included in Channel Restoration strategy.	Selected
Culvert/barrier removal to improve fish habitat access			X	Benefit cannot be modeled. Included in Channel Restoration strategy.	Selected

Management Strategy	Water Quality	Flow	Other Env Benefits	Notes	Selection Status
Reforestation and forest management	X		X	May be a cost effective alternative. Included in Full Shade strategy.	Selected
Riparian vegetation restoration for shade and large woody debris	X			Included in Full Shade strategy.	Selected
Stormwater control requirements under an Approved Basin Plan		X		Currently there is no basin plan for Whipple Creek.	Not Selected
Redevelopment and infill policies (incentives for infill)	X	X		Future Scenario 2 assumes the entire urban area is retrofitted to manual standards.	Not Selected
Regional stormwater facilities for infill and redevelopment	X	X	X	This action is inherent in the Structural Retrofits strategy, but it was not discretely modeled.	Not Selected
Natural resources conservation (critical/sensitive areas protection)	X	X		Critical areas are currently protected under Title 40, and future scenario models recognize some protected areas as undevelopable.	Ongoing
Stream corridor protection (critical/sensitive areas protection, Shoreline Management Areas protection)			X	Shoreline Management Areas are currently protected under Title 40.	Ongoing
General county-wide stormwater program outreach, education, and technical assistance	X		X	Benefit cannot be modeled. Any effects of the ongoing program are inherent in the calibrated models of exiting conditions.	Ongoing
Wetland protection strategies	X	X	X	Wetlands are currently protected under Title 40, and future scenarios models recognize some wetlands as undevelopable.	Ongoing
Roof downspout disconnects (that are not flow control facilities)				Uncertain benefit	Not Selected
Enhanced street sweeping	X			Benefit cannot be modeled.	Not Selected
Enhanced catch basin cleaning	X			Benefit cannot be modeled.	Not Selected
Targeted outreach	X			Benefit cannot be modeled.	Not Selected
Enhanced source control inspections	X			Benefit cannot be modeled.	Not Selected
Enhanced conveyance system cleaning	X			Benefit cannot be modeled.	Not Selected

Optional Strategies Modeled

Two optional strategies were combined into a single strategy for adding shade to reduce stream temperatures, which can be modeled. These are:

- Reforestation and forest management
- Riparian vegetation restoration for shade and large woody debris

See Future Scenario 3 in Section D for more on the Full Shade strategy.

Optional Strategies Not Modeled

Several other optional strategies were selected as management options, although their benefits cannot be modeled in future scenarios.

Four optional strategies were combined into a single strategy of Channel Restoration. These are:

- Floodplain reconnection to improve hydrology
- Stream channel and floodplain repair
- Stream channel restoration to improve hydrology
- Culvert/barrier removal to improve fish habitat access

D. Future Scenario Models

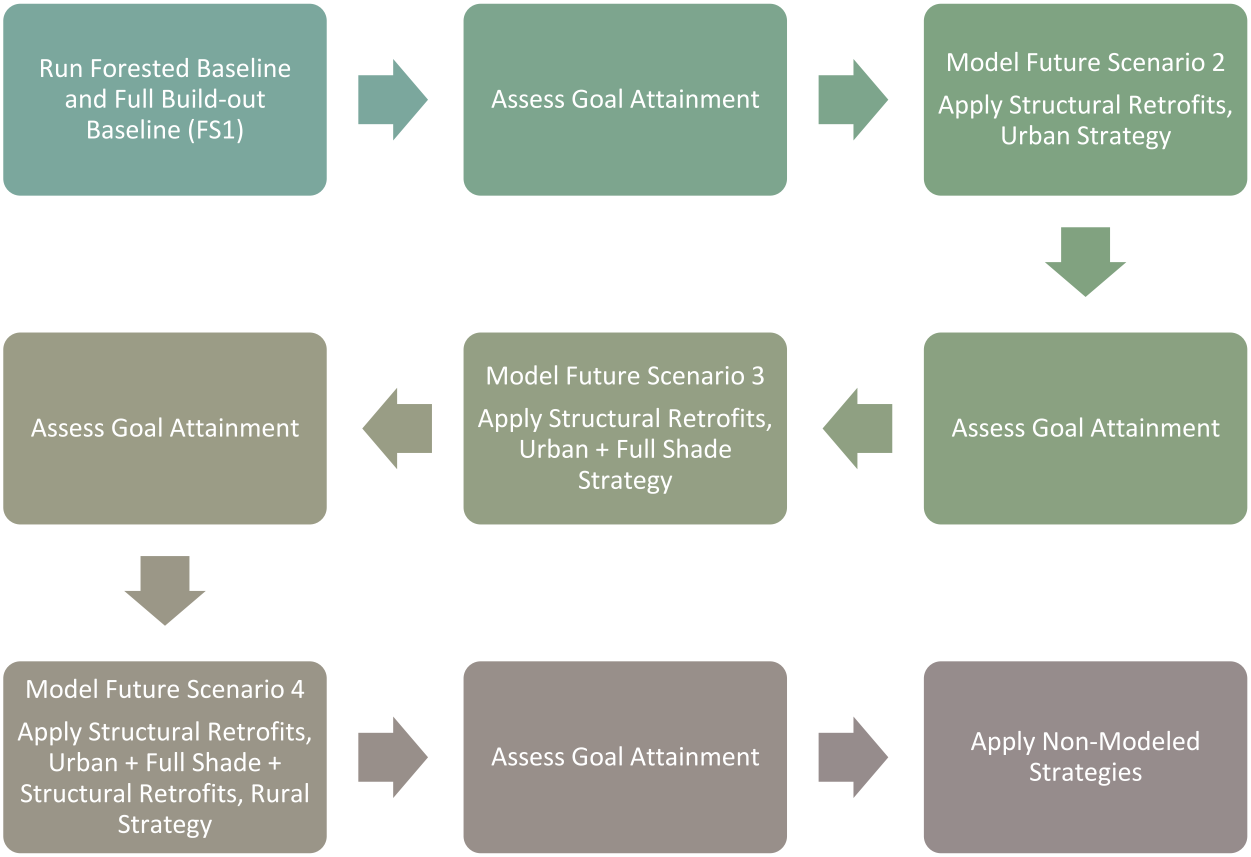
Future scenarios were modeled following Task 5 of The Whipple Creek Watershed-Scale Stormwater Planning Scope of Work and Schedule, June 2014.

To model strategies required or allowed by the Permit, this Report combines strategies into future scenarios.

Future scenarios were modeled sequentially. The results of each future scenario were evaluated to determine if water quality standards were met and if salmonid use goals were attained. If not, additional strategies were contemplated in the subsequent future scenario.

Figure 11 illustrates the sequential modeling of scenarios.

Figure 11: Sequential Scenario Modeling and Strategy Application Concept



i. Future Scenario 2 – Urban Structural Retrofits

Description of Future Scenario 2

Future Scenario 2 (FS2) simulates the effects of providing new water quality treatment and detention facilities for the currently urbanized areas of the Whipple Creek watershed.

FS2 builds on FS1 and includes all of the water quality and detention facilities described for future build-out, as well new structural stormwater retrofits for areas of existing development within the UGA sub-basins.

Structural retrofits were assumed to apply to the land area that is currently designated urban impervious and lawn land cover.

As with FS1, urban structural retrofits were modeled as a single bioretention facility and a single stormwater detention pond for each sub-basin. The bioretention facility included infiltration for Soil Group 3 (SG3), but no infiltration for Soil Group 4 (SG4).

Like facilities modeled in FS1, the retrofit facilities for existing development were sized using the WWHM2012 to the design standards for water quality treatment, LID performance, and flow control described in the CCSM. Pollutant removal rates for facilities were also the same as those used in FS1.

Model Results

FS2 model results simulated stream flow and water quality parameters for five water years (2004-2008).

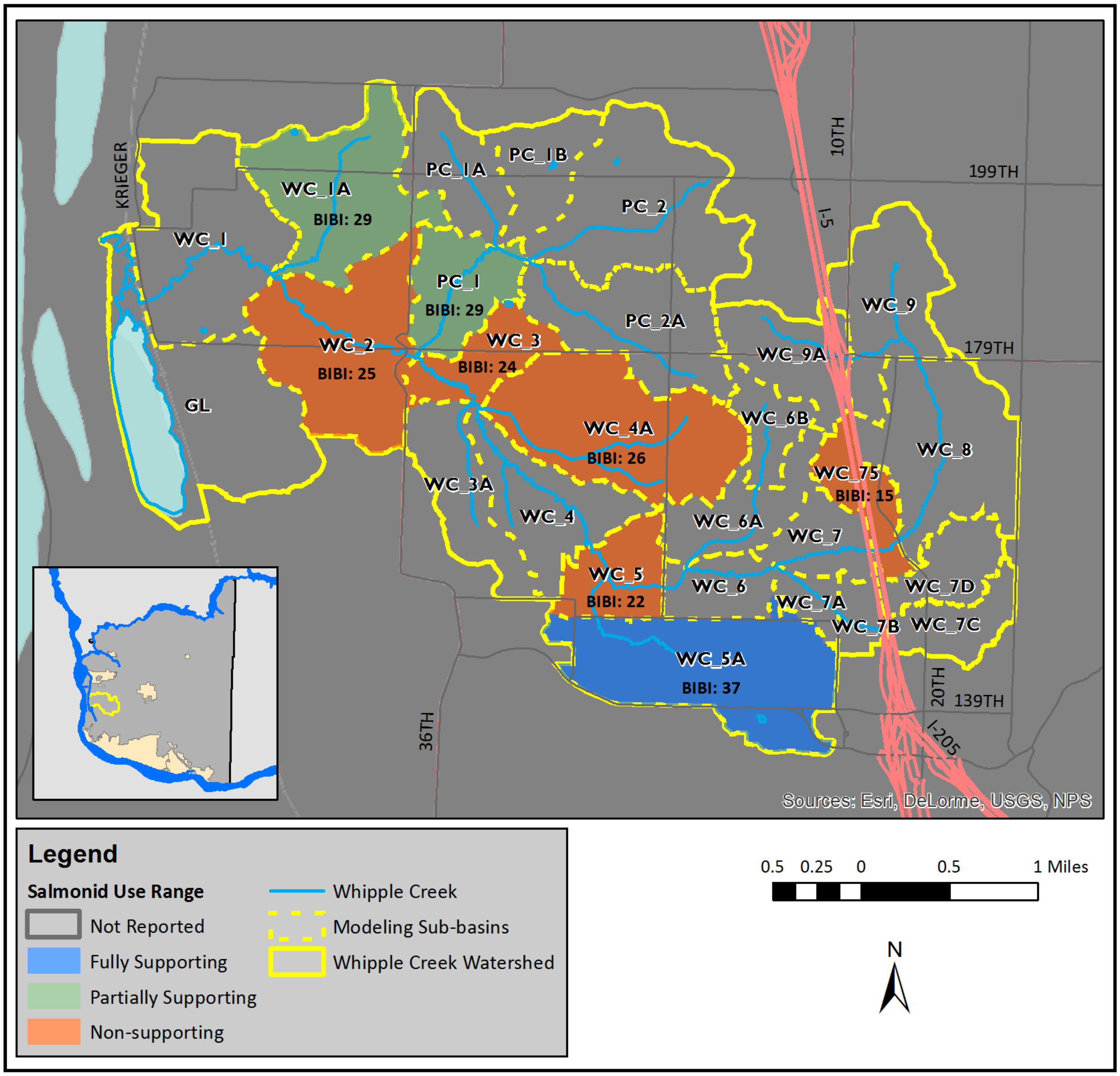
For reporting sub-basins, predicted B-IBI scores were calculated from simulated flow metrics as the average annual scores for five years, estimated using the relationships established each for T_{Qmean} and HPC. Predicted flow metrics were also directly reported.

The B-IBI scores, flow metrics, and related salmonid use ranges are shown in Table 20. Figure 12 is a map of B-IBI scores.

Table 20: Predicted B-IBI, Flow Metrics, and Salmonid Use Ranges - Urban Structural Retrofits (FS2)

	B-IBI			T_{Qmean}		HPC	
Sub-basin	Average B-IBI	Adjusted Salmonid Use Range	Adjusted Fully Supporting B-IBI	Average T_{Qmean}	Salmonid Use Range	Average HPC	Salmonid Use Range
WC-1A	29	Partially Supporting	>31	34%	Partially Supporting	6	Fully Supporting
WC-2	25	Non-supporting	>30	34%	Partially Supporting	10	Partially Supporting
WC-3	24	Non-supporting	>31	33%	Partially Supporting	11	Partially Supporting
WC-4A	26	Non-supporting	>30	33%	Partially Supporting	9	Partially Supporting
WC-5	22	Non-supporting	>30	33%	Partially Supporting	15	Non-supporting
WC-5A	37	Fully Supporting	>32	37%	Partially Supporting	3	Fully Supporting
WC-7.5	15	Non-supporting	>31	26%	Partially Supporting	20	Non-supporting
PC-1	29	Partially Supporting	>30	33%	Partially Supporting	7	Partially Supporting

Figure 12: Map of Predicted B-IBI Scores and Adjusted Salmonid Uses - Urban Structural Retrofits (FS2)



With urban structural retrofits, B-IBI scores in the lower main stem improve compared to FS1 but remain low and in the non-supporting range of salmonid use attainment. Tributary WC-5A improves to from a non-supporting score in FS1 to a score fully supporting salmonid uses in FS2. Other tributaries in the rural area are not impacted by structural retrofits in existing urbanized areas.

Under FS2, T_{Qmean} improves slightly in three main stem sub-basins – WC-2, WC-3, and WC-5 – but not enough to move from partially supporting to fully supporting salmonid uses. HPC improves in five sub-basins. WC-2 improves from non-supporting to partially supporting salmonid uses, and WC-5A improves significantly from non-supporting to fully supporting based on HPC.

The water quality results are presented in terms of violations of the state water quality standards for copper, zinc, fecal coliform, and water temperature. The number of violations occurring during the five-year simulation period are shown in Table 21.

Table 21: Water Quality Violations, Urban Structural Retrofits (FS2)

Sub-basin	Copper – Acute Violations	Copper – Chronic Violations	Zinc – Acute Violations	Zinc – Chronic Violations	Fecal Coliform Violations	Water Temperature Violations
WC-1A	0	0	0	0	1263	9
WC- 2	0	0	0	0	1190	468
WC-3	0	0	0	0	1087	371
WC-4A	0	0	0	0	1266	2
WC-5	0	0	0	0	587	287
WC-5A	0	0	0	0	19	0
WC-75	0	0	0	0	938	112
PC-1	0	0	0	0	1268	6

As with FS1, copper and zinc concentrations in Whipple Creek are not predicted to exceed state water quality standards.

Fecal coliform and water temperatures remain high in most reporting sub-basins. Sub-basin WC-5A shows the greatest improvement in reduction of fecal coliform and water temperature violations because 400 acres of existing development, which is more than 80% of the sub-basin total drainage area, is directed into a stormwater control or retrofit facility for water quality treatment.

The best management practice for urban areas that can eliminate fecal coliform in stormwater runoff is infiltration, including infiltration in bioretention facilities. Unfortunately, soil conditions prevent use of infiltration through much of the watershed, so eliminating fecal coliform violations from Whipple Creek's urban sub-basins may not be feasible.

Comparative Benefits

Compared to FS1, FS2 maintains attainment of water quality standards for dissolved metals. FS2 reduces exceedances of standards for temperatures and for concentrations of fecal coliform, but does not meet standards in the reporting sub-basins.

FS2 improves B-IBI scores and flow metrics, and improves one reporting sub-basin from non-supporting to fully supporting salmonid uses.

For these gains, the Urban Structural Retrofits components of FS2 could cost $263 million for capital improvements.

Table 22: Comparative Benefits of FS2

Constituent or Metric	Forested Baseline	FS1	FS2
Dissolved Copper	✔ *	✔	✔
Dissolved Zinc	✔ *	✔	✔
Temperature	✔ *	✘	✘
Fecal Coliform	✘ *	✘	✘
Salmon Use (B-IBI)†	Partially Supporting	Non-supporting	Non-supporting

* These parameters were not modeled, and assessments of goal attainment under the forested baseline scenario were determined using professional judgement.
† Reported as the majority of use ranges associated with average B-IBI within the set of reporting sub-basins

Conclusions

Overall FS2 results in low to moderate B-IBI scores, high fecal coliform, and high water temperatures.

ii. Future Scenario 3 – Adding Riparian Restoration for Full Shade

Description of Future Scenario 3

Future Scenario 3 (FS3) includes all of the stormwater control and retrofit facilities contemplated in FS1 and FS2. In addition, FS3 simulates the effects of increased stream channel shading in stream reaches that are not currently fully shaded.

Shading of the stream channel reduces direct solar radiation on the water surface area and that, in turn, reduces water temperatures. Shading has no impact on B-IBI scores or on copper, zinc, and fecal coliform. In the model, shading is expressed as a percentage of water surface that is fully shaded. All of the tributaries except Packard Creek are assumed to be fully shaded in the base model.

Existing and proposed percentages of stream channel shading for sub-basins that are not fully shaded are shown in Table 23.

Table 23: Existing and Future Shade (in % of Stream Reach Where Base Model was not Fully Shaded)

Sub-basin	Existing % of Reach Surface Area Shaded	FS3 % Shaded
WC-1	50.0%	99.9%
WC-2	50.0%	99.9%
WC-3	50.0%	99.9%
WC-4	50.0%	99.9%
WC-5	50.0%	99.9%
WC-6	50.0%	99.9%
WC-7	50.0%	99.9%
WC-8	50.0%	99.9%
PC-2	90.0%	99.9%
PC-2A	90.0%	99.9%

Model Results

FS3 model results simulated stream temperature for five water years (2004-2008).

The strategy to increase stream shading impacts temperature only. Neither water quality nor flow metrics are impacted by FS3, so they are not reported. Table 24 compares the number of water temperatures violations from FS1 to FS3.

Table 24: Comparison of Water Temperature Violations, FS1 and FS3

Sub-basin	FS1		FS3	
	Water Temperature Violations	Meet State Water Quality Standard?	Water Temperature Violations	Meet State Water Quality Standard?
WC-1A*	9	✗ †	9	✗ †
WC-2	494	✗	4	✗ †
WC-3	407	✗	0	✓
WC-4A*	2	✗ †	2	✗ †
WC-5	413	✗	0	✓
WC-5A	20	✗	0	✓
WC-7.5	295	✗	0	✓
PC-1	6	✗ †	4	✗ †

*Note: WC-1A and WC-4A are fully shaded in the base model.
† These very nearly met the standards.

Water temperature violations improve significantly with simulated full shading. Under FS3, violations of the state temperature standard for salmonid uses are reduced by more than 1,000 violations over five years. Four sub-basins meet the standard, and four other sub-basins nearly meet the standard.

Comparative Benefits

Compared to FS2, FS3 nearly eliminates exceedances of standards for temperatures in the reporting sub-basins. FS3 is not intended to have any impact on fecal coliform, B-IBI, or flow metrics.

For these gains, the Full Shade components of FS3 could cost $2.7 million in one-time expenditures.

Table 25: Comparative Benefits of FS3

Constituent or Metric	Forested Baseline	FS1	FS2	FS3
Dissolved Copper	✓ *	✓	✓	✓
Dissolved Zinc	✓ *	✓	✓	✓
Temperature	✓ *	✗	✗	✓
Fecal Coliform	✗ *	✗	✗	✗
Salmon Use (B-IBI)†	Partially Supporting	Non-supporting	Non-supporting	Not reported

* These parameters were not modeled, and assessments of goal attainment under the forested baseline scenario were determined using professional judgement.
† Reported as the majority of use ranges associated with average B-IBI within the set of reporting sub-basins

Conclusions

Increasing the shading to the maximum amount possible eliminates high water temperatures violations in a majority of the sub-basins. Although not all sub-basins reach zero violations, this Report assumes that full shading is effective in supporting salmonid beneficial uses through control of temperature as the watershed recovers from existing impacts and develops to full build-out.

iii. Future Scenario 4 – Adding Rural Area Structural Retrofits

Description of Future Scenario 4

Future Scenario 4 (FS4) includes all of the stormwater control and retrofit facilities of FS1 and FS2 plus the increased shading of the stream channel of FS3. In addition, FS4 simulates the effects of stormwater retrofit facilities to treat runoff from existing impervious surfaces and lawn/landscaping in the rural watershed outside the UGA.

Rural structural retrofits were modeled as a single bioretention facility and a single stormwater detention pond for each sub-basin outside of the UGA. The bioretention facility included infiltration for Soil Group 3 (SG3), but no infiltration for Soil Group 4 (SG4).

As in FS1 and FS2, the retrofit facilities were sized using the WWHM2012 to meet applicable standards under the CCSM and were modeled to remove pollutants at the same rates as facilities modeled in prior future scenarios.

Model Results

FS4 model results simulated stream flow and water quality parameters for five water years (2004-2008).

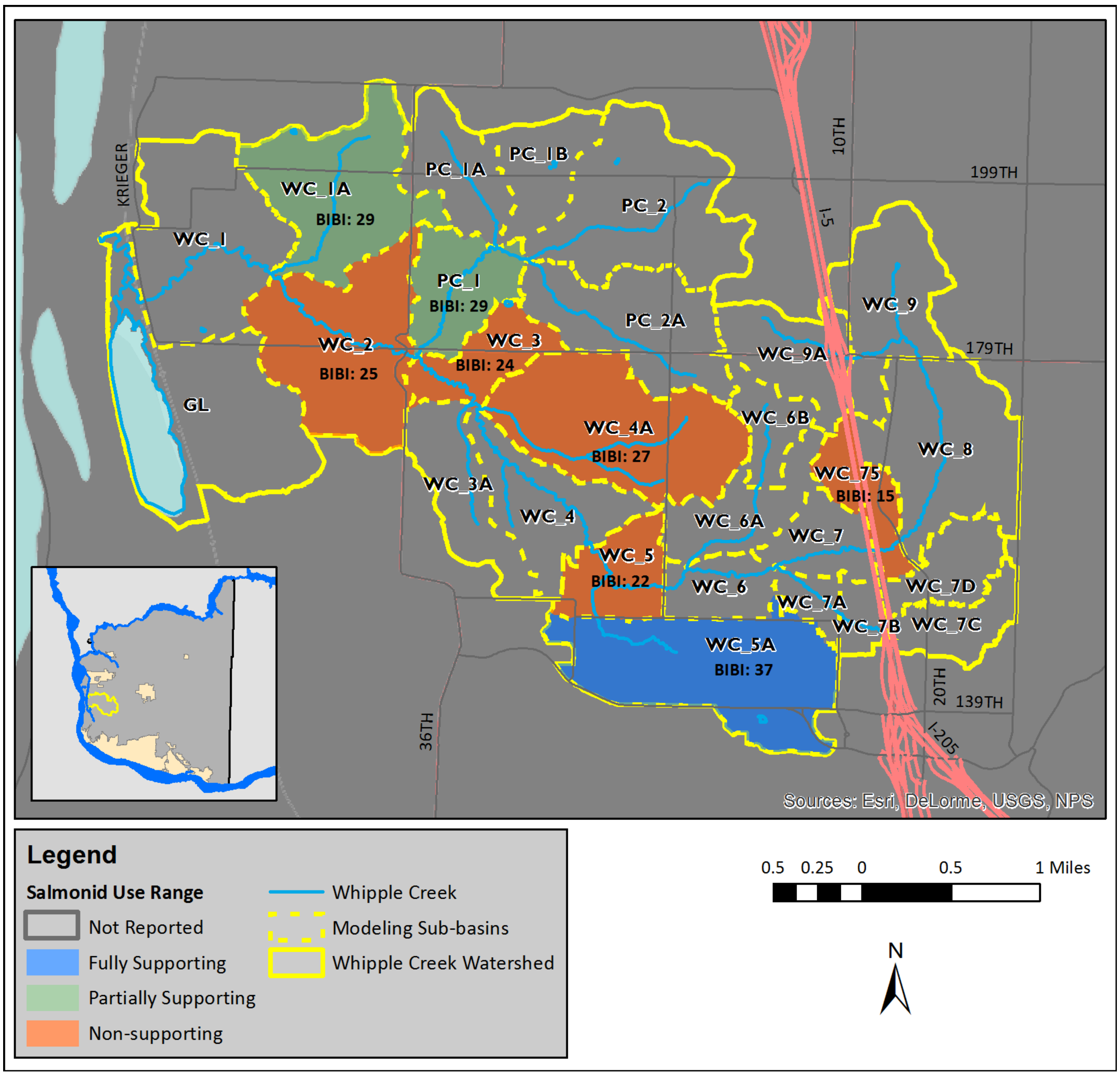
Predicted B-IBI scores were calculated from simulated flow metrics as the average annual scores for five years estimated using the relationships established each for T_{Qmean} and HPC. Predicted flow metrics were also directly reported. The B-IBI scores, flow metrics, and related salmonid use ranges are shown in Table 26. Figure 13 is a map of B-IBI scores.

Table 26: Predicted B-IBI, Flow Metrics, and Salmonid Use Ranges - Adding Rural Structural Retrofits (FS4)

	B-IBI			T_{Qmean}		HPC	
Sub-basin	Average B-IBI	Adjusted Salmonid Use Range	Adjusted Fully Supporting B-IBI	Average T_{Qmean}	Salmonid Use Range	Average HPC	Salmonid Use Range
WC-1A	29	Partially Supporting	>31	34%	Partially Supporting	6	Fully Supporting
WC-2	25	Non-supporting	>30	34%	Partially Supporting	10	Partially Supporting
WC-3	24	Non-supporting	>31	34%	Partially Supporting	12	Partially Supporting
WC-4A	27	Non-supporting	>30	34%	Partially Supporting	9	Partially Supporting
WC-5	22	Non-supporting	>30	33%	Partially Supporting	15	Non-supporting

	B-IBI			T_{Qmean}		HPC	
Sub-basin	Average B-IBI	Adjusted Salmonid Use Range	Adjusted Fully Supporting B-IBI	Average T_{Qmean}	Salmonid Use Range	Average HPC	Salmonid Use Range
WC-5A	37	Fully Supporting	>32	37%	Partially Supporting	3	Fully Supporting
WC-7.5	15	Non-supporting	>31	26%	Non-supporting	20	Non-supporting
PC-1	29	Partially Supporting	>30	33%	Partially Supporting	6	Fully Supporting

Figure 13: Map of Predicted B-IBI Scores and Adjusted Salmonid Uses - Rural Retrofits (FS4)



Based on predicted metrics there is no real improvement in B-IBI scores or salmonid use attainment in comparison to FS2. This is probably because the rural sub-basins do not produce as much stormwater runoff as the urban sub-basins mitigated in FS2 and, thus, the rural structural retrofit facilities do not significantly change the stream flow values in the main stem of Whipple Creek. Another factor is that bioretention is infeasible in large parts of the rural headwaters of Packard Creek and Whipple Creek.

Water quality results are presented in terms of violations of the state water quality standards for fecal coliform and water temperature. Because FS2 eliminated water quality violations for copper and zinc, those results are not shown for FS4. Table 27 compares the number of fecal coliform and temperature violations during the five-year simulation period for FS2, FS3, and FS4.

Table 27: Comparison of Water Quality Violations in Different Scenarios

	Fecal Coliform				Water Temperature	
Sub-basin	Violations (FS1)	Violations (FS2)	Violations (FS4)	% Reduction in Violations from FS1 to FS4	Violations (FS3)	Violations (FS4)
WC-1A	1263	1263	933	26%	9	0
WC-2	1352	1190	993	27%	4	5
WC-3	1365	1087	743	46%	0	0
WC-4A	1266	1266	1034	18%	2	0
WC-5	1384	587	587	58%	0	0
WC-5A	1358	19	19	99%	0	0
WC-75	1440	938	938	35%	0	0
PC-1	1268	1268	945	25%	4	0

Under FS4, fecal coliform remains high in most sub-basins. WC-3 sub-basin fecal coliform violations are reduced by 32%, but they remain high with 743 violations over a five year period. With an 18% reduction in violations, WC-4A still has more than 1,000 violations under FS4. Fecal coliform contributions from forest and pasture provide a significant source of this pollutant in the watershed. These sources generally cannot be controlled with public structural retrofits of the MS4.

Minor improvements in the number of water quality violations shows that all sub-basins except WC 2 would meet water quality standards for temperature under FS4. However, the improvements are extremely small because the violations were nearly eliminated under FS3.

Comparative Benefits

Compared to FS2 and FS3, FS4 has very little benefit.

For these questionable gains, the Rural Structural Retrofits component of FS4 could cost $56 million for capital improvements.

Table 28: Comparative Benefits of FS4

Constituent or Metric	Forested Baseline	FS1	FS2	FS3	FS4
Dissolved Copper	✔ *	✔	✔	✔	✔
Dissolved Zinc	✔ *	✔	✔	✔	✔
Temperature	✔ *	✘	✘	✔	✔
Fecal Coliform	✘ *	✘	✘	N/A	✘
Salmon Use (B-IBI)†	Partially Supporting	Non-supporting	Non-supporting	N/A	Non-supporting

* These parameters were not modeled, and assessments of goal attainment under the forested baseline scenario were determined using professional judgement.
† Reported as the majority of use ranges associated with average B-IBI within the set of reporting sub-basins

Conclusions

Overall, FS4 does little to reduce the impacts of stormwater runoff from existing and expected future new development in the watershed.

E. Future Scenario Supplemental Strategies (Not Modeled)

i. Channel Restoration

Channel restoration is a strategy that can improve habitat conditions for fish by reducing turbidity, preserving or restoring gravel stream beds used for spawning, restoring access to functioning habitat, and providing refuge for fish and macroinvertebrates from high flows, high temperatures, and predators.

Clark County has experience restoring approximately 1,000 feet of the Whipple Creek main stem just upstream of I-5 using grade controls and channel spanning log jams to create floodplain detention and improve channel hydraulics. See Appendix L for an initial analysis of floodplain detention opportunities.

Description of Channel Restoration Techniques

Channel restoration was selected for consideration in this Report. A discussion of techniques and benefits is below.

Grade Control

Grade control uses obstructions in the stream to slow the flow of water and sometimes to create step-pools. Slowing the flow helps prevent or slow channel lowering. Channel lowering can result from headcuts or incision. Channel lowering can drain wetlands, disconnect a stream from its floodplain, and increase flow rates during storms.

Structural grade controls use large rocks, large logs, or engineered obstructions. These are appropriate for streams subject to high flows. Low-tech grade controls use fascines or wooden posts to span the channel of smaller streams that are not subject to high flows.

Grade controls tend to mimic the natural functions of beaver dams and log jams in a functioning forested stream system.

Stream Bank Stabilization

Stream bank stabilization includes numerous techniques both natural, engineered, or some combination thereof, to protect stream banks from erosion, landslide, and slumping. A few examples are bioengineered slope, brush matting, tree revetments, rock buttressing, and retaining walls.

Protecting stream banks, in turn, helps aquatic habitat by reducing turbidity and protecting gravel spawning beds from being buried by silt or landslide.

Stream Bed Fill and Gravel Enhancement

A stream channel that has already been damaged by erosion, resulting in incision, headcuts, or an undermined toe of a bank can benefit from fill. Rocks, gravel or other materials are placed in the stream channel and the banks. Fill may restore an incised channel, prevent further erosion, protect banks, or restore spawning beds. This technique may improve habitat for aquatic species in an already degraded stream.

Stream Culvert Fish Barrier Removal

In some stream systems, good fish habitat is left unused because culverts or other obstructions block access. Culverts built before modern regulations often did not consider fish passage or did not properly accommodate it. Replacing culverts with new designs or bridges can restore access to good fish habitat.

Comparative Benefits

Degree of improvement in B-IBI score resulting from Channel Restoration cannot be modeled using the tools employed in this Report. Channel Restoration is assumed to have a positive effect on fish habitat in targeted locations, but it is not expected to have a watershed-wide impact on fish use attainment.

Channel Restoration could result in improvements to B-IBI scores, but would in most cases have no effect on dissolved metals, fecal coliform, or flow metrics, and little effect on temperature.

Nonetheless, because of its ability to target improvements in fish habitat, Clark County considers Channel Restoration to be among the most effective strategies for improving fish use attainment in targeted locations and preventing further channel degradation such as bank erosion, even if those gains cannot be estimated through correlation with B-IBI scores or flow metrics.

For these gains, the Channel Restoration strategy could cost $23.7 million for capital improvements.

F. Goal Attainment

The success of strategies contemplated in this Report for reducing copper, zinc, and temperatures in the Whipple Creek watershed is clear. These parameters may be managed using LID and traditional stormwater management techniques appropriate for a large MS4. Modeled scenarios predict the watershed can meet state standards for copper, zinc, and temperature through stormwater management, urban structural retrofits, and riparian restoration techniques.

The success of strategies analyzed for meeting state standards for fecal coliform and salmonid beneficial uses is less clear. Investigations into the existing conditions of the Whipple Creek watershed suggest that watershed conditions may never have reached these standards.

It is possible that background levels of fecal coliform from natural sources and other non-stormwater sources (e.g. beaver, water fowl, livestock, and possibly septic systems) exceed state standards even without discharges of urban runoff from the county's MS4. DNA studies of fecal coliform could reveal the background levels of fecal coliform that cannot be managed using stormwater strategies.

Likewise, information on fish presence in the watershed suggest that some of the reasons for limited salmonid use are inherent in the watershed's stream sizes, topography, and natural substrate (see Chapter I, Section F).

Table 29: Summary of Goal Attainment Under All Strategies

Constituent or Metric	Forested Baseline	FS1	FS2	FS3	FS4	Channel Restoration
Dissolved Copper	✔ *	✔	✔	✔	✔	N/A
Dissolved Zinc	✔ *	✔	✔	✔	✔	N/A
Temperature	✔ *	✘	✘	✔	✔	N/A
Fecal Coliform	✘ *	✘	✘	N/A	✘	N/A
Salmon Use (B-IBI)†	Partially Supporting	Non-supporting	Non-supporting	N/A	Non-supporting	Non-supporting*

* These parameters were not modeled, and assessments of goal attainment under the forested baseline scenario and channel restoration strategy were determined using professional judgement.
† Reported as the majority of use ranges associated with average B-IBI within the set of reporting sub-basins

The Implementation Plan (Chapter IV) discusses potential future actions to implement strategies modeled in future scenarios.

i. Stream Temperature

Implementing the riparian Full Shade strategy modeled in FS3 would essentially eliminate violations of state stream temperature standards.

ii. Dissolved Metals

Whipple Creek would not exceed state water quality standards for dissolved metals under the baseline full build-out scenario. This suggests that continuing to implement the current stormwater management program plan would maintain compliance with state water quality standards for dissolved metals.

iii. Fecal Coliform

No modeled strategy evaluated in this Report would completely eliminate fecal coliform violations. This result suggests stormwater management alone would not be effective in attaining compliance with standards. Activities outside the scope of the Permit would be needed.

Investigations into existing patterns of fecal coliform counts indicate that wildlife, livestock, or failing septic systems may contribute to baseline conditions in several tributaries. In addition, soils with low permeability throughout the watershed inhibit the use of LID or other infiltration techniques to manage contributions of fecal coliform from urban runoff.

iv. Aquatic Life as Defined by B-IBI

No modeled strategy evaluated in this Report makes an unambiguous improvement to stream flow conditions to the point where resulting B-IBI scores suggest the stream would fully support aquatic life. Of the eight reporting sub-basins, only the WC-5A sub-basin may achieve a B-IBI score indicating full support of salmonid uses using the Urban Retrofit strategy modeled in FS2.

Table 30: Best B-IBI-Correlated Salmonid Use Ranges Achieved Under Modeled Scenarios

Sub-basin	Adjusted Salmonid Use Range (B-IBI)
WC-1A	Partially Supporting
WC-2	Non-supporting
WC-3	Non-supporting
WC-4A	Non-supporting
WC-5	Non-supporting
WC-5A	Fully Supporting
WC-7.5	Non-supporting
PC-1	Partially Supporting

IV. Implementation Plan

An Implementation Plan is a Permit-required component of the Whipple Creek Watershed-Scale Stormwater Plan Report. The Permit requires an implementation plan and schedule to include:

- Potential future actions to implement the identified stormwater management strategies;
- Responsible parties;
- Estimated costs; and
- Potential funding mechanisms.

Potential actions are based on the results of the modeling exercise and the recognition that existing budgets are insufficient to begin implementation of the strategies evaluated in this Report.

A. Scope and Limitations

This Report's strategies to improve water quality and in-stream conditions in Whipple Creek are conceptual-level considerations based on broad evaluations of existing conditions and future land uses. The described undertakings are massive in scope and, by necessity, imprecise at a sub-basin-scale.

Structural facilities modeled in the Report provide one illustration.

Modeled structural facilities are purely hypothetical. Models simulate the facility size needed to achieve desired results using only one water quality facility and one detention facility per sub-basin. Facilities may not be realistically designed or constructed as modeled.

Further development of a capital program to support the state's goals would include intensive capital planning to identify feasible locations, developing individual planning-level project designs, and prioritizing projects. Capital project development furthermore would be subject to the availability of capital funding and the acquisition of land and rights-of-way (including likely actions to condemn private property under the county's eminent domain authorities in both urban and rural areas), engineering design, and construction.

In aggregate, land area required for conceptual structural facilities and riparian restoration in this Report is nearly 0.5 square miles and exceeds 4% of the watershed's land area. Total one-time capital costs of nearly $346 million exceed the county's Stormwater Capital Program's six-year budget by more than $330 million dollars.

This Implementation Plan is intended as long-term guidance that may assist in meeting Permit objectives. It is not intended to recommend or prioritize particular capital projects, strategies, or management actions.

B. Responsible Parties

Clark County is responsible for enforcing its development and stormwater codes, operating and maintaining its MS4, and for meeting Permit requirements.

This Report assumes certain actions by private land owners and land developers that are part of the current program, such as maintaining private stormwater facilities and developing land under the standards of the CCSM.

FS1 describes the full build-out of the Vancouver UGA in Whipple Creek. These activities are carried out principally by private developers who convert forest or pasture to developed residential or commercial properties and redevelop urban areas. Landowners and developers acting to build in Whipple Creek, as everywhere in the county, are required to comply with the Title 40 and zoning, including assumptions for densities, critical areas protection, and stormwater and erosion control requirements.

This Report assumes other public entities and quasi-governmental organizations operating in the Whipple Creek watershed continue their actions to benefit water quality and in-stream conditions in the watershed.

For example, Washington Department of Transportation (WSDOT) is also subject to a NPDES municipal stormwater permit, and it expands and replaces roads and operates transportation facilities and associated stormwater facilities in the watershed.

As another example, the Clark County Conservation District has programs that help the watershed by preserving the productivity of agricultural lands through reducing soil erosion, helping with manure management plans, and restoring riparian buffers. These activities also reduce transport of eroded soils to Whipple Creek and its tributaries and benefit water quality and fish habitat in the stream.

C. Estimated Costs

Conceptual-level cost estimates were prepared for each modeled strategy and the Channel Restoration strategy based on model outputs of hypothetical facilities to estimate the relative magnitude of costs for each strategy. Capital cost estimates rely on the county's recent historical costs for land, engineering design, construction, and operation & maintenance.

Costs are estimated independently for each strategy. Costs for each future scenario would include the costs of the component strategies. The sum of one-time capital costs for all modeled strategies and the Channel Restoration strategy is nearly $347 million. Operation and maintenance of structural facilities is estimated at $4 million annually once fully built.

All costs are in 2017 dollars.

Detailed cost estimates are given in Appendix O.

i. Costs of FS1, Full Build-out Baseline

FS1, the full build-out baseline, is implemented by private developers and has no new costs for the county.

ii. Costs of Urban Structural Retrofits Strategy

The Urban Structural Retrofits strategy is modeled as a component of FS2, FS3, and FS4. It results in 29 acres of bioretention (at pond surface) and 38 acres of detention pond (at pond surface). Additional land would be needed.

A conceptual-level cost estimate, below, does not include capital planning to identify and study feasibility of individual projects, nor does it attempt to anticipate a realistic number of facilities that would provide the modeled treatment and hydrology performance.

Table 31: Conceptual Cost Estimate of Urban Structural Retrofits

Modeled Facility Size		Capital Costs ($Millions)				O&M Costs ($Millions)
Bioretention Surface Area (ac)	Detention Pond Surface Area (ac)	Bioretention	Detention	Land Acquisition	Total One-Time Capital Costs	Annual
29	38	$62.23	$11.54	$189.69	$263.46	$2.70

iii. Costs of Full Shade Strategy

The Full Shade strategy is modeled as a component of FS3 and FS4. It assumes riparian restoration spans 75 feet on each side of an unshaded stream channel. 3.79 miles of channel are assumed to be eligible for riparian restoration.

A conceptual-level cost estimate of the Full Shade strategy, below, includes capital planning to identify and study feasibility of individual projects, easement costs, and three years of anticipated maintenance for plant establishment as a one-time capital cost.

Table 32: Conceptual Cost Estimate for Full Shade Strategy

Stream Length with Shade BMP Applied (mi)	Total Cost ($ Millions)
3.79	$2.65

iv. Costs of Adding Rural Structural Retrofits

The Rural Structural Retrofits strategy is modeled as a component of FS4. It results in 14 acres of bioretention (at pond surface) and 21 acres of detention pond (at pond surface). Additional land would be required.

A conceptual-level cost estimate, below, does not include capital planning to identify and study feasibility of individual projects, nor does it attempt to anticipate a realistic number of facilities that would provide the modeled treatment and hydrology performance.

Table 33: Conceptual Cost Estimate for Adding Rural Structural Retrofits Strategy

Modeled Facility Size		Capital Costs ($Millions)				O&M Costs ($Millions)
Bioretention Surface Area (ac)	Detention Pond Surface Area (ac)	Bio-retention	Detention	Land Acquisition	Total One-Time Capital Costs	Annual
14	21	$30.41	$6.21	$19.36	$55.98	$1.34

v. Costs of Channel Restoration Strategy

The Channel Restoration strategy could consider channel restoration on approximately 7 miles of main stem Whipple Creek. A conceptual-level cost estimate, below, does not include capital planning to identify and study benefits and feasibility of individual projects. Only stream miles on the main stem are included.

Table 34: Conceptual Cost Estimate for the Channel Restoration Strategy

Channel Restoration Stream Length (mi)	Capital Costs ($ Millions)
7.18	$23.68

vi. Other Costs

The cost estimate does not include ongoing Stormwater Management Program actions, even when program elements are anticipated to benefit Whipple Creek.

Initial costs of implementing strategies discussed in this Report are not itemized. Initial costs would be anticipated to include recommended studies such as a Use Attainability Study, a detailed revenue requirements and financial study, and initiation of a capital planning protocol for Whipple Creek.

vii. Total Costs by Sub-basin

Capital and annual operation & maintenance costs are summarized by sub-basin in Table 35 and Table 36.

By a factor of three, WC-5A is the costliest sub-basin for capital projects, at $85 million. On the other hand, WC-5A is also the only reporting sub-basin that appears to improve sufficiently to fully support salmonid uses.

Three sub-basins in the Packard Creek tributary are estimated to cost less than $2 million each for capital projects, solely for rural structural retrofits. Reporting sub-basin PC-1 remains in the partially supporting salmonid use range under all modeled future scenarios and shows a 25% decrease in violations of fecal coliform standards. For PC-1, violations of temperature standards drop from six to zero.

Table 35: Total Conceptual Capital Costs by Sub-basin

Total Capital Costs ($ Millions)					
Sub-basin	Urban Retrofits (FS2)	Full Shade (FS3)	Rural Retrofits (FS4)	Channel Restoration	Total
WC-5	$19.53	$0.21		$2.01	$21.75
WC-5A	$85.01	$0.00		$0.00	$85.01
WC-6	$24.68	$0.26		$2.42	$27.35
WC-6A	$22.28	$0.00		$0.00	$22.28
WC-6B	$10.54	$0.00		$0.00	$10.54
WC-7	$9.38	$0.20		$1.91	$11.49
WC-7A	$6.96	$0.00		$0.00	$6.96
WC-7B	$10.96	$0.00		$0.00	$10.96
WC-7C	$9.72	$0.00		$0.00	$9.72
WC-7D	$11.75	$0.00		$0.00	$11.75
WC-75	$9.39	$0.00		$0.00	$9.39
WC-8	$18.41	$0.41		$0.00	$18.82
WC-9	$11.10	$0.00		$0.00	$11.10
WC-9A	$13.76	$0.00		$0.00	$13.76
GL		$0.00	$6.33	$2.55	$8.88
WC-1		$0.44	$10.01	$4.17	$14.62
WC-1A		$0.00	$3.96	$0.00	$3.96
WC-2		$0.38	$7.72	$3.61	$11.72
WC-3		$0.37	$1.91	$3.45	$5.73
WC-3A		$0.00	$3.64	$0.00	$3.64
WC-4		$0.38	$3.11	$3.56	$7.05
WC-4A		$0.00	$3.87	$0.00	$3.87
PC-1		$0.00	$1.22	$0.00	$1.22
PC-1A		$0.00	$1.88	$0.00	$1.88
PC-1B		$0.00	$1.24	$0.00	$1.24
PC-2		$0.00	$4.75	$0.00	$4.75
PC-2A		$0.00	$6.34	$0.00	$6.34
Total	**$263.46**	**$2.65**	**$55.98**	**$23.68**	**$345.77**

Table 36: Total Conceptual Annual O&M by Sub-basin at Full Implementation

Total Annual O&M Costs ($Millions)					
Sub-basin	Urban Retrofits (FS2)	Full Shade (FS3)	Rural Retrofits (FS4)	Channel Restoration	Total
WC-5	$0.15	N/A		N/A	$0.15
WC-5A	$0.91	N/A		N/A	$0.91
WC-6	$0.21	N/A		N/A	$0.21
WC-6A	$0.20	N/A		N/A	$0.20
WC-6B	$0.11	N/A		N/A	$0.11
WC-7	$0.07	N/A		N/A	$0.07
WC-7A	$0.05	N/A		N/A	$0.05
WC-7B	$0.11	N/A		N/A	$0.11
WC-7C	$0.13	N/A		N/A	$0.13
WC-7D	$0.14	N/A		N/A	$0.14
WC-75	$0.11	N/A		N/A	$0.11
WC-8	$0.25	N/A		N/A	$0.25
WC-9	$0.12	N/A		N/A	$0.12
WC-9A	$0.14	N/A		N/A	$0.14
GL		N/A	$0.14	N/A	$0.14
WC-1		N/A	$0.21	N/A	$0.21
WC-1A		N/A	$0.10	N/A	$0.10
WC-2		N/A	$0.19	N/A	$0.19
WC-3		N/A	$0.04	N/A	$0.04
WC-3A		N/A	$0.08	N/A	$0.08
WC-4		N/A	$0.07	N/A	$0.07
WC-4A		N/A	$0.11	N/A	$0.11
PC-1		N/A	$0.03	N/A	$0.03
PC-1A		N/A	$0.05	N/A	$0.05
PC-1B		N/A	$0.04	N/A	$0.04
PC-2		N/A	$0.13	N/A	$0.13
PC-2A		N/A	$0.16	N/A	$0.16
Total	**$2.70**	**$ -**	**$1.34**	**$ -**	**$4.04**

D. Financial Analysis

A high-level financial study was completed to determine capital and operational costs of strategies over 30 years.

See Appendix P for a summary of the financial analysis.

i. Cost Summary

The cost summary reflects the assumption that Future Scenarios 2, 3, and 4, as well as the Channel Restoration strategy projects, would be implemented over a 30-year span.

Capital implementation is assumed to occur on a straight-line basis, with 1/30th of capital costs, plus construction cost inflation, anticipated for each year. Operational costs are assumed to occur over a 25-year period beginning in Year 6 of implementation. In each subsequent year, operational costs are assumed to increase by 1/25th of the estimated annual operating costs, plus general cost inflation. Industry-standard cost inflation factors were used to project cost increases over time.

Table 37 summarizes projected costs over 30 years.

Table 37: Cost Summary

Year from Start	1	2	3	4	5	10	20	30
	2018	2019	2020	2021	2022	2027	2037	2047
Base Revenue	$534,844	$543,035	$551,352	$559,797	$568,370		$613,249	$713,916
Additional O&M Cost	0	0	0	0	0	962,962	3,442,929	6,838,717
Additional Capital Cost	11,862,591	12,209,400	12,566,348	12,933,731	13,311,856	15,374,903	20,509,732	27,359,464
Adjusted Revenue	12,397,435	12,752,435	13,117,700	13,493,528	13,880,226	16,951,114	24,666,578	35,029,289
Percentage Increase	2218%	2248%	2279%	2310%	2342%	2664%	3355%	4115%

ii. Stormwater Fee Revenue

The revenue summary assumes that all revenues for actions considered in this Report would be generated from stormwater fees within the Whipple Creek watershed itself.

Equivalent residential units (ERUs) are the basis for calculating stormwater fees. One ERU is 3,500 square feet of hard surface (roof, driveway, roadway, etc.).

In 2017, the Whipple Creek watershed has 10,626 ERUs generating approximately $525,000 annually. If the watershed were fully built-out to maximum densities allowed under the Comp Plan, then the number of ERUs was estimated to be 16,765.

The financial analysis estimates the impact to stormwater fee rates in the watershed over time.

Table 38 shows potential increases in annual stormwater fees over 30 years.

Table 38: Annual Stormwater Fee Increase per ERU

Year from Start	1	2	3	4	5	10	20	30
	2018	2019	2020	2021	2022	2027	2037	2047
Base ERU Rate	$49.83	$50.08	$50.34	$50.59	$50.84	$52.08	$54.39	$56.56
Additional O&M Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$81.77	$262.31	$465.40
Additional Capital Cost	$1,105	$1,126	$1,147	$1,168	$1,190	$1,305	$1,562	$1,861
Adjusted ERU Rate	$1,155	$1,176	$1,197	$1,219	$1,241	$1,439	$1,879	$2,383
Percentage Increase	2218%	2248%	2279%	2310%	2342%	2664%	3355%	4115%

iii. Other Potential Revenue

Beyond stormwater fee revenue from developed properties within the Whipple Creek watershed, other potential funding mechanisms could include stormwater fees generated county-wide (Clean Water Fund), the county's Legacy Lands Fund, the County Road Fund, state grants, and partnerships with quasi-governmental organization such as the Clark Conservation District or non-profit organizations such as Fish First.

E. Adaptive Management

As long-term guidance that may assist in meeting Permit objectives, this Report is not readily implementable. Yet, there are actions that can be taken to set foundations for actions in the Whipple Creek watershed.

Adaptive management would allow goals and methods to change in response to new information, feedback on progress, changing technologies, and new or updated regulatory and community goals. Key elements of the adaptive management program would include a Use Attainability Analysis and future data gathering.

i. Assess Where Designated Uses are Attainable

The objective of the CWA is to restore and maintain the integrity of the nation's waters in terms of chemical composition, physical form, and aquatic life. Unless other uses are designated, water quality must support fishing and swimming (Copeland, 2016). The law allows a designated use that has been assigned to a water body to be removed if evidence shows that attaining the use is not feasible. Six conditions must be met and demonstrated through a Use Attainability Analysis to remove a use (Ecology, 2005).

This Report recommends studying attainability of salmonid uses for Whipple Creek. Historic accounts indicate that anadromous fish once used Whipple Creek in greater numbers than they do today, but the magnitude of historic fish use is unclear given what is known about the geology of the watershed.

Current fish use is clearly limited, although due to Whipple Creek's low priority for salmon recovery, almost no field data exist. To illustrate this point, Whipple Creek is such a low priority for salmon recovery that is it not evaluated in the Lower Columbia Fish Recovery Plan (LCFRB, 2010).

Also recommended is a study of attainability of the primary contact recreation designated use. A large portion of the Whipple Creek watershed is rural in nature and, as is common for streams in rural and forested areas, hosts wildlife populations that contribute fecal coliform directly and indirectly to streams. Whipple Creek's urbanized and urbanizing areas largely have soil conditions that are incompatible with the use of infiltration to remove bacteria from runoff. Given these limitations, it may be infeasible for some reaches in the watershed to attain the primary contact recreation designated use.

This Report considers a Use Attainability Analysis as precursor to any other strategy or action contemplated for the Whipple Creek watershed, but not as an effort to update state standards under WAC 173-201A.

See Appendix M for an initial discussion of use attainability in Whipple Creek.

ii. Modify the Stormwater Capital Program

The county has been formally planning stormwater capital improvements since 2007. Current planning allocates approximately $9.8 million for the 2013-2018 Stormwater Capital Program, which covers the entire Permit area.

A 2019-2024 plan is currently under development. At the time of writing, 17 structural projects are under consideration in the Whipple Creek watershed, comprised of nine channel restoration projects, one facility repair, two retrofits where treatment and detention are currently lacking, and five retrofits of existing facilities to increase treatment and/or detention capabilities.

This Report suggests considering that capital projects prioritized for Whipple Creek be incorporated into the county's Stormwater Capital Program for planning and construction as funding allows.

iii. Prioritization Categories

An adaptive management approach could consider a number of prioritization strategies in contemplating management actions in the Whipple Creek watershed.

Implementation Plan

Table 39 (next page) lists potential prioritization categories in a Whipple Creek adaptive management approach.

Table 39: Prioritization Categories

Category	Description	Prioritization
Goal Attainment by Sub-basin	Some sub-basins come much closer to meeting water quality standards and attaining beneficial fish uses than others. Other sub-basins remain degraded under all future scenarios. Sub-basins with best overall goal attainment for all variables should be prioritized if further study of the sub-basin indicates that strategies are feasible in the area. Factors such as land availability, availability of capital funding, and availability of operational funding help determine feasibility. A capital planning process should take predictions of sub-basin goal attainment into account both when prioritizing investigations to identify potential projects (locations and designs) and when prioritizing projects.	Consider prioritizing sub-basins with the best potential for goal attainment, as determined through further study. Consider incorporating analysis of predicted goal attainment into capital planning procedures for Whipple Creek.
Channel Restoration	Channel restoration, such as grade controls, stream bank stabilization, floodplain detention, and stream bed fill, could help preserve or restore pockets of viable salmon habitat in the Whipple Creek main stem. Fish passage barrier removal can restores access to currently inaccessible stream channels that may have good salmon habitat.	Consider prioritizing channel restoration.
Areas of Special Attention	Areas include regulated critical areas such as wetlands and habitat conservation areas and areas characterized by stream channel erosion, floodplain disconnection, suitable salmon spawning habitat, low temperatures suitable for thermal refugia for salmon, complete lack of stormwater detention, complete lack of stormwater treatment, and degraded riparian conditions on public land. (See Appendix E for a discussion of these areas.) A capital planning process could take areas of special attention into account both when prioritizing investigations to identify potential projects (locations and designs) and when prioritizing projects..	Consider incorporating areas of special attention into capital planning procedures for Whipple Creek.
Planned Projects	The county's Stormwater Capital Program may include projects in Whipple Creek watershed.	Take advantage of existing planned capital investments in the watershed.
Land Availability	Project feasibility due to access to land is likely a concern for most capital projects that would be proposed in the Whipple Creek watershed.	Incorporate land availability into capital planning procedures for Whipple Creek.
MS4 Nexus	Numerous factors outside of discharges from the MS4 impact water quality and in-stream conditions. Some strategies discussed in this Report, such as the riparian Full Shade strategy (see FS3) and the Channel Restoration strategy, operate outside the boundaries of Clark County's MS4. These strategies may be the most cost-effective strategies for progressing toward achieving beneficial uses. On the other hand, riparian and channel restoration projects do not assist Clark County in meeting the regulatory requirements of its Permit.	Prioritize the most cost-effective projects for protecting or restoring beneficial uses, regardless of relationship to MS4.

iv. Whipple Creek Monitoring

In following its scope of work for writing this Report, Clark County expanded elements of its ongoing county-wide monitoring program to focus on Whipple Creek.

An adaptive management approach could continue the targeted data collection effort in Whipple Creek to include continuous flow monitoring, temperature monitoring, water quality sampling, and macroinvertebrate sampling. Special projects could look for problem areas such as bacteria sources. Data and analyses could contribute to the Use Attainability Study, capital planning, modeling, and prioritization of management options.

v. Continue Model Development

The hydrology model is well-calibrated at the watershed scale, but additional work could improve the accuracy at the sub-basin scale based on data collected in Packard Creek and upper Whipple Creek. Continued model development could lead to detailed modeling of UGA sub-basins as part of an effort to plan effective restoration or protection plans.

vi. Other Prioritization Tools

Recently, the Washington Department of Commerce released a guidance document titled *Building Cities in the Rain – Watershed Prioritization for Stormwater Retrofits.* The aim is to most effectively deploy scarce resources to protect and restore receiving waters for stormwater runoff by prioritizing areas for stormwater retrofitting. The guidance relies heavily on companion guidance by Ecology for elaborate GIS-based watershed characterization and the newer proposed stormwater control transfer program that would promote placing restorative stormwater controls where there is the greatest benefit.

An adaptive management approach could classify subareas for protection, restoration or development based on hydrologic modeling, water quality modeling, and areas of special interest such as salmon bearing stream reaches.

An assessment of the *Building Cities in the Rain* methodology is included in Appendix Q.

F. Schedule

This Report uses a 30-year planning horizon.

By 2040, the median prediction for population of Clark County nears 600,000, up from 425,000 in 2010 (State of Washington Office of Financial Management, 2012). Population in the entire Vancouver UGA (not limited to Whipple Creek) is predicted to rise from 315,000 to 372,000 by 2035 (Clark County, 2016). It seems likely that the Vancouver UGA could continue to expand west into the Whipple Creek watershed as decades pass.

Land use assumptions are based on the 20-year Comp Plan through 2035. No land cover conversions beyond full build-out at 20 years are anticipated in this Report.

A start date has not been established. Actions are conceptually scheduled from Year 1.

Implementation Plan

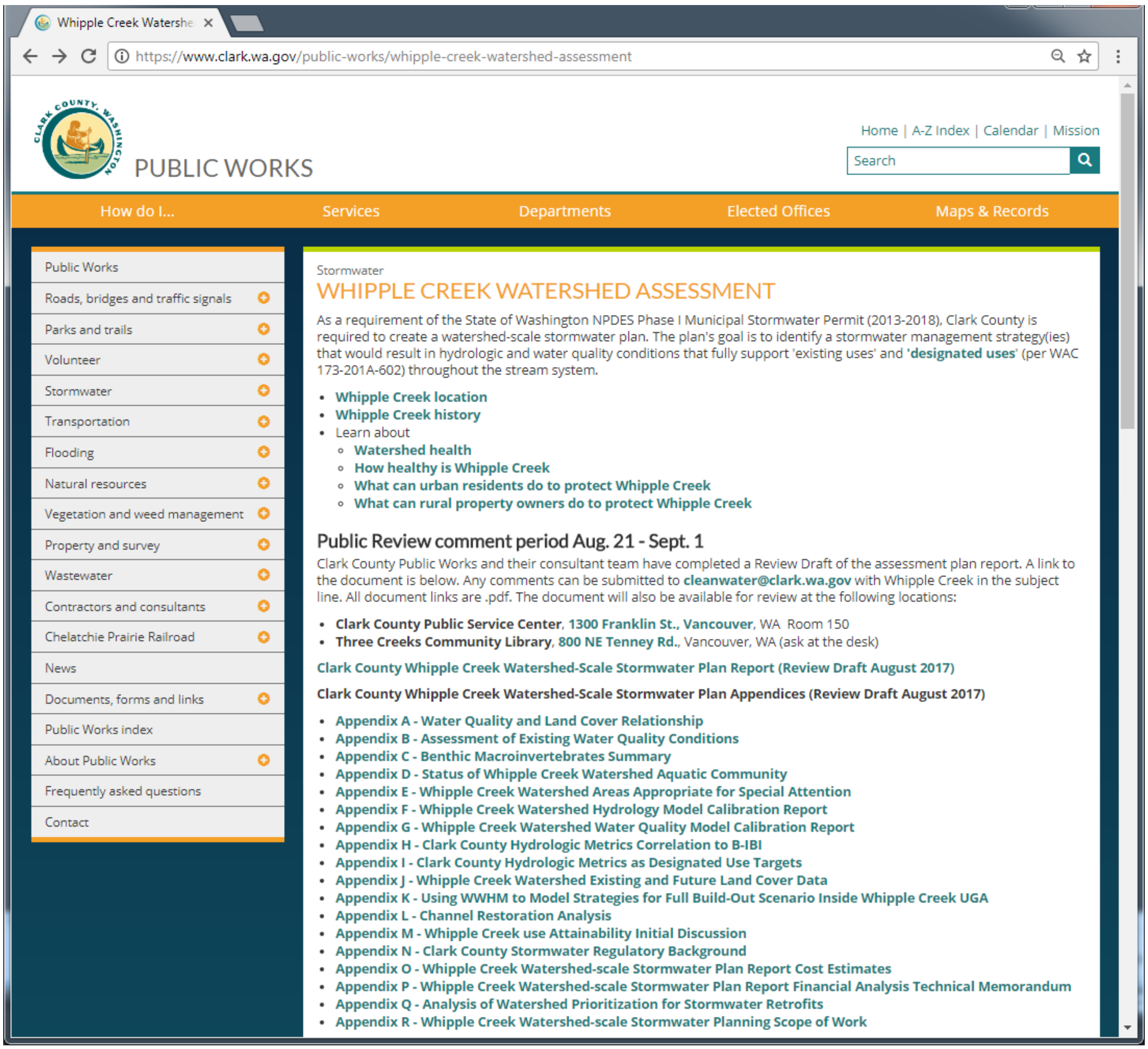
Table 40: Conceptual Schedule

Years 1 - 5	• Implement the contemporaneous Clark County Stormwater Management Program and Stormwater Capital Program • Continue Whipple Creek targeted monitoring studies • Initiate a Use Attainability Analysis
Years 6 - 15	• Implement the contemporaneous Clark County Stormwater Management Program • Adaptive Management • High Priority Capital Projects as Funding Allows
Years 16 - 30	• Implement the contemporaneous Clark County Stormwater Management Program • Adaptive Management • Medium Priority Capital Projects as Funding Allows

V. Public Review Process

Clark County published a web page about the watershed planning process in 2015 at https://www.clark.wa.gov/public-works/whipple-creek-watershed-plan. The draft report was available online and in public libraries for public comment for a two week period from August 21 to September 1, 2017.

Figure 14: Screenshot of Whipple Creek Watershed Assessment Web Page



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Appendix A

Whipple Creek Watershed-Scale Stormwater Plan Report

Water Quality and Land Cover Relationship

Prepared by

Bob Hutton, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

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Contents

Figures

Tables

Introduction

Exploratory statistical analyses was performed on the relationships between Whipple Creek subwatersheds' water quality and general land covers to support the stormwater planning assessment of existing local water quality conditions, screen for broad potential pollution sources, and provide insights for water quality modeling. For nonpoint source pollution analysis and watershed management, linear regression is often used to determine the extent to which water quality (dependent variable) is influenced by hydrological or land use factors (independent variables) such as the percentage of land treatment (EPA, 1997, pp. 1-4). Practical applications of these regression results include the ability to predict water quality impacts due to changes in the independent variables.

Stormwater management planning encompasses a wide range of site-specific issues including understanding local problems and pollutant sources that monitoring can help identify (Burton and Pitt, 2002, p. 10). Discharge from storm drainage systems includes warm weather stormwater, snowmelt, baseflows, and inappropriate discharges to the storm drainage that all may be important to consider when evaluating alternative stormwater management options. Given that stormwater management's main purpose is to reduce adverse impacts on receiving water beneficial uses, it is important in any stormwater runoff study to assess the detrimental effects that runoff is actually having on a receiving water.

Nationally, accumulated data on stormwater quality indicate that concentrations and loads vary widely, but several important factors are involved including land use (Minton, 2002, p.13, 17-18). Minton summarizes the influence of land use factors as:

> "Researchers have differed as to the significance of different land uses. There appears to be a general agreement that loading differs between land uses, whereas there is a lack of agreement as to whether concentration differs. At a minimum, land use can be divided into two broad groups with respect to concentration differences: open space and low-density residential and all other urban land uses. The data from the most comprehensive study ever undertaken suggest no significant difference in event mean concentrations between land use types with the exception of open space. It was concluded that land use type is virtually useless as a predictor of concentration. The data indicate that variation is greater within, rather than between, residential, commercial, industrial, and mixed-use sites."

Given this limited applicability of ***event mean concentrations and land use*** data as well as sparse local continuous flow data for estimating loads, this Whipple Creek study performed only exploratory statistical analyses of ***grab sample water quality*** relationships with ***land cover*** (note not specific ***land use*** types). It is acknowledged that multiple interacting factors determine the quality of stormwater and even more so that of receiving waterbodies where additional in-stream processes occur. The underlying complex interactions of mechanistic factors impacting subwatershed stream water quality (such as the magnitude and timing of individual storm event flows, surface runoff impacts, evapotranspiration, in-stream processes, etc.) are addressed through this watershed planning project's implementation of HSPF continuous flow water quality modeling. Importantly, both this statistical analyses and the HSPF model utilize the same watershed wide land cover data while the model calibration focuses on water quality data from the long running lower-watershed monitoring station (WPL050) also included in this study.

Therefore, only Whipple Creek subwatersheds' portions of general land covers falling within open space or development categories are related to their respective stream's median water quality values using simple linear regression. This study's goals are to see if land cover helps explain variation in grab sample monitored water quality and gain insights on potential general pollution sources and possible anomalies.

Methods

Stream water quality monitoring occurred at nine monitoring stations (Figure 1) located at the mouth of four main channel or main stem (labeled from downstream to upstream as WPL010, WPL050, WPL065, and WPL080) and five tributary drainages (from most downstream to upstream depicted as PCK010 [Packard Creek], WPLT01, WPLT02, WPLT03, and WPLT04). From at least July 2014 through May 2015, Clark County staff followed standard operating procedures in taking stream field measurements and collecting grab samples (Clark County, 2014). All water samples were analyzed at a nearby Washington State Department of Ecology accredited laboratory to help meet analytical hold times.

Water quality is represented by six parameters' median values to assign dependent variable values for relationships based on flow type (Table 1). Medians are used for central tendency because they are more resistant to outliers. Each median is based on at least 11 monitoring events per station (grouped by flow type) except for one tributary station with slightly fewer events (WPLT03). Typically, monitoring events at each station included at least 12 random base flow and 11 storm events for most parameters except for 8 base flow events for WPLT03. Additionally, water quality monitoring was performed monthly during unclassified flow events at the Packard Creek tributary and most main stem stations in water year 2012 with substantially more similar monitoring occurring at WPL050 going back to water year 2002 (yielding between 31 and 165 monthly monitored parameter results as part of a long-term monitoring project).

Land cover is represented by the relative portion of five general land cover types upstream from each monitoring location (based on previously mapped catchments). The catchments and land cover types are the same used for input to the Whipple Creek Watershed Plan's HSPF model. Most land cover data was originally derived using methods developed in the Puget Sound area (Hill and Bidwell, 2003) and applied to 2000 Landsat satellite imagery. Clark County staff then aggregated some closely related land cover classes and updated acreages using a Geographic Information System (ESRI, 2014, ArcGIS 10.2.2 for Desktop) and interpretation of 2014 aerial photographs as well more recent subdivision documentation. Final land cover types included forest, pasture, grass, impervious surfaces, and water. During the update, open areas around development were interpreted as falling within the grassy (urban lawn-like) land cover.

Data management and analyses utilized standardized procedures (Clark County, 2014) and existing software systems operated by Clark County staff. Data management included data review, finalization, and upload into the County's water quality database (WQDB based on Microsoft Access) and data manipulation using spreadsheets (Microsoft Excel). Statistical analyses were performed using MiniTab Statistical Software (Minitab Inc., Version 14, 2003). Analyses focused primarily on a straightforward screening of relationships between individual pairs of variables representing available Whipple Creek subwatershed water quality data (using medians) versus proportion of each subwatershed in a particular general land cover category. Relationships were evaluated via simple linear regression (Helsel and Hirsch, 2000, pp. 221 - 222) where one explanatory or independent variable (land cover) is used in statistical models. More complex multiple explanatory variable / multivariate regression statistical models were not evaluated in this basic screening study.

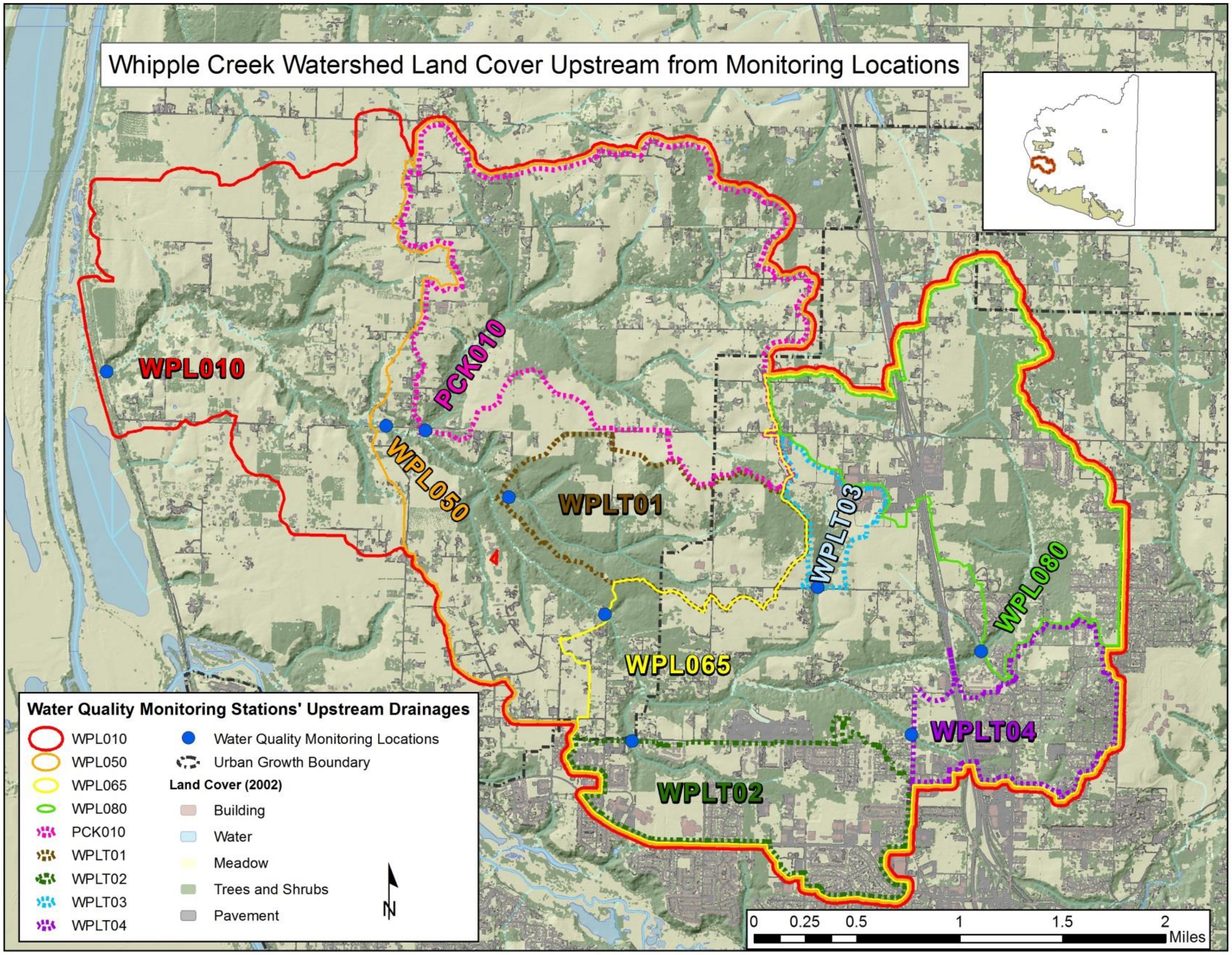

Figure 1 Whipple Creek Subwatersheds Water Quality Monitoring Stations and General Land Covers

Table 1 Whipple Creek main stem and tributary subwatershed median water quality values and sample sizes by flow type

Whipple Creek Main Stem Subwatersheds Water Quality Medians															
Station	WPL010 Medians				WPL050 Medians				WPL065 Medians			WPL080 Medians			
Monitoring Period	WY12 Monthly, July'14-May '15				WY'02-'15 Monthly, July '14 - May '15				July '14 - May '15			WY12 Monthly, July'14-May '15			
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Unclassif.	Overall
Sample Size *	12	12	12	36	12	12	*	*	12	12	24	12	12	12	36
Parameter (units)															
Water Temperature (degrees C)	11	10.9	12.6	11.3	11	10.6	11.2 (164)	11.1 (188)	11.4	10.7	10.7	10.8	11	13.4	11.3
Tubidity (NTU)	8.9	35.3	14.5	13.5	7.6	39.6	8.2 (165)	8.6 (189)	7.6	24.5	11.1	6.2	20.7	6	8.4
pH	7.48	7.37	7.22	7.4	7.89	7.5	7.53 (158)	7.53 (182)	7.52	7.26	7.46	7.54	7.41	7.37	7.38
Dissolved Copper (ug/L)	0.71	1.32	NA	0.87 (24)	0.76	1.28	1.14 (31)	1.13 (55)	0.9	1.86	1.17	0.96	1.82	NA	1.22 (24)
Dissolved Zinc (ug/L)	1.5	0.9	NA	1.0 (24)	1	1	1.1 (34)	1.0 (58)	1.5	2.3	1.8	1.4	3.1	NA	2.3 (24)
Fecal Coliform (CFU/100 mL)	340	800 (11)	335	420 (35)	262	1865 (10)	275 (136)	315 (158)	203	390 (8)	265 (20)	57	280 (11)	76	100 (35)

Whipple Creek Tributary Subwatersheds Water Quality Medians																
Station	PCK010 Medians				WPLT01 Medians			WPLT02 Medians			WPLT03 Medians			WPLT04 Medians		
Monitoring Period	WY12 Monthly, July'14-May '15				July '14 - May '15			July '14 - May '15			July '14 - May '15			July '14 - May '15		
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall
Sample Size *	12	12	12	36	12	11	23	12	11	23	8	11	19	12	11	23
Parameter (units)																
Water Temperature (degrees C)	10.8	10.5	12.3	11.1	10.5	10.7	10.7	11.1	11.1	11.1	6.1	10.5	9.8	11.5	11.5	11.5
Tubidity (NTU)	9.6	56	13.2	17.3	11.7	50.9	20.8	4.6	32	6.9	9.9	38.6	22.6	9.6	37.9	12.5
pH	7.69	7.6	7.5	7.6	7.89	7.56	7.74	7.65	7.37	7.57	7.46	7.52	7.47	7.2	7.37	7.32
Dissolved Copper (ug/L)	0.82	1.69	NA	1.32 (24)	0.67	1.25	0.8	0.74	1.73	1.25	1.15	1.93	1.85	0.66	2.44	0.88
Dissolved Zinc (ug/L)	0.8	1	NA	1.0 (24)	0.5	0.7	0.6	1.7	6	2.2	2.4	3.3	2.9	2.1	11.2	3.1
Fecal Coliform (CFU/100 mL)	395	3350	276	650	485	1040	760	780	665 (10)	695 (22)	31	660	280	71	740 (9)	250 (21)

* Common sample size across all station parameters unless noted otherwise in parentheses after median value.

Results and Discussion - Water Quality versus Land Cover Relationships

Land Covers

It is assumed that the main stem monitoring stations' water quality reflects that of nested upstream tributary and / or other main stem subwatersheds' land cover (Table 2). Forest, pasture, and grass dominate the main stem subwatersheds' land cover which, combined, total at least 80 %t of each drainage (Figure 2). WPL080 and even more so WPL065 have relatively more grass and impervious surface but less pasture and forest than WPL010 and WPL050. WPL065's higher levels of grass and impervious land covers is impacted by the higher percentages of these same land covers contributed from its nested main stem WPL080 and tributary WPLT02, WPLT03, and WPLT04 subwatersheds (Table 2 and Figure 3).

Table 2 Whipple Creek water quality monitoring stations upstream drainage areas

Whipple Creek Monitored Subwatersheds Nested Hierarchy, Land Cover Acreages and Relative Percentages												
Drainages		**Forest**		**Pasture**		**Grass**		**Impervious**		**Water**		**Total**
Nested Main Stem	**Tributaries**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**
	WPLT01	228	44	199	38	79	15	16	3	0	0	522
	WPLT02	83	15	61	11	263	47	152	27	3	0	561
	WPLT03	19	16	21	18	41	34	39	32	0	0	119
	WPLT04	64	18	31	9	183	51	83	23	1	0	363
	WPL080*	323	32	223	22	299	30	158	16	0	0	1003
WPL065 Total		743	26	554	19	1031	35	572	20	5	0	2906
	PCK010	535	35	674	44	250	16	59	4	0	0	1517
WPL050 Total		1747	31	1745	31	1459	26	672	12	5	0	5628
WPL010 Total		2136	30	2434	34	1749	25	746	11	7	0	7071

*WPL080 is the main stem headwater tributary

Screening of Overall Flow Type Water Quality versus Land Cover Relationships

A scatterplot matrix allows assessing many pairs of variable relationships at once (MiniTab Release 14 Statistical Software Help). Figure 4 allows a visual assessment of water quality versus land cover pairs of variables and the shape of their relationships for the overall flow type data. The scatterplots' dashed-red lowesss ("LOcally-Weighted Scatterplot Smoother") lines allow exploration of the relationship between two variables without fitting a specific model such as a regression line (MiniTab Release 14 Statistical Software Help). However, the scatterplots are also fitted with linear regressions for comparisons with this basic statistical model. Throughout Figure 4, the overall shape of many of the lowess lines suggests that linear regression often is a reasonable statistical model to use. However, of the six water quality parameters evaluated, dissolved zinc most commonly appears to have relatively little scatter around its linear regression. These simple linear regression plots suggest multiple Whipple Creek subwatershed land covers help predict dissolved zinc levels while impervious surfaces may suggest dissolved copper levels.

Significant Overall Flow Type Water Quality versus Land Cover Relationships

Table 3 summarizes formal statistical tests, using Pearson product moment correlation coefficients (r), of the strength of linear relationships (Ott, 1988, pp. 319-320) or associations between pairs of water quality (response) versus land cover (predictor) variables for overall flow types. The p-values are the likelihood for each null hypothesis of an individual correlation equaling zero versus the two-tailed alternative hypothesis of a correlation not equaling zero (MiniTab Release 14 Statistical Software Help). The r^2 values give the proportion of the total variability (Ott, 1988, p. 320) in the y-values (individual water quality parameter) that can be accounted for by the independent variable (individual land cover type).

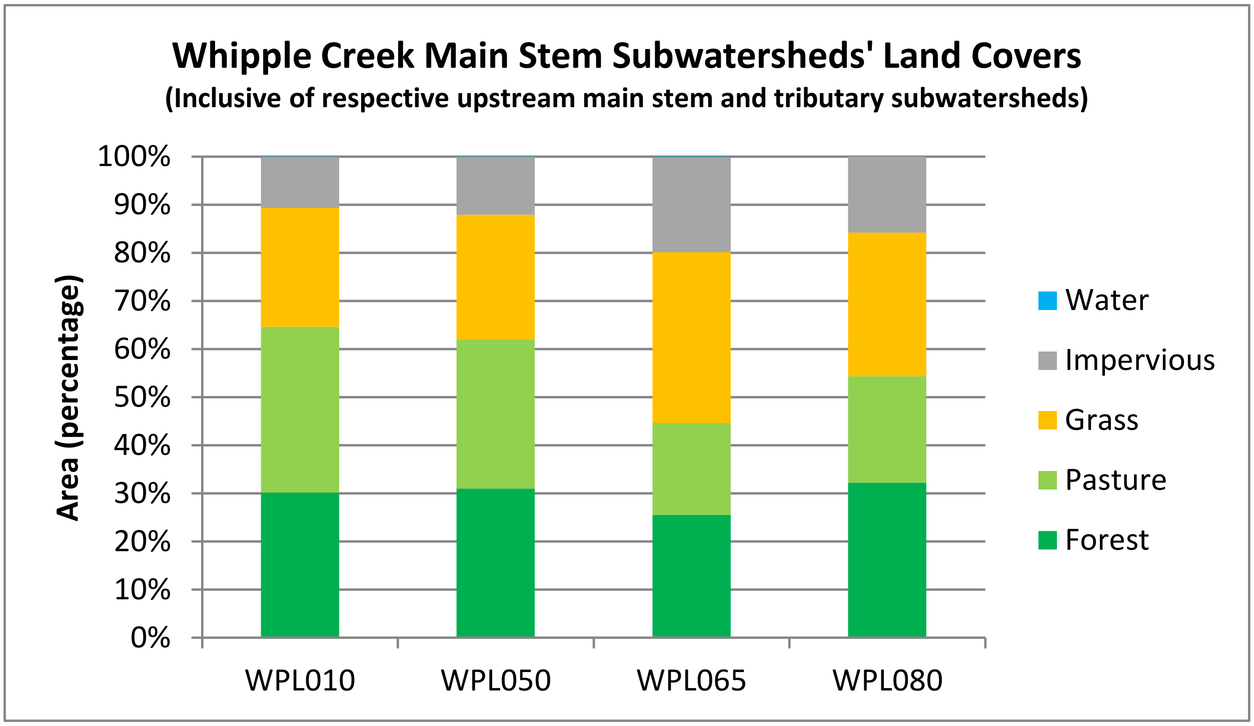

Figure 2 Whipple Creek main stem subwatersheds upstream land cover percentages

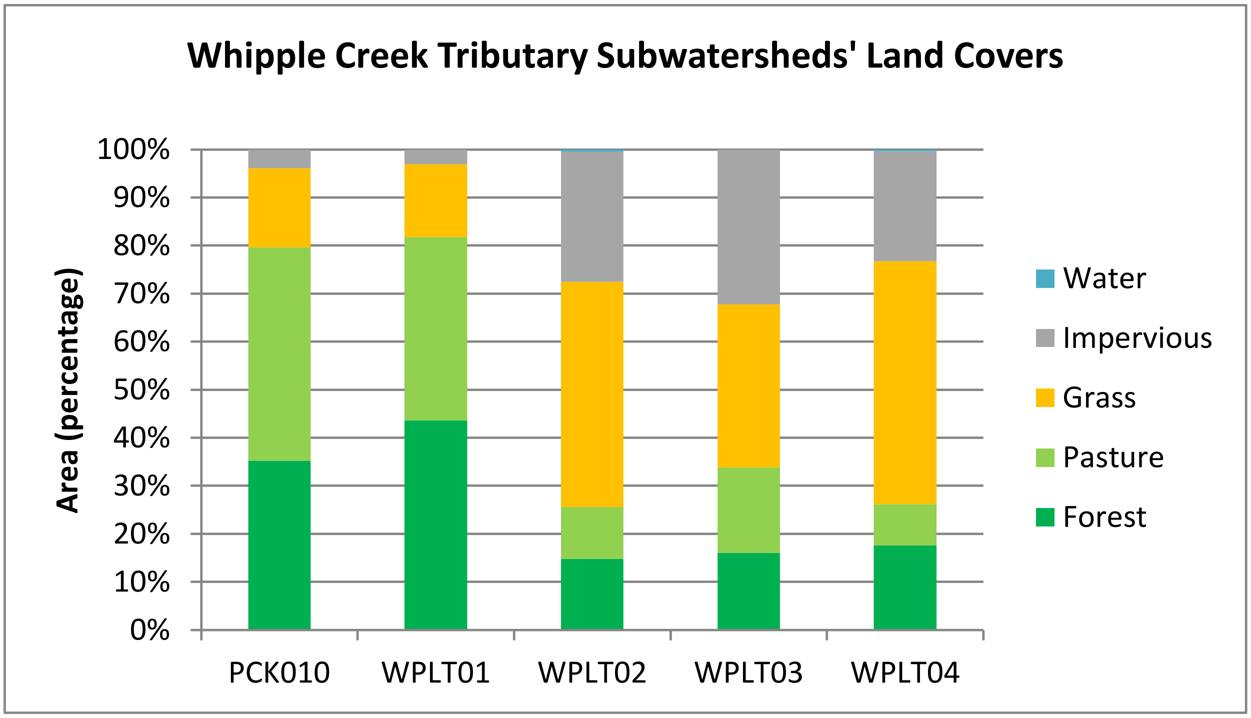

Figure 3 Whipple Creek tributary subwatersheds upstream land cover percentages

Significant linear relationships are high-lighted by two hues of green borders around their respective scatterplots in Figure 4 and two shades of grey cells in Table 3.

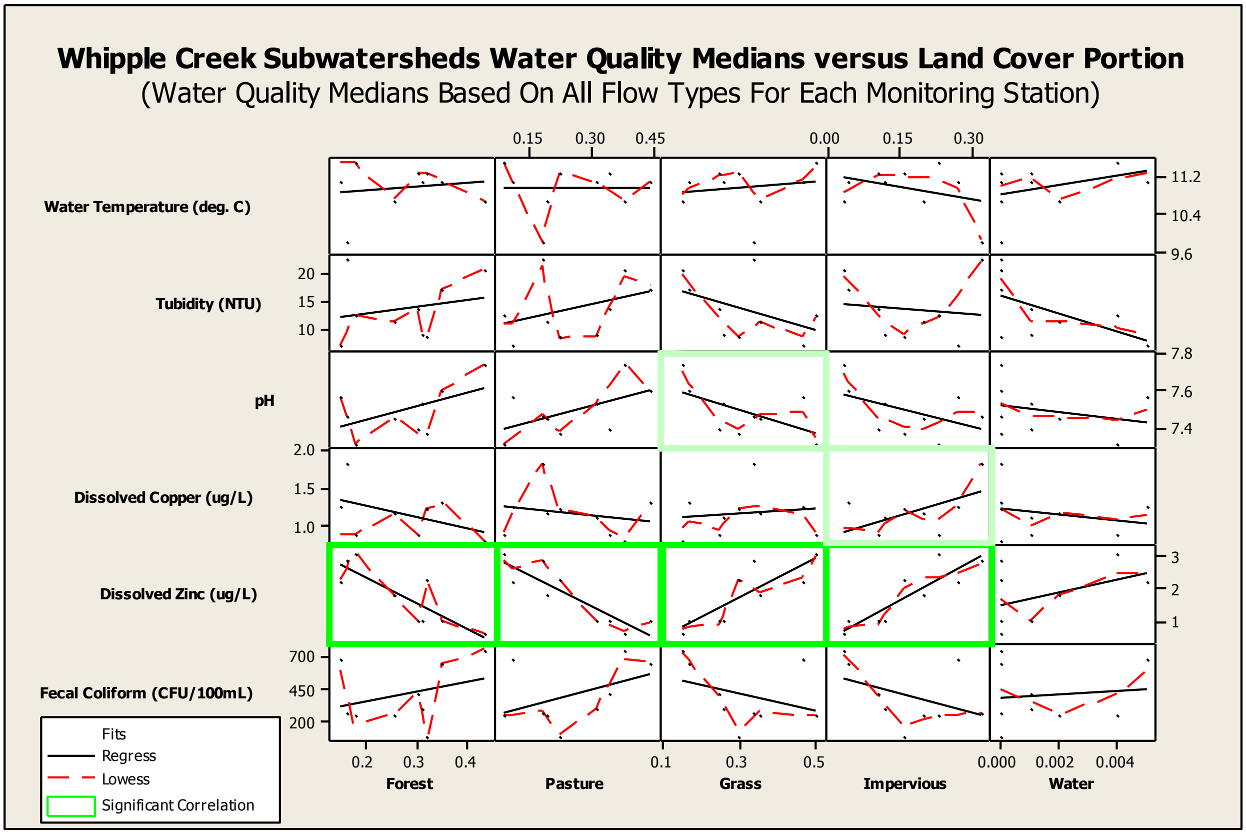

Figure 4 Scatterplot matrix of Whipple Creek subwatersheds' water quality medians versus portion of general land covers fit with linear regression and lowess smoother lines (borders depict significance at 0.05 – bright green and ~ 0.10 - light green)

Table 3 Correlation coefficient matrix for individual Whipple Creek subwatersheds' overall flow type water quality medians versus portion of general land covers relationships

Water Quality Parameter*	Forest			Pasture			Grass			Impervious			Water		
	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Temperature	0.167	0.667	0.03	0.028	0.943	0.00	0.142	0.716	0.02	-0.376	0.319	0.14	0.377	0.317	0.14
Turbidity	0.228	0.555	0.05	0.383	0.309	0.15	-0.454	0.220	0.21	-0.135	0.729	0.02	-0.558	0.118	0.31
pH	0.521	0.150	0.27	0.554	0.122	0.31	-0.582	0.100	0.34	-0.478	0.193	0.23	-0.246	0.523	0.06
Dissolved Copper	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33	-0.218	0.572	0.05
Dissolved Zinc	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77	0.440	0.236	0.19
Fecal Coliform	0.303	0.428	0.09	0.434	0.243	0.19	-0.348	0.358	0.12	-0.409	0.274	0.17	0.099	0.800	0.01

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

At a significance level (α) of 0.05 (highly significant), only overall flow's dissolved zinc medians had any significant linear relationships with or were found to be linearly dependent on (Helsel and Hirsch, 1993, p. 219) any of the land covers (bright green bordered scatterplots in Figure 4 and dark grey shaded p-value cells in Table 3). In fact, dissolved zinc's linear regressions on four of the five land cover types were significant at this level. Water was the only land cover type found to be not significantly associated with dissolved zinc. Water as a land cover is not of practical significance for further subwatershed analyses given its relatively very small total surface area of 7 acres, which represents about 1/1000 of the total Whipple Creek watershed area. The analyses show dissolved zinc has indirect significant relationships (negative r's in Table 3 and scatterplot slopes in Figure 4) with the more open space land cover categories of forest and pasture versus direct relationships (positive r and scatterplot slope) with the more development linked categories of grass and impervious surfaces.

Taking the square of the coefficient of linear correlation (r^2) gives the percent of variance in the response variable that is helped explained by the predictor variable (Helsel and Hirsch, 2000, p. 231). The r^2 for the significant overall flow's dissolved zinc linear relationships, indicates that between 69 and 77 percent of the variance of dissolved zinc medians is explained by the individual effect of four of the five land covers (Table 3). In addition, dissolved copper medians had somewhat of a significant (p-value of 0.105) direct linear relationship with impervious land cover that explained 33 percent of the variation in the median values for this metal. Median pH values also had a moderately significant (p-value of 0.10) indirect linear relationship with grass land cover that explained 34 percent of pH variation. While pH's relationship is statistically significant, most of its values across all monitoring stations fell in an acceptable relatively narrow range (mostly 6.5 to 8.0) as far as possible impacts. Therefore, pH is not discussed further.

Using subwatershed symbols, Figure 5 and Figure 6 depict significant relationships between overall flow's dissolved metal medians versus land cover based on data from all flow types (their overall flow regression equations are in the appendix). In most of the remaining figures, subwatershed symbol colors match those used in the map of Figure 1. The identical vertical and horizontal scales of the individual land cover panels in Figure 6 facilitate comparisons of its fitted regression and lowess lines' slopes and directions. Figure 5 shows dissolved copper's single significant land cover relationship with impervious land cover. Compared to dissolved zinc, dissolved copper medians are lower and its linear relationship's slope appears much smaller suggesting its slower rate of increase with greater amounts of impervious surfaces.

The patterns depicted in Figure 6 reflect the similar and complimentary impacts on dissolved zinc levels from open space versus development related land covers. The direction and slopes of the regression lines are very similar for each of the pairs of open space (forest and pasture) versus development (grass and impervious) relationships. These two groups' regressions also tend to be mirror images of each other. The comparable nature of and apparent parallel regression slopes for each of the open space versus development dominated land cover regressions suggests possible intercorrelations within these pairs of independent land cover variables. This implies that using either regression from each pair may suffice for predicting dissolved zinc. However, multiple regression statistical analysis would be required to evaluate potential intercorrelations of each additional independent variable and their contribution to the prediction of the response variable (Kleinbaum et al. 1988, pp. 106 and 124) of water quality. This level of analysis is beyond the scope of this basic screening study especially given that each linear relationship is based on just nine water quality / land cover pairs of variable values.

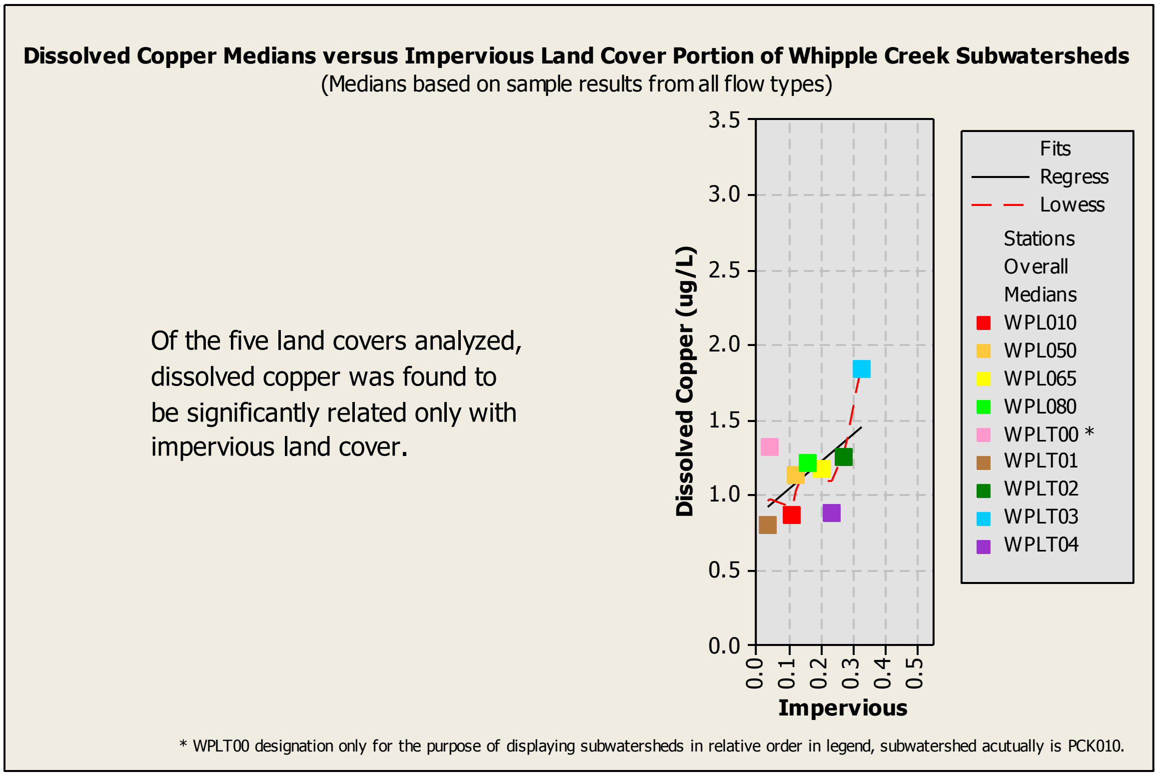

Figure 5 Scatterplot of dissolved copper median concentrations versus impervious surface land cover within subwatersheds

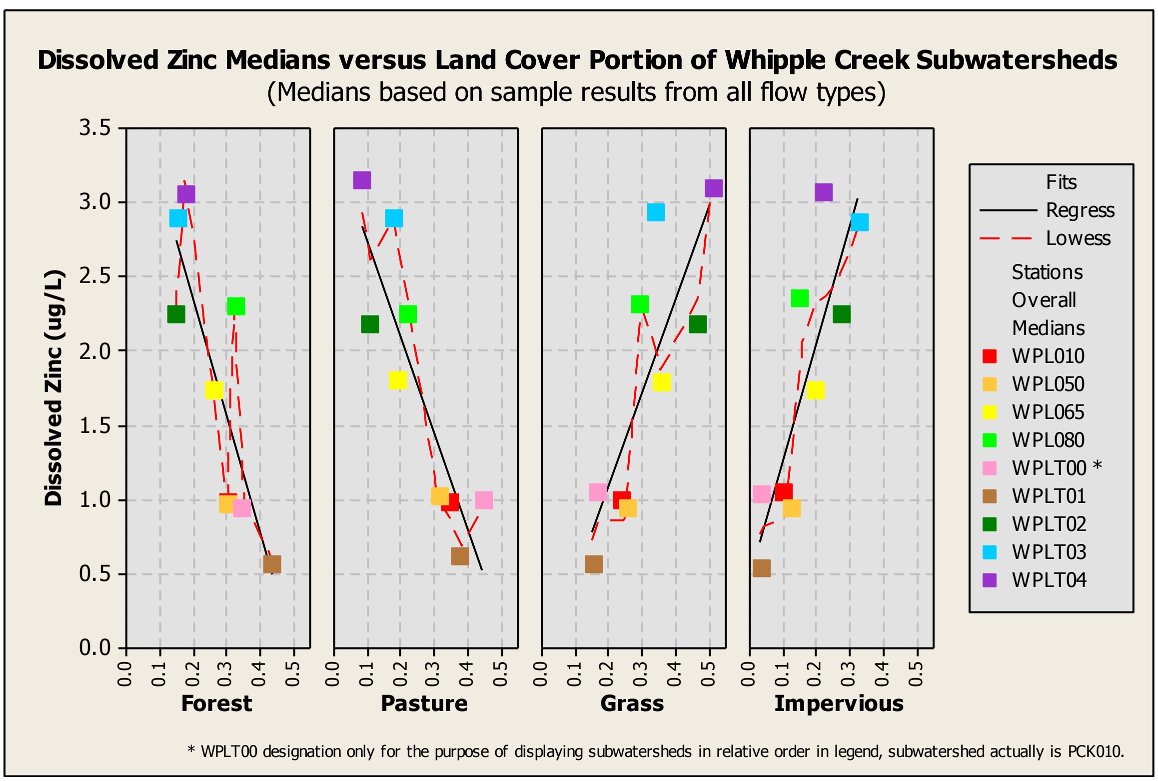

Figure 6 Scatterplot panels of dissolved zinc median concentrations versus general land cover within subwatersheds

Flow Type Dissolved Zinc and Dissolved Copper Distributions

Since dissolved zinc's and to a lesser extent dissolved copper's significant overall flow type linear relationships may have practical watershed management implications, additional exploratory analyses focused primarily on their subwatershed flow-type descriptive statistics and their role in linear regression relationships. Boxplots in Figure 7 and Figure 8 compare these parameters' distribution and central tendencies for each of the monitored Whipple Creek subwatersheds (using color-coding to illustrate flow types for each monitoring station). Each subwatershed boxplot can depict values for its: median (darker color-filled circle), interquartile range or IQR (outer box), 95% confidence intervals around the median (inner boxes), whiskers (values falling within 1.5 times the IQR from the median), and outliers beyond the whiskers (asterisks). These flow type medians represent a more detailed look than the calculated overall medians (based on all of a subwatershed's flow type results) presented so far in the above graphs. Importantly, since all of the base and storm flow boxplots are based on approximately the same sample sizes (except a slightly smaller sample size for WPLT03 base flow, also see Table 1) equivalent weight can be given to their interpretation for flow type boxplots and regressions.

Figure 7 shows the important role storm flow plays in dissolved zinc concentrations for more developed subwatersheds. For the more developed subwatersheds, dissolved zinc median storm flow concentrations (depicted by the blue boxplots' inner boxes illustrating 95% confidence intervals [C.I.] around their medians) are mostly significantly higher than those for their respective subwatershed's base flows (yellow boxplots' inner boxes). The most developed subwatersheds of WPLT02, WPLT03, and WPLT04 have at least 23% impervious and 34% grass land covers (also see Figure 2 and Figure 3). Additionally, WPLT02 and WPLT04 tributary subwatersheds' storm flow dissolved zinc median confidence intervals are much higher than those for all the other subwatersheds' storm and base flows except for WPLT03 (possibly due to fairground's galvanized roofs). Conversely, the two furthest downstream main stem (WPL010 and WPL050) and tributary (PCK010 and WPLT01) stations' storm flow dissolved zinc medians are significantly lower (depicted by their inner blue coded boxes not overlapping with those for WPLT02 – WPLT04) and their respective percentages of grass/impervious surfaces both are relatively low (at most 12% impervious and 26% grass). The relatively inverse pattern of land cover proportions of open space land covers (forest/pasture) for these same subwatersheds reflects their remaining larger undeveloped areas. Importantly, there are no significant differences in the base flow dissolved zinc median concentrations across all of the subwatersheds (all of the inner yellow boxes appear to overlap). The overall contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in dissolved zinc concentrations in the more developed subwatersheds. All of these patterns are consistent with the significant relationships found between the land covers and overall median dissolved zinc values but provide more specific information to support the hypothesis that stormwater runoff from these land covers contribute to those significant relationships.

Figure 8 shows a few different patterns for dissolved copper medians from those for dissolved zinc. Compared to base flows, higher storm flow median dissolved copper concentrations are more widespread across subwatersheds than for dissolved zinc. Dissolved copper has six while dissolved zinc has four subwatersheds with significantly higher storm flow versus base flow median concentrations. However, as shown by the boxplot median confidence intervals' pattern across subwatersheds as well as their ranges and magnitudes about their medians, dissolved zinc appears to be more sensitive than dissolved copper to development's impact on storm flow water quality. Similar to dissolved zinc, there are no significant differences in the base flow dissolved copper median concentrations across all of the subwatersheds.

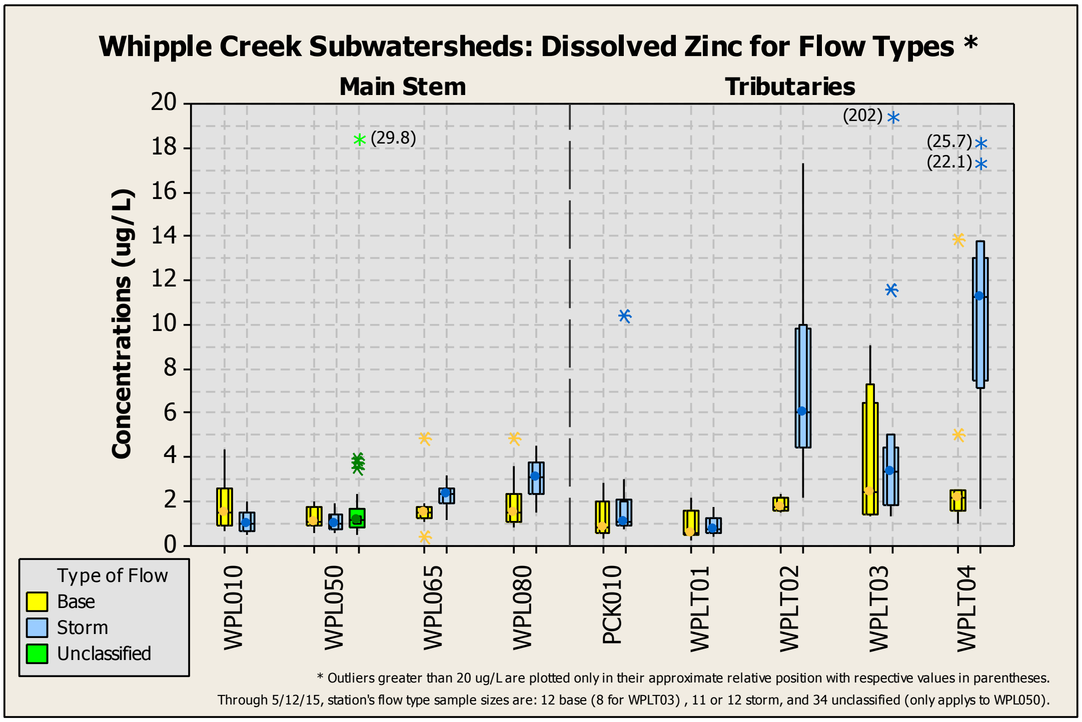

Figure 7 Boxplots of Whipple Creek subwatersheds' dissolved zinc by flow type

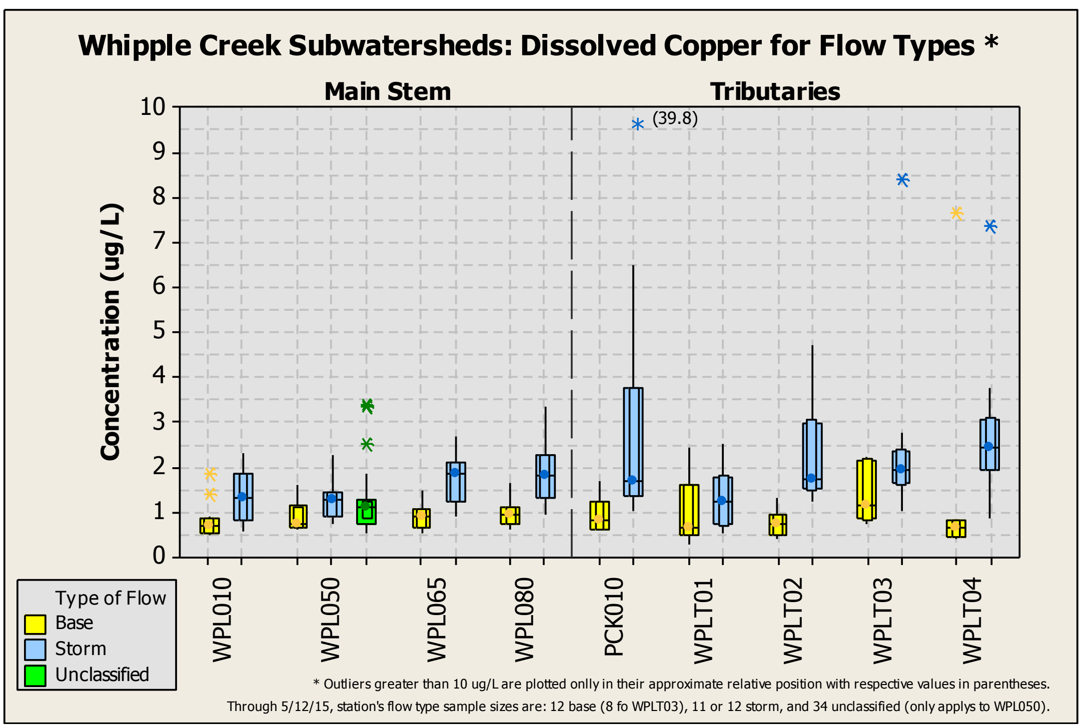

Figure 8 Boxplots of Whipple Creek subwatersheds' dissolved copper by flow type

Flow Type Dissolved Zinc and Dissolved Copper Relationships

Figure 9 through Figure 13 present more detailed analyses of the previously identified overall flow type's significant dissolved metal medians versus land cover linear relationships to help explore base and storm flow's potential impact on the relationships. These figures use the same ranges on their axes to facilitate comparisons. Within each of these figures, each monitoring station's dissolved metals medians are classified into one of the three flow types of base, storm, and overall (symbolized respectively with downward-point triangles, upward-pointing triangles, or squares). Overall is a combined data set consisting of medians calculated from base and storm flow's respective dissolved copper or zinc data values plus unclassified flows' dissolved metals values for just WPL050. The overall regressions are identical to those presented in Figure 5 and Figure 6 but are included for relative comparisons to base and storm flow regressions. In general, based on the lowess lines fitted to these flow type data sets, it appears linear regression is a reasonable model for consistent use across all variable combinations but possibly least applicable for forest and pasture storm flows.

As noted previously, most of the regressions' dissolved metal base and storm flow medians are calculated from very similar sample size data sets. The generally similar sample size exceptions are for WPL050 metals' overall medians which include a much larger sample size that is dominated by unclassified flow type values. However, most of WPL050's unclassified flow dissolved metal values are similar to their respective base and storm flow values. This similarity is shown by WPL050's unclassified data interquartile ranges and whiskers overlapping with those for its base and storm values except for 4 outliers of 34 dissolved zinc values in Figure 7 and 3 outliers of 31 dissolved copper values in Figure 8. Thus, equal weight is assumed in regressions for each base and storm flow dissolved metal median versus land cover data point and WPL050's overall regression is interpreted similarly as all others.

These flow type plots show the substantial and important role that WPLT02 and especially WPLT04 storm flow concentrations have on the slope of their dissolved metals versus land cover linear relationships. The horizontal scatterplot positons for WPLT02's and WPLT04's relatively high storm flow median dissolved zinc concentrations (up-pointing darker green and purple triangle symbols, respectively, in Figure 9 through Figure 12) are consistent with their subwatersheds' relative amounts of potentially pollutant generating land covers. Conversely, all flow types' relatively low dissolved zinc medians for the lower main stem, Packard, and WPLT010 subwatersheds tend to be clustered in the scatterplots' lower right for forest / pasture or lower left for grass / impervious surface. This is also consistent with the expected lower dissolved zinc pollutants levels across all flow types for these mostly open space dominated subwatersheds.

While the dissolved metals versus impervious land cover flow type linear regressions' slopes were not tested statistically for differences, dissolved zinc concentrations across both base and storm flow types appear to respond more than those for dissolved copper to potential impacts from development. This is depicted by the consistent appearance of steeper dissolved zinc versus impervious land cover regression slopes across flow types in Figure 12 compared to those of dissolved copper in equivalently scaled Figure 13. Even though dissolved coppers values are lower overall, this would be a valid comparison in absolute concentration terms since both graphs use the same scales on their axes. Figure 14 shows dissolved copper medians versus impervious land cover using an expanded view of axes scales to better depict differences between dissolved copper flow types across their full range of results.

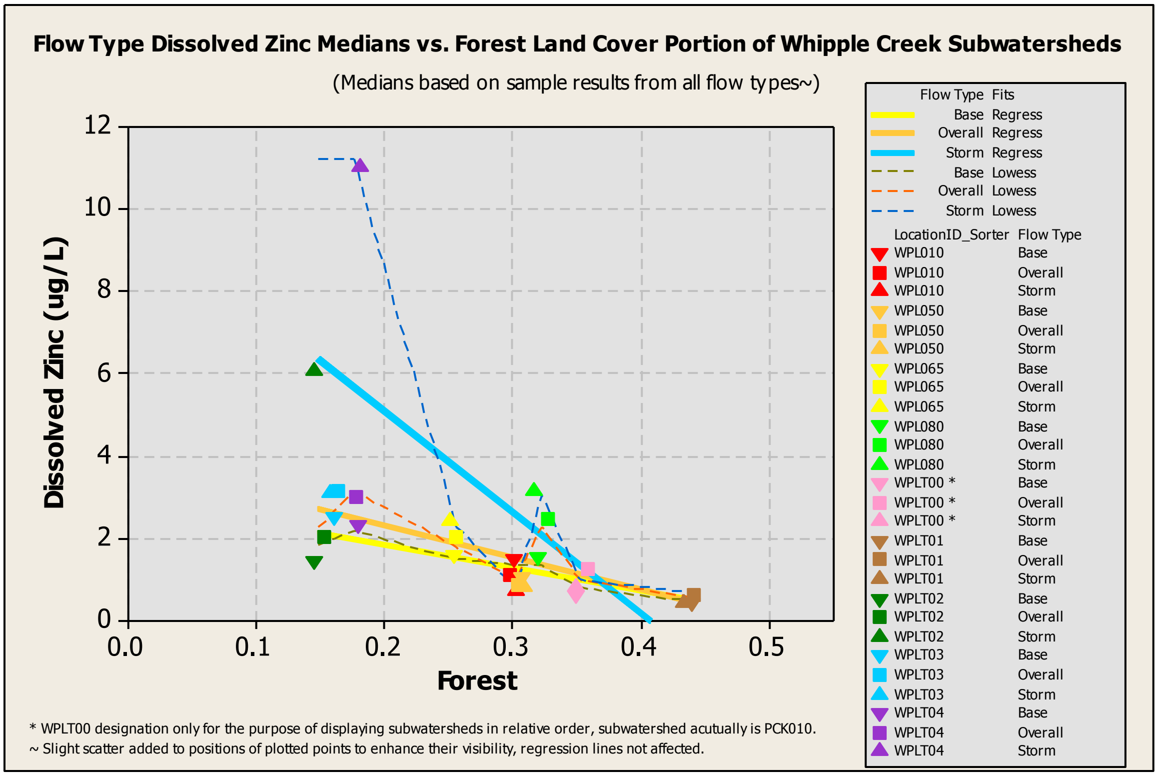

Figure 9 Flow type dissolved zinc medians versus proportion of forest land cover

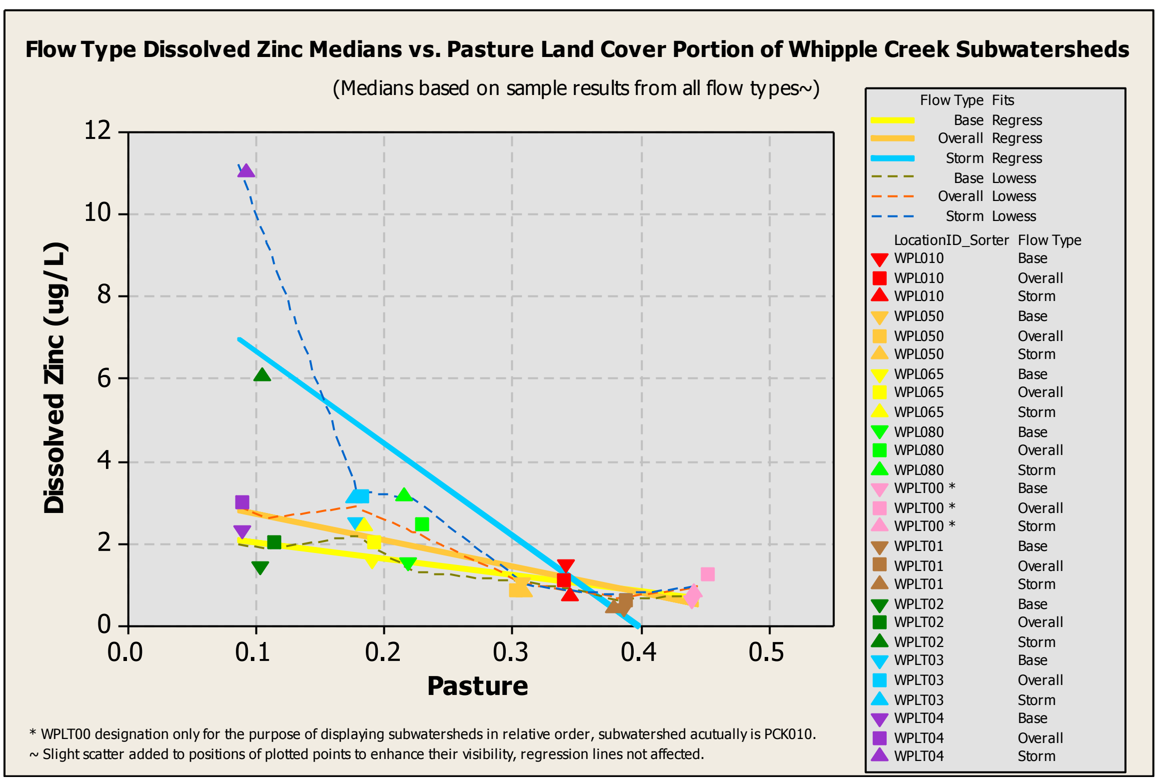

Figure 10 Flow type dissolved zinc medians versus proportion of pasture land cover

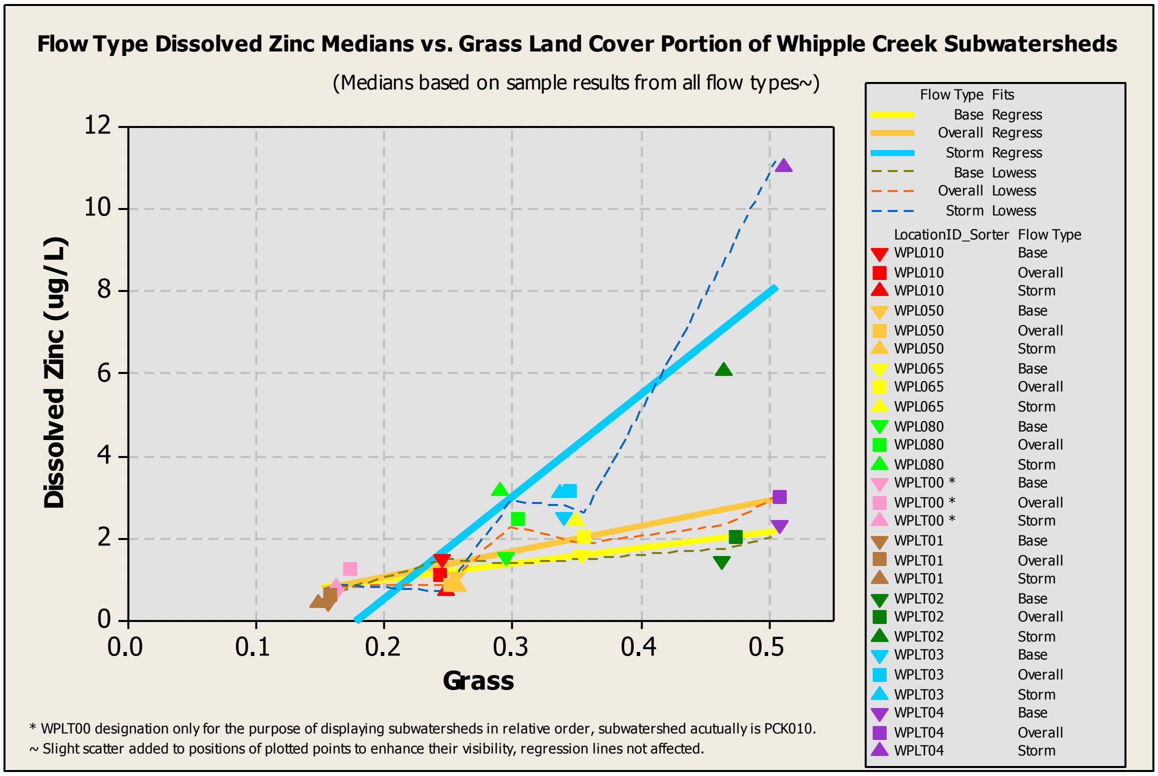

Figure 11 Flow type dissolved zinc medians versus proportion of grass land cover

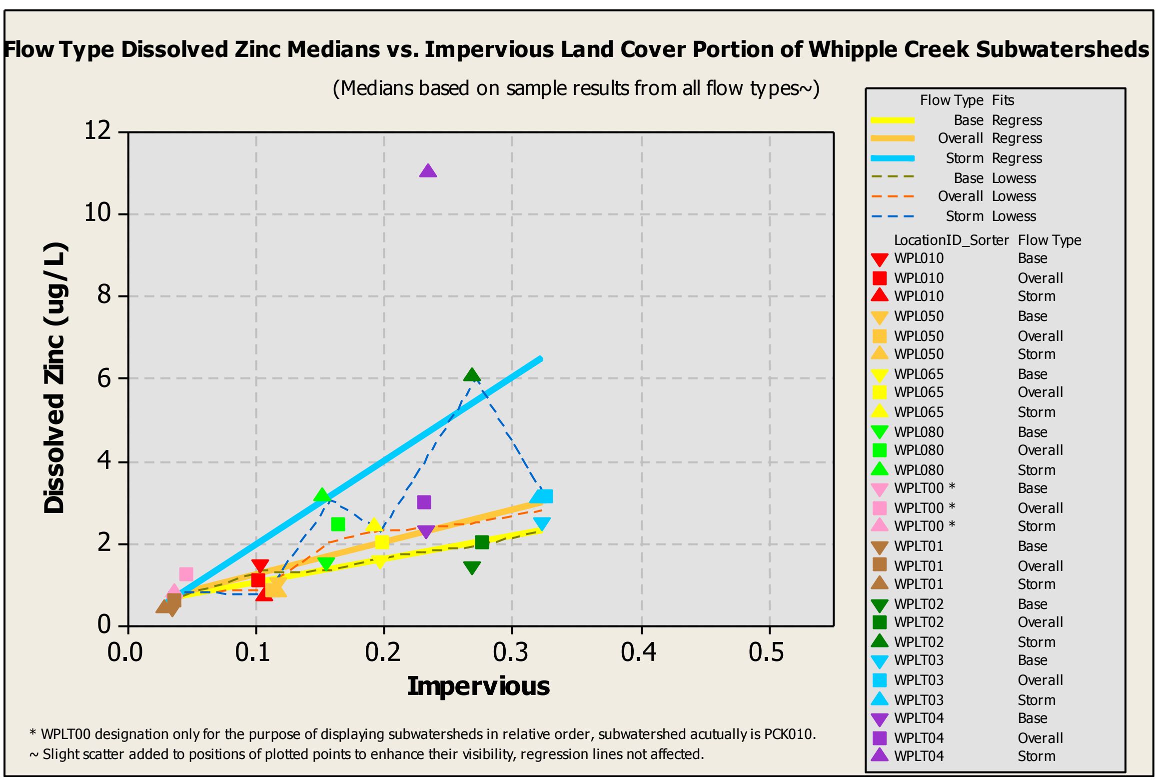

Figure 12 Flow type dissolved zinc medians versus proportion of impervious land cover

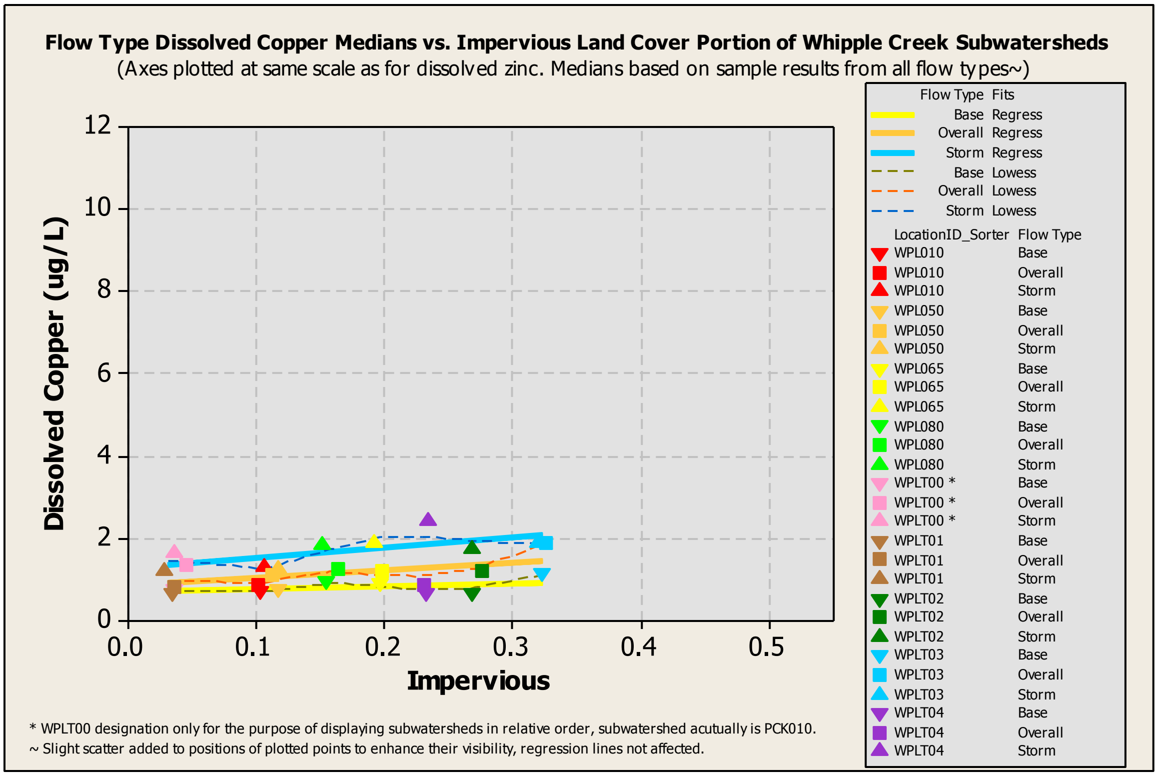

Figure 13 Flow type dissolved copper medians versus proportion of impervious land cover (same scales as dissolved zinc)

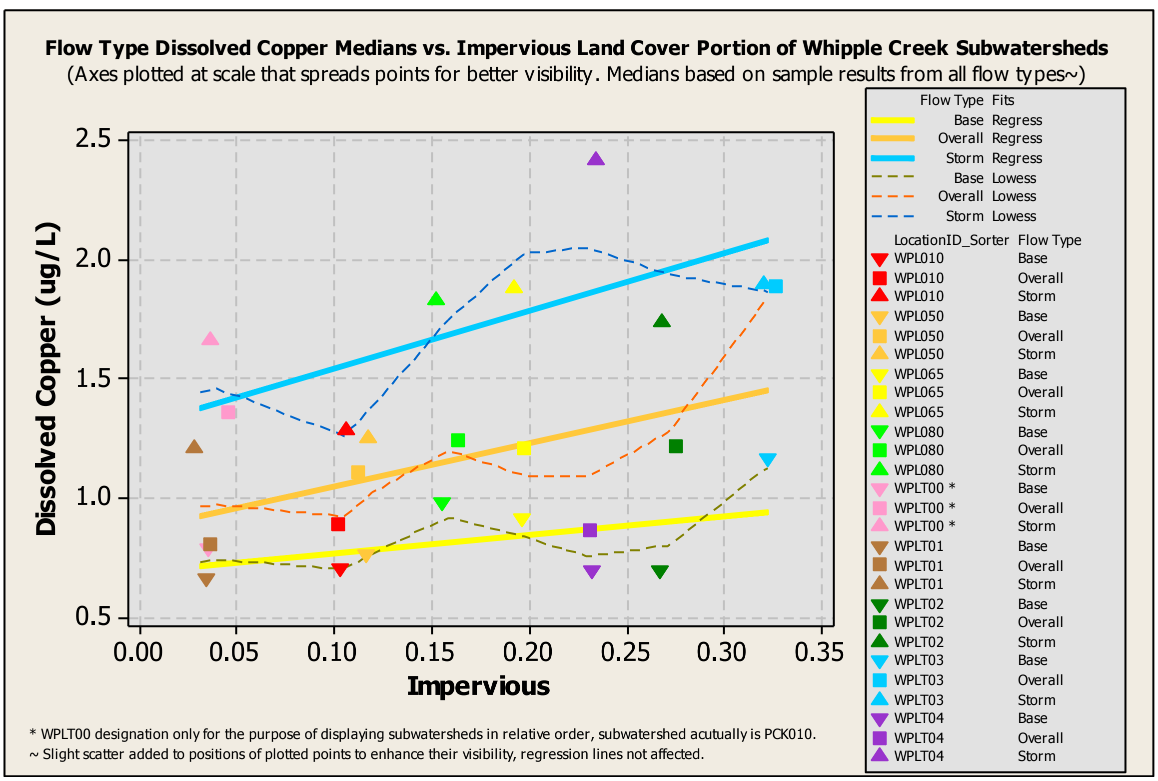

Figure 14 Flow type dissolved copper medians versus proportion of impervious land cover (scales expanded to range of data)

This study's appendix contains the calculated linear regression equations and graphs for Whipple Creek subwatersheds' dissolved zinc medians versus most land covers and dissolved copper medians versus impervious land cover depicted across all flow types. The regressions represent the modeled mean response values (MiniTab Release 14 Statistical Software Help) for a range of predictor values. The potential limited representativeness of this study's small sample size of nine subwatershed monitoring locations was somewhat offset by using water quality medians as dependent variable values for developing the regressions. Each median is based primarily on between 11 and 189 individual parameter results. Importantly, differences in dissolved metals flow type medians versus land cover regressions' slopes were not formally tested statistically given this study's limited screening purpose, the relatively small available sample sizes, and differing correlation significance levels for some base and storm flow type relationships.

Correlation values for base and storm flow dissolved copper versus impervious and dissolved zinc versus four land covers are presented in Table 4 for those relationships found to have significant overall flow type relationships. The overall flow type correlations are identical to those presented in Table 3 but are included here for relative comparisons. Only the correlation for dissolved copper medians' storm flow versus impervious land cover linear relationship was found to be even moderately significant (p-value of 0.066). In contrast, all of the correlations for dissolved zinc medians' base and storm flow types versus the four land covers' linear relationships were highly significant except for storm flow versus impervious which was moderately significant.

Table 4 Correlation coefficient matrix for individual Whipple Creek subwatersheds' with significant overall flow type water quality medians versus portion of general land covers relationships – base and storm flow type correlations

Water Quality Parameter*	Flow Type	Forest			Pasture			Grass			Impervious		
		r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Dissolved Copper	Base	NA	NA	NA	NA	NA	NA	NA	NA	NA	.50	0.172	.25
	Storm	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.636	0.066	.40
	Overall	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33
Dissolved Zinc	Base	0.908	0.001	0.82	0.807	0.009	0.65	0.783	0.013	0.61	0.919	0.000	0.85
	Storm	0.698	0.037	0.49	0.811	0.008	0.66	0.881	0.002	0.78	0.60	0.088	0.36
	Overall	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

However, insights on the potential impacts of flow type on the regressions' modeled average response slope and range are possible from examining their respective confidence interval bands in the detailed regression graphs found in this study's appendix. Overall, potentially significant differences in base versus storm flow regression dissolved zinc values appear more often at the extremes of land cover percentages. This pattern is partially due to storm flow's apparent steeper slope compared to that of base flow. Storm flow's dissolved zinc values appear to become significantly larger over those of base flows when forest or pasture land cover drops below approximately 25% of the subwatershed area (no overlap between their respective storm flows' lower and base flows' upper red dashed confidence interval bands). Conversely, with increasing subwatershed portions of grass land cover over approximately 30%, storm flow dissolved zinc appears to become increasingly larger than that for base flow (increasing gap between their respective lower and upper red-dashed interval bands). Less difference between dissolved zinc's storm and base flow versus impervious land cover relationships is depicted by the slight overlap in their respective lower and upper confidence bands when impervious exceeds 20%. However, this overlap is minimal and probably impacted by dissolved zinc stormflow versus impervious land cover's moderately significant correlation. These preliminary analyses patterns suggest, at or close to the 95% confidence level, that as the portion of Whipple Creek subwatersheds' developed area exceeds 20 to 30 percent there is substantially more average dissolved zinc in storm flows compared to their respective base flows.

Additionally, the location of Clark County Fairgrounds mostly within the smallest monitored subwatershed of WPLT03 could be confounding dissolved metals relationships with land cover. This subwatershed is unique in that its only substantial impervious surface includes the large concentration of Clark County Fairground structures and their adjoining impervious surfaces in the northeast corner of the subwatershed. This group of structures likely represents the largest concentrated galvanized metal surface area (typically a large potential dissolved zinc source) within the entire Whipple Creek watershed. However, this WPLT03 subwatershed has a relatively low storm flow dissolved zinc median value compared to its linear regression model (but still within the regression's 95% confidence interval). Beneficial removal of dissolved zinc could be occurring in the several stormwater treatment facilities treating runoff from the fairgrounds. The low WPLT03 median may also be due to the infrequent seasonal usage of impervious surfaces for vehicle traffic compared to the more constant traffic patterns on impervious surfaces for other more developed subwatersheds. Additionally, the fairground's most intense use is during the month of August which is typically one of the driest months of the year but could conceivably have heavy rainfall events. Nevertheless, there were no such concurrent intense rain events during the annual fair during this monitoring period and any such potential outlier results would be mitigated by using water quality medians. Finally, comparing the respective storm and base flow dissolved zinc medians versus impervious land cover regression lines and their confidence bands after excluding WPLT03 in storm flow results in: increasing the stormflow regression slope by one half, increasing its r^2 to 55% (p-value of 0.035), and decreasing the threshold for significant difference between them to about 17% impervious land cover. This supports the unusual impact that this subwatershed has on the dissolved zinc and likely also the dissolved copper regressions.

Interestingly, while both dissolved copper base and storm flow medians versus impervious land cover regression slopes and values appear substantially less than those for dissolved zinc, there was no overlap in the confidence bands between dissolved copper's base and storm flow regressions. This implies that predicted storm flow dissolved copper values are significantly higher than those of base flow throughout the range of approximately 5% to 30% of impervious land cover.

Based on this limited monitoring data, these storm flow versus base flow dissolved metals concentration differences for various land covers reinforces the need to control stormwater dissolved metals sources especially in more urbanized subwatersheds. This finding has stormwater management implications for the Whipple Creek Plan area.

Statistical Assumption Evaluations

Statistical assumptions were briefly evaluated for the linear regressions of subwatershed median dissolved zinc versus most land covers and dissolved copper versus impervious land cover relationships (primarily by examination of diagnostic plots). The review of linear regression assumptions was limited to just these base, storm, and overall storm flow relationships because they appeared to have the best linear fit of all the parameters monitored (Figure 4). Additionally, the narrow screening purposes of this study and the relatively small subwatershed sample sizes of water quality medians, respectively, reduced the need for and ability to evaluate assumptions.

The five assumptions associated with linear regression (Helsel and Hirsch, 2000, pp. 224 – 225 and 231-238) and their interpretation for this study's limited statistical analyses are summarized below. First, as noted above and depicted by the lowess fitted lines in Figure 4 the linear model appears reasonable for all the significant dissolved metal relationships. Second, the data used to fit the regression model are generally representative of both monitored Whipple Creek subwatershed water quality and land cover. Third, as suggested by the lack of extreme changes in dissolved zinc over time (Figure 15) and displayed more clearly in this study's appendix "Residual Versus the Fitted Values" plots, the variance of the relationships' residuals appears fairly constant (homoscedastic). For each of the land covers evaluated, there appears to be one or two residuals that are slightly larger (usually for the difference between each fitted line and the median of WPLT04 storm flow and less often for WPLT03 base flow) than the remaining others. Fourth, as depicted in the appendix's "Residuals Versus the Order of the Data" plots there may be some correlation between residuals over space (residual are not totally independent) as suggested by consecutive positive or negative residuals clumping together. Given the order of subwatersheds plotted, the net potential effect of this assumption violation suggests that the regression lines somewhat under-predict storm flow dissolved zinc and copper values more often especially for the more developed WPLT04 subwatershed. Alternatively, the linear regression assumption that y-values are statistically independent of one another ((Kleinbaum et al., 1988, p. 45) is supported by the use of median water quality values. Fifth, the appendix's "Normal Probability Plots" and "Histograms of the Residuals" plots and their Anderson-Darling statistics (p-values less than significance level suggest non-normality, MiniTab Release 14 Statistical Software Help) suggest almost all of the residuals are normally distributed at a 0.05 significance level except for dissolved zinc's storm flow versus impervious land cover regression (p-value of 0.02). A lack of normality could slightly reduce the power (Helsel and Hirsch, 2000, p. 236) of this study's storm flow dissolved zinc median versus impervious land cover statistical tests of correlation, thus increasing the chances of falsely declaring the correlations were significant.

However, it is important to not read too much into plots, especially from a couple of odd points or residual variances that seem to both grow and shrink over the range of predicted values (Helsel and Hirsch, 2000, p. 232). For example in small sample sizes (n<50), the normal probability plot may display curvature (that increases as sample size decreases) in the tails even if residuals are normally distributed (MiniTab Help "Residual Plot Choices", 2003). Additionally, the likely correlation between residuals over space is not surprising given the nested hierarchy of the monitored subwatersheds where several upper subwatersheds are part of downstream main stem subwatersheds. Also, potential correlations between residuals over time have been minimized by using medians of water quality values collected over time. Therefore, likely violations of some of the linear regression assumptions are deemed acceptable trade-offs given the overall study's main purpose of limited exploratory screening of potential sources or unusual patterns for stormwater pollution.

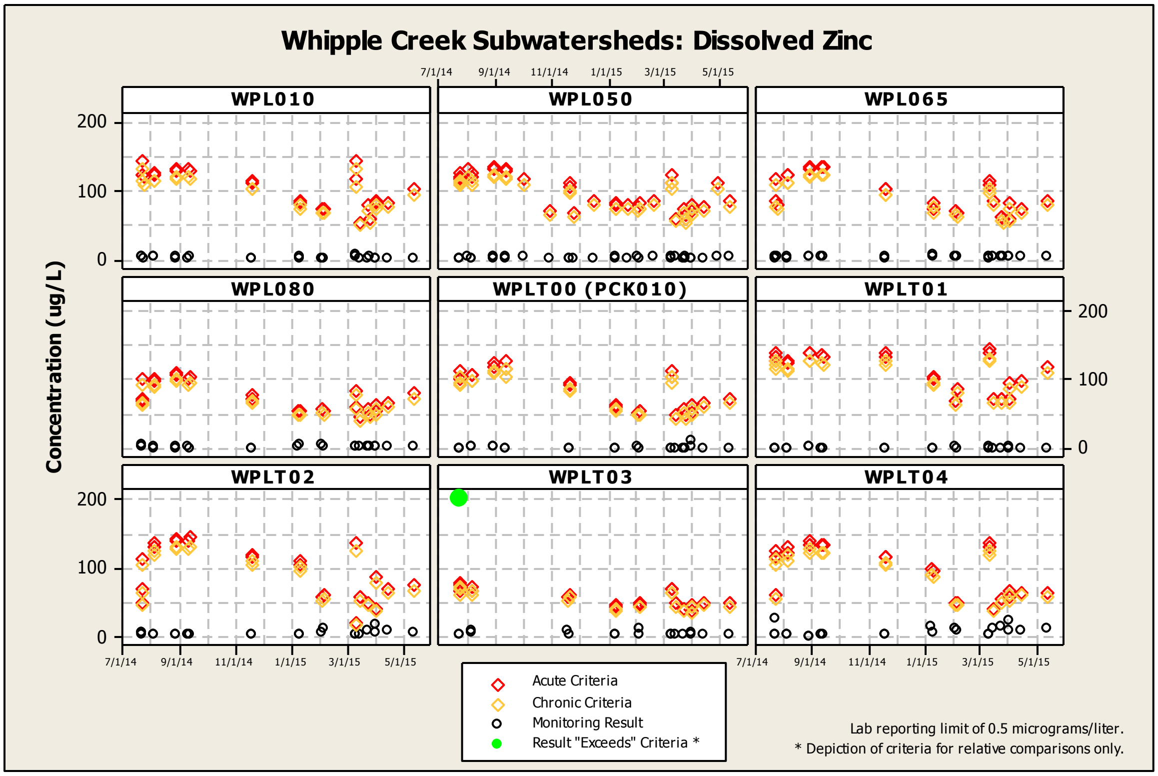

Figure 15 Plot of Whipple Creek subwatersheds' dissolved zinc values over time and applicable state criteria values

Conclusion

In support of Clark County's required stormwater planning for the Whipple Creek watershed, this report summarizes and interprets the relationships between the existing conditions of the watershed's stream water quality and general land covers. The goals of analyzing these relationships focused on screening them for practical insights and potential pollutant anomalies that could affect watershed management approaches as well as providing context for continuous water quality modeling. This report's emphasis on stream water quality versus land cover relationships precludes interpretation of state water quality standards, which is addressed in the Whipple Creek Watershed Plan's "Assessment of Existing Water Quality Conditions" section. The fundamental analyses tools in this report may serve as a template for supporting stormwater planning in other Clark County watersheds.

This Whipple Creek watershed study leveraged limited existing data to evaluate potential general sources of pollution based on broad land cover types that typically reflect relatively low to high stormwater pollutant risk. As watersheds become developed, their proportions of forest and pasture decline while impervious surfaces and residential grass areas increase. This study compared water quality median values from monitoring stations with their upstream relative portions of these general land cover types. An underlying assumption is that subwatershed streams' water quality reflects varying degrees of stormwater impacts typical of broad land cover types. Under this assumption, basic statistical relationships were developed and evaluated based on changes in water quality associated with the proportion of general land covers across nine Whipple Creek subwatersheds. Regression statistical analysis was used to screen the broad land cover types and their impacts as potential stormwater pollutant sources within the Whipple Creek watershed planning area. Specifically, using simple linear regression, the variation in six water quality parameters' medians (response variable) were related to the proportion of each subwatershed in five general land cover types (predictor variable) on a pair-wise basis sequentially for overall, base and storm flow monitored conditions.

This study's important practical findings include:

- No substantial anomalies from what would be typically expected were found in the type and direction of the monitored water quality versus land cover relationships that would otherwise suggest unusual sources of pollution.
- Most of the six monitored water quality parameters were found to be not significantly correlated with land cover under overall flow conditions. However, the uncorrelated parameters of water temperature and pH are often strongly influenced by localized site factors while turbidity and fecal coliform can be impacted by a range of land cover sources.
- Under overall flow conditions, only dissolved zinc had multiple statistically significant (at 95% significance levels) linear relationships with relative amounts of various land covers while dissolved copper had only a single less significant direct relationship with impervious land cover. Subwatershed dissolved zinc median concentrations had four significant linear relationships: inverse relationships (negative correlations) with forest and pasture as well as direct relationships (positive correlations) with impervious and grass land covers. Linear regression correlation (r^2) showed that at least 69% of the variance in dissolved zinc is explained by each of these land covers. Dissolved copper's lone significant linear relationship correlation with impervious land cover was weaker with a p-value of 0.105 and an r^2 indicating 33% of variance explained.
- The direction and slopes of the overall flow type dissolved zinc regression lines are very similar for each of the pairs of open space (forest and pasture) as well as development (grass and

impervious) relationships. The regression lines' mirror image patterns for open space versus development related land covers reflect their likely similar and complimentary impacts.

- Boxplots showed that storm flows from those subwatersheds with more development related land covers usually had significantly and substantially higher median dissolved zinc values than their respective base flows. This, in turn, impacted the slopes of their relationships' regression lines.
- Importantly, boxplots also showed there are no significant differences in the base flow dissolved zinc or dissolved copper median concentrations across all of the subwatersheds.
- Dissolved zinc appears to be more sensitive than dissolved copper to development's impact on stream water quality. While dissolved metals versus impervious land cover regressions' slopes were not tested statistically for differences, dissolved zinc's correlations with land covers were highly significant across both base and storm flows for seven of the eight relationships compared to dissolved copper storm flow versus impervious land cover's one moderate correlation.
- Overall, potentially significant differences in base versus storm flow regression modeled average dissolved metals values become clearer at thresholds of Whipple Creek subwatershed development percentages. These preliminary analyses suggest at or close to the 95% confidence level, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate.
- Given the predominant and consistent patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.

Dissolved zinc and copper have a range of possible sources associated with development's impervious surfaces with many related to vehicle transportation. Among other possible sources, they include: galvanized metal products, building exteriors, public infrastructure and especially vehicle tires, brakes, and bodies (Minton, 2002, pp. 14 - 18). The significant dissolved zinc versus multiple land covers and dissolved copper versus impervious land cover relationships found in this study's analysis of the Whipple Creek watershed are consistent with the amount of development and its typical potential sources of pollution.

Based on this study's limited monitoring data, the potential implications of the overall and especially the apparent storm flow versus base flow dissolved metals relationship differences as subwatersheds become more developed reinforces the need to control stormwater dissolved metals sources. The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in the more developed subwatersheds. These results are consistent with the idea that common development land covers such as impervious surfaces and development's typical associated human activities can be significant sources of some stormwater pollutants. As part of the Whipple Creek watershed planning project's existing conditions assessment, this initial and basic statistical analysis of local data is intended to provide context for and compliment more in-depth, sophisticated mechanistic water quality modelling using the continuous HSPF model. This study met its exploratory analyses goals for gaining insights on potential general pollution sources and checking for anomalies in Whipple Creek watershed pollutant versus land cover relationships.

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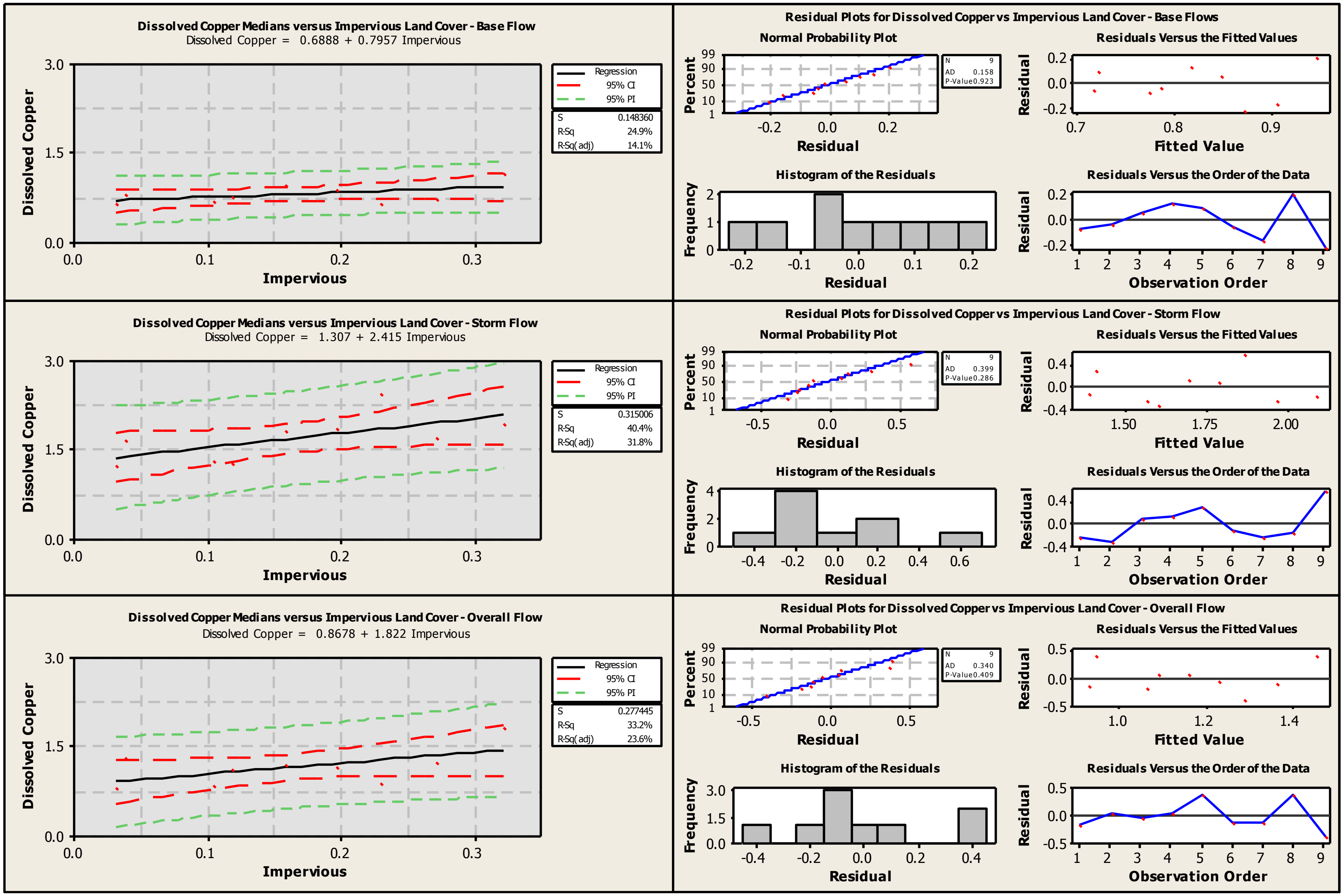
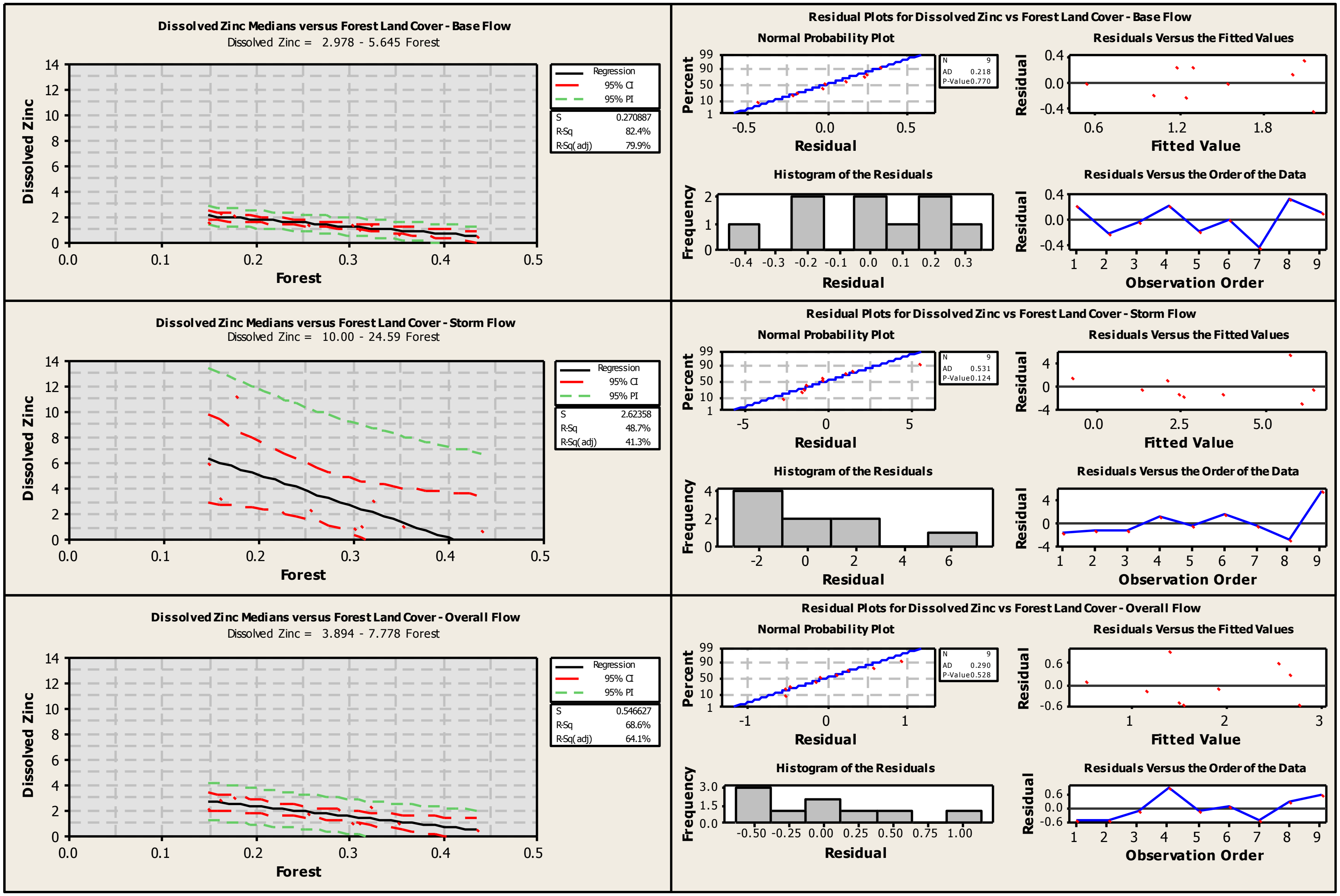
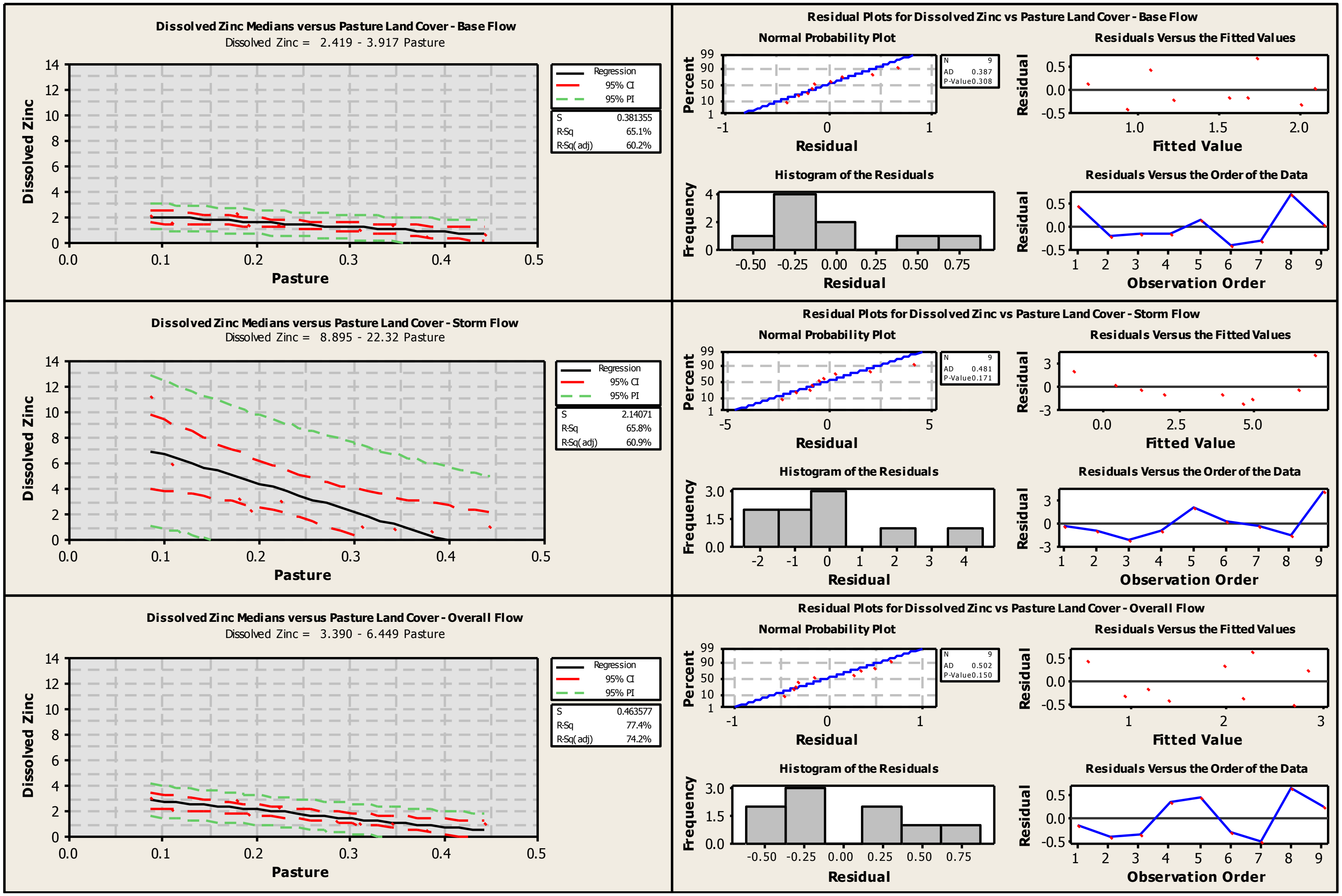
Appendix 1 Detailed Graphs Summarizing Flow Type Dissolved Metals versus Land Cover Regressions' Confidence / Prediction Intervals and Assumption Evaluations



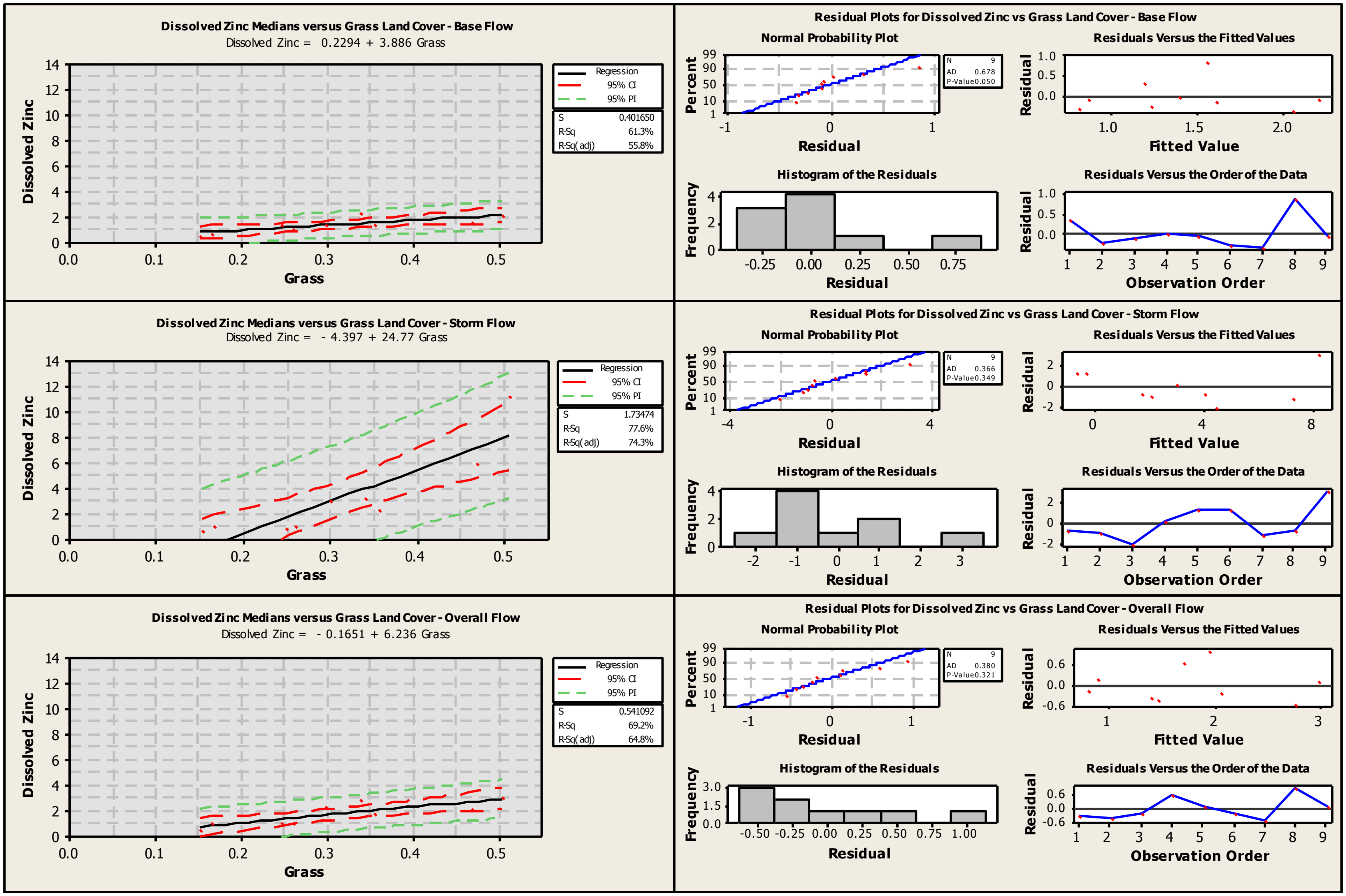
Flow Type Dissolved Copper versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



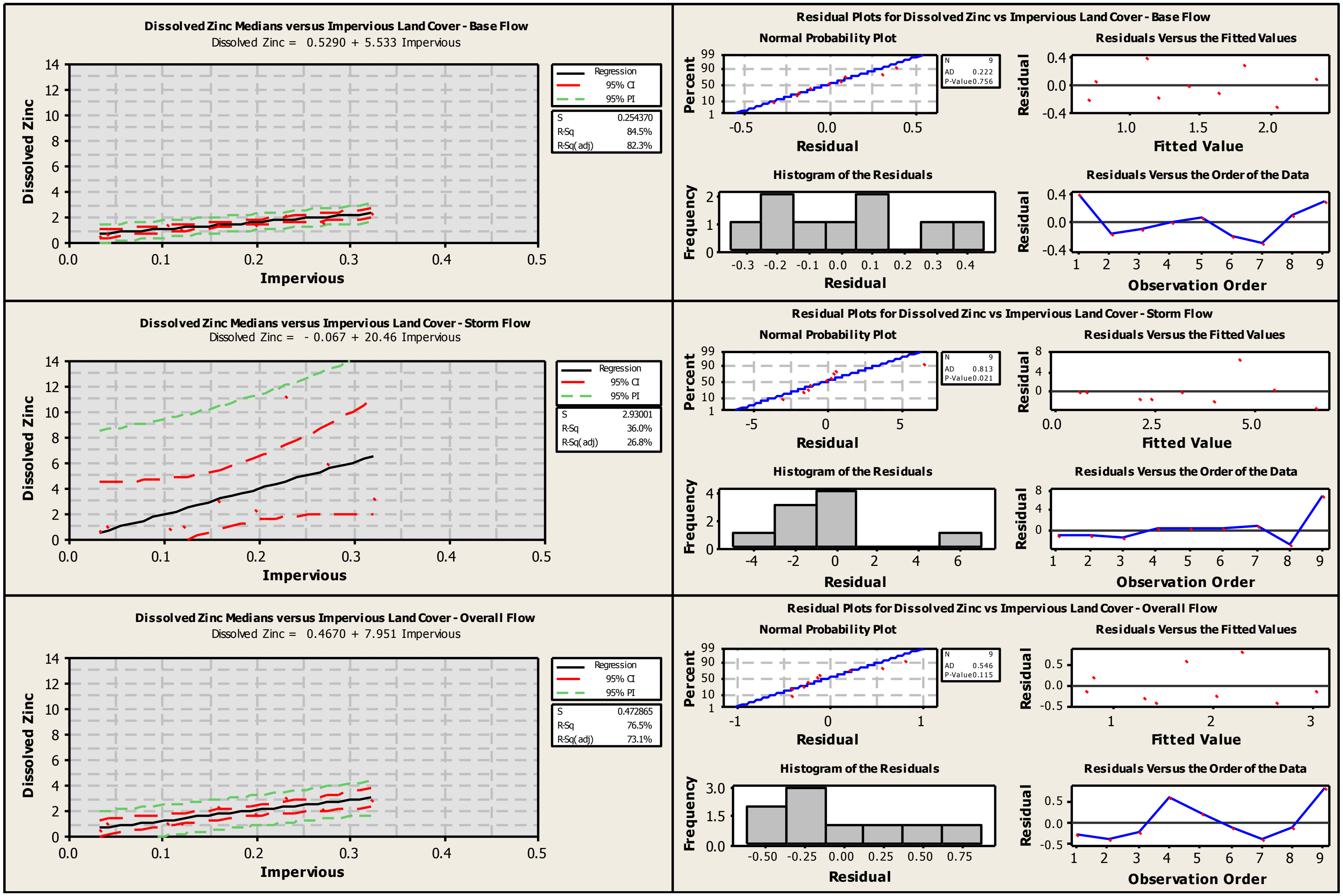
Flow Type Dissolved Zinc versus Forest Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Pasture Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Grass Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations

Appendix B

Whipple Creek Watershed-Scale Stormwater Plan Report

Assessment of Existing Water Quality Conditions

Prepared by

Bob Hutton, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

December 2016

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Summary

This addresses Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (hereafter referred to as "Permit" but specifically Permit Section S5.C.5.c.ii.1.a) watershed-scale stormwater planning requirement to assess existing water quality conditions as applied to the Whipple Creek watershed. Under Washington's latest state-wide water quality assessment from 2014, 1.4 miles of Whipple Creek's lower main stem have been identified in the state's 303(d) list or category 5 as polluted waters with impaired beneficial uses due to water temperatures, bacteria, and bioassessment results. This report and its appendices summarize Whipple Creek watershed water quality conditions and likely general pollutant sources based on county water quality monitoring from August 2001 through October 2015 and recent land cover mapping. Exploratory data analysis was systematically applied to enhance perspectives and gain insights on potential stormwater impacts to inform watershed planning.

This watershed planning report's assessment of existing water quality conditions is based on three Clark County sources of monitoring results that used subsets of the same nine monitoring locations (Figure 1). The first is a relatively long-term (starting as early as August 2001 and running through June 2014) monthly data set from a central Whipple Creek watershed main stem monitoring station. The second source utilized spans one year of monthly data (October 2011-September 2012) from one tributary and two main stem sites. The third set includes up to sixteen months (July 2014-Oct 2015) of watershed-wide base and storm flow stream monitoring results from all nine monitoring locations. All water quality monitoring was performed by trained county staff following standard operating procedures and project quality assurance project plans (QAPPs). The assessment relies on data derived from field trip meter readings, water quality samples' laboratory analyses (except continuous water temperature data from summertime deployed sensors / loggers for this important and uniquely monitored parameter that is addressed in detail in this report's appendices), and geographic information system (GIS) analyses.

The overall approach used for this Whipple Creek watershed planning water quality assessment starts with comparing monitoring results to state water quality standards, followed by equally important exploratory data analyses of the full range of water quality results and land cover relationships for subtle water quality patterns or anomalies suggestive of pollutant sources. For streams, such as those in the Whipple Creek watershed, not specifically listed in Washington's revised 2012 surface water quality standards (Washington Department of Ecology, 2012) the highest and most relevant state designated beneficial uses to be protected are: 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use of primary contact recreation such as swimming. While this assessment's dissolved metals data may not meet the standard's monitoring frequencies typically intended for industrial outfalls, the state standard's criteria are conservatively applied in an effort to leverage limited data to assess if metals pollution even appears as a possible stormwater issue in the Whipple Creek watershed.

This assessment concludes that the Whipple Creek watershed's existing water quality is substantially degraded. Existing water quality conditions for the Whipple Creek watershed are summarized in Table 1 based on applicable state water quality standards. The latest watershed-wide data indicate four of the seven evaluated standards' parameters were often exceeded throughout much of the watershed; including water temperature, fecal coliform, turbidity, and dissolved oxygen. Only the state standards' criteria for dissolved copper, dissolved zinc, and pH were mostly met throughout much of the monitored watershed.

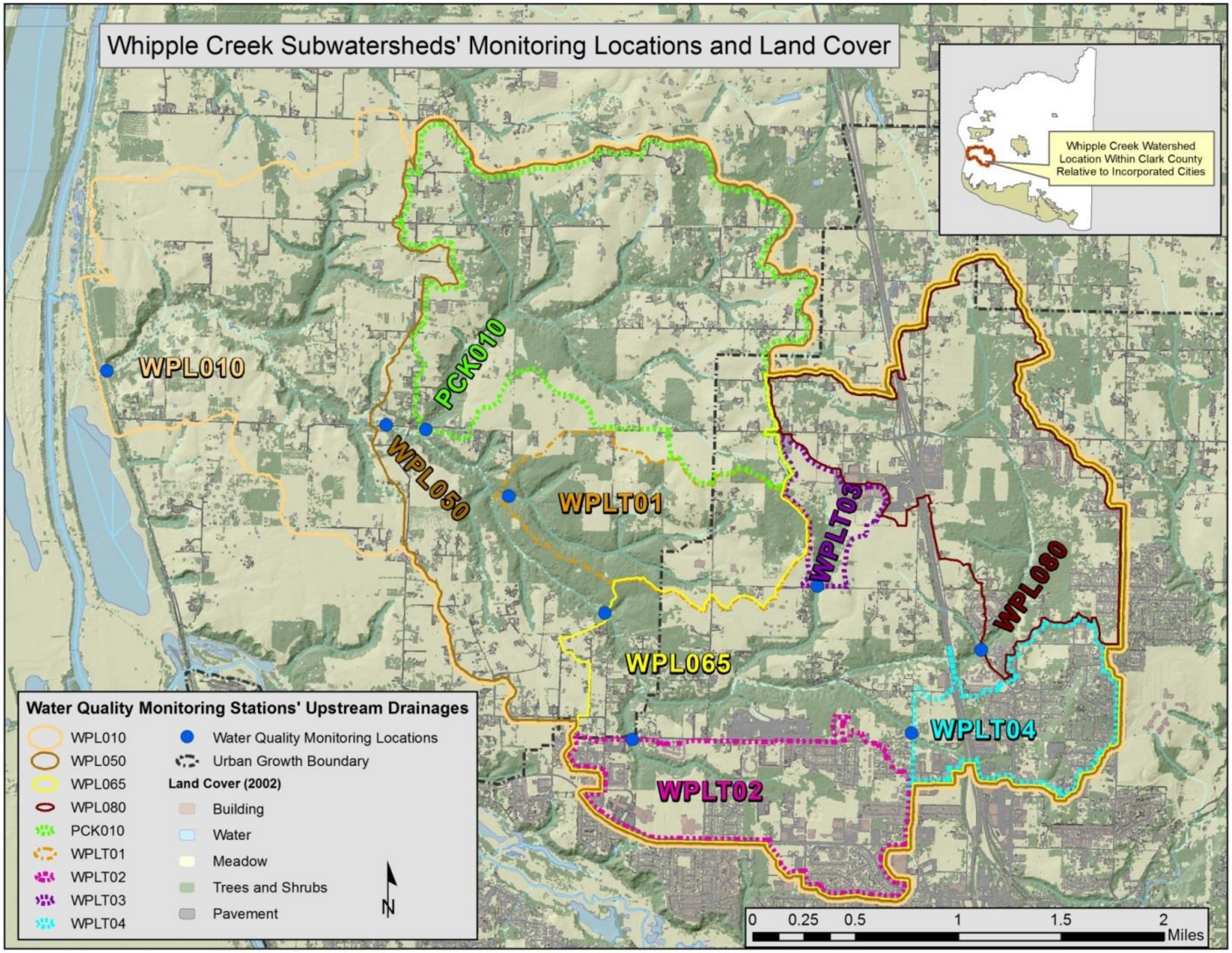

Figure 1 Whipple Creek watershed water quality monitoring locations and general land cover

Table 1 Summary of Whipple Creek watershed water quality per state water quality standards

Water Quality Parameter	State Designated Use Protection: Water Quality Standard Criteria & As Applicable Exceedance Frequency Limit	Met Water Quality Standard	Comments on 2014-2015 Watershed-wide Monitoring Results Exceedance of State Water Quality Standards Criteria
Temperature	Aquatic Life Use: 7-Day Average Daily Maximum (7-DADMax) of 17.5°C once every 10 years on average	No	Most lower main stem and some tributary subwatersheds commonly exceeded criteria especially during July & August, up to 87 and 77 times / year, respectively
Fecal Coliform	Primary Contact Recreation Use: < geom. mean of 100 cols./100 mL & < 10% of samples: 200 cols./100 mL Preferable to average by season of < 12 months	No	Except for WPL065 and WPL080 wet season, all of the other subwatersheds exceeded the state's geometric mean criterion during both seasons. All the stations also exceeded the 10% criterion during both the wet and dry seasons.
Dissolved Copper	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 & WPLT04 exceed chronic and acute criteria and for both stations' criteria in only 6% of their respective samples. PCK010 exceeds chronic in 11% and acute in 6% of samples
Dissolved Zinc	Aquatic Life Use: Criteria formula using water hardness Acute: 1 hr. avg. < once every 3 yrs. Chronic: 4 day avg.<once every 3 yrs. Apply both acute & chronic on average over 3 years	Mostly Yes	Only WPLT03 exceeded either criterion but did so for both in only 6% of its samples
pH	Aquatic Life Use: 6.5 – 8.5 pH units	Mostly Yes	Across all monitoring stations, only a very few were slightly below (lowest value of 5.86) lower 6.5 criteria boundary. WPL050 – 2.8%, WPL080- 4.7%, and WPLT02 3.2% of all their measured values.
Turbidity	Aquatic Life Use: 5 NTU over background or 10% increase when background is >50 NTU	No	High turbidity is a watershed-wide issue: 55-95% of main stem station values exceeded criterion, 55-98% of tributary station values exceeded criterion.
Dissolved Oxygen	Aquatic Life Use: 1-day minimum of 8.0 mg/L once every 10 years on average	No	Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching minimum criterion.

Additionally, most parameters' discrete sample or field measurement data are assessed through statistical exploratory data analysis graphs including scatterplots of values over time and, as applicable, in boxplots and probability plots of results grouped by location, wet or dry season, and base or storm flow. The different nature of stream temperature's in situ logged data, consisting of one-hour interval large data sets, allows a more detailed assessment using different graphical tools that include bar charts, time series plots, empirical cumulative distribution function plots, and scatterplots (included in this report's appendices). Monitoring was performed at locations chosen using professional judgement to target likely representative subwatersheds at their most downstream sites and reflect results from a wide range of flows. Patterns and especially anomalies in the graphed results were evaluated in light of subwatersheds' predominant land covers to gain insights on likely pollution sources and delivery mechanisms.

From a watershed planning perspective, the following are the most important exploratory analyses observations:

Water Temperature

- Given consistent recent stream temperature patterns between many watershed- wide stations and the long running mid-watershed WPL050 station, frequent high summer stream temperatures have likely been an ongoing and widespread issue where riparian shading is limited. This is especially true for the exposed lower half of the main stem of Whipple Creek, on Packard Creek, and the more developed WPLT04 tributary.
- Much of the watershed's tributary and headwater (i.e. WPL080) summer flows likely comes directly from relatively cool shaded groundwater whereas lower main stem waters are heated by direct sunlight for longer periods. Benefits from cooler streams also need to consider their relative flow contributions in reducing downstream heat loading.
- Other positive feedback heating factors beyond warm air temperatures such as decreased streamflow and upstream cumulative heat loading contribute to disproportionate upswings in stream heating during the very hottest summer periods for the lower main stem, Packard Creek, and WPLT04.

Fecal Coliform

- Similar to the overall patterns seen for stream temperatures, high fecal coliform levels are likely an ongoing watershed-wide issue since most locations exceeded both of the state standard's dual fecal coliform criteria.
- Fecal coliform overall patterns in location medians showed lower calculated median fecal coliform levels for the main stem group than for the tributary groups (but most not significantly different) except for WPLT04 and a tendency for increasing medians from upstream to downstream within each of these groups.
- Among the tributaries, the highly developed WPLT04 subwatershed has the lowest calculated median and has the least variable fecal coliform values whereas the less developed Packard Creek's fecal coliform median is almost significantly higher and its fecal coliform is much more variable. These contrasting patterns suggest non-stormwater sources of fecal coliform for these subwatersheds.
- Resident beaver and less dilution likely play a role in relatively more significantly higher main stem dry season fecal coliform medians than corresponding medians for tributaries.
- The consistent pattern of higher calculated storm flow than base flow fecal coliform medians (though not often statistically significant) across all monitoring stations strongly suggests surface runoff factors play an important role in bacterial levels.
- Consistent patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source

bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows.

- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems.
- The relative impact on fecal coliform concentrations from flow type is much greater than from season based on patterns found in nested location-season-flow type boxplots.

Dissolved Copper

- The relatively few dissolved copper state standards' criteria exceedances occurred during storm flows in just three mixed to more developed tributary subwatersheds.
- There tends to be slight increases in calculated dissolved copper medians from down to upstream within groups of main stem and tributary stations.
- Significantly higher storm flow dissolved copper medians for the most developed WPLT02 and WPLTO4 subwatershed stations supports idea of storm first flush impact from developed areas.

Dissolved Zinc

- The single WPLT03 sample that exceeded both chronic and acute criteria suggests isolated high dissolved zinc issues.
- However, the tendency of increasing calculated dissolved zinc medians from downstream to upstream and associated Water Quality and Land Cover Relationships findings of significant direct relationships between development and dissolved zinc suggest consistent widespread development related zinc pollutant impacts.
- Significantly higher storm flow dissolved zinc medians for the most developed WPLT02 & WPLTO4 subwatershed stations supports the idea of first flush impacts from developed areas.
- Relatively low storm flow dissolved zinc levels in the lower main stem suggest dilution, travel time factors, or instream pollutant reduction mechanisms taking place.

pH

- Excessively low or high pH is not a substantial issue anywhere in the Whipple Creek watershed.

Turbidity

- High turbidity is a widespread issue throughout the Whipple Creek watershed with more than three-quarters of all monitored values substantially elevated above background levels.
- Turbidity is almost always elevated with storm flows, often more than two orders greater than base flow for middle to high range values, likely due to soil erosion during surface runoff and instream channel erosion.

Dissolved Oxygen

- Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching state standard's minimum criterion.

More detailed descriptions of patterns found in the monitored water quality parameter results and observations on likely pollutant sources from the exploratory data analyses graphs are summarized in

Table 2. This report's Appendix 1 contains the full more detailed analyses of Whipple Creek watershed stream temperatures.

Whipple Creek Watershed Water Quality and Land Cover Relationship Evaluation Conclusions

Exploratory statistical analyses was performed on the relationships between Whipple Creek subwatersheds' water quality and general land covers to support the stormwater planning assessment of existing local water quality conditions, screen for broad potential pollution sources, and provide insights for water quality modeling. For nonpoint source pollution analysis and watershed management, linear regression can be used to generally explore the extent to which water quality (dependent variable) is influenced by hydrological or land use factors (independent variables). This watershed study's basic statistical analyses (see Appendix 2) of relationships are between nine subwatershed's median water quality parameter values and their percentages of land covers with additional evaluations focused on specific flow types for relationships initially found to be significant under all flow types. The six water quality parameters evaluated included temperature, turbidity, pH, dissolved copper, dissolved zinc, and fecal coliform bacteria. The associated five land covers evaluated included forest, pasture, grass, impervious surfaces, and water. The water quality data analyzed for the relationship evaluations spanned most of water year 2002 through 2015 for one main stem monitoring location, water year 2012 for two main stem and one tributary locations, and from July 2014 through May 2015 for nine monitoring locations spread watershed-wide. The end point of May 2015 for the watershed-wide data period is sooner than that used for the water quality assessment because that was the latest data available when this water quality versus land cover analyses occurred. The following summarizes the more relevant findings from the relationship analyses that are directly applicable to watershed stormwater planning:

- No substantial anomalies from what would be typically expected were found in the type and direction of the monitored water quality versus forest, pasture, grass, or impervious land cover relationships that would otherwise suggest unusual sources of pollution.
- Of the six water quality parameters evaluated under overall (base, storm, and unclassified) flow conditions, only dissolved zinc had multiple statistically significant linear relationships with relative amounts of four land covers while dissolved copper had only a single less significant direct relationship with impervious land cover. Subwatershed dissolved zinc median concentrations had four significant linear relationships: inverse relationships (negative correlations) with forest and pasture as well as direct relationships (positive correlations) with impervious and grassland covers.
- Under overall flow conditions, linear regression correlation (r^2) showed that at least 69% of the variance in dissolved zinc is explained by each of the four land covers. Dissolved copper's lone significant linear relationship correlation with impervious land cover was weaker with a p-value of 0.105 and an r^2 indicating 33% of variance explained.

- Boxplots showed that storm flows from those subwatersheds with more development related land covers usually had significantly and substantially higher median dissolved zinc values than their respective base flows.
- Dissolved zinc appears to be more sensitive than dissolved copper to development's impact on stream water quality. While dissolved metals versus impervious land cover regressions' slopes were not tested statistically for differences, dissolved zinc's correlations with land covers were highly significant across both base and storm flows for seven of the eight relationships compared to dissolved copper storm flow versus impervious land cover's one moderate correlation.
- Preliminary linear regression analyses suggest at or close to the 95% confidence level, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate.
- Given the predominant and consistent patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays for this pollutant in the more developed subwatersheds.

Table 2 Summary of Whipple Creek watershed water quality per exploratory data analyses

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
Water Temperatur e	• WPL050 exceeded criteria 13-70 times annually from 2002-2013 • Watershed-wide monitoring during the summers of 2014 & 2015 showed many exceedances during both summers (sites / frequency): WPL010 / 42 & 61, WPL050 / 63 & 85, WPL065 / 64 & 87, Packard / 61 & 75, and WPLT04 / 77 (just 2015) • WPL080's water temperatures tended to decline slightly during the warmest months of 2014 & 2015	• NA	• Cumulative distribution function (CDF) plots of 7-day average daily (7-DAD) maximum stream temperatures during the summers of 2014 and 2015 show only a small percentage of some of the watershed tributaries and headwater reaches exceeded state standards • Summer 2014 and 2015 CDFs show from 40 to 60 percent of lower mains stem sites' 7-DAD maximum stream temperatures exceeded state standards. • During 2015 periods that include the hottest 10% of 7-DAD maximum stream temperatures, the intensity of their stream water heating increases compared to the rest of the temperature range • Over both the 2014 and 2015 summers, scatterplots showed relationships where almost all of the monitored streams 7-DAD maximum temperatures increased at fairly constant rates of about 1 degree Celsius water temperature for every 2.5 to 3 degree rise in 7-DAD maximum air temperatures. • During the summer of 2015, WPLT04 exhibited a steeper slope in its scatterplot of 7-DAD maximum stream versus air temperature relationship above 30 degrees Celsius suggesting this stream site may be the most susceptible to direct heating with air temperature.	• *The lower main stem WPL050 has commonly exceeded applicable water temperature criteria 13-70 times per year from 2002-2013, with most occurring during July and August.* • *Watershed-wide monitoring during the summers of 2014 & 2015 showed many exceedances each summer (especially during the record warm summer of 2015) for the three lower main stem sites (42 – 87 times per summer), Packard Creek (61 & 71,) and WPLT04 (77 during summer 2015).* • *The above sites with many exceedances tended to be for stream reaches having little shading from riparian forests based on digital land cover maps.* • *WPL080 appears to have an unusually high proportion cool groundwater flow since its temperatures tended to decline during the warmest summer months of both 2014 & 2015.* • *Much of the watershed's tributary and headwater summer flows likely comes directly from relatively cool shaded groundwater whereas lower main stem waters are heated by direct sunlight for longer periods and impacted by warm flows from upstream.* • Lower main stem, Packard Creek and especially WPLT04 tributaries appear to be susceptible to a greater rate of stream heating during very hottest summer days and nights (possibly due to less stream cooling at night) compared to other sites. • The relatively stable relationships for monitored streams versus air temperatures suggests that these streams react similarly over a range of energy inputs but *the duration and magnitude of heat impact how warm they get on the hottest days of summer.* • The contrasting patterns for some the of warmest stream temperatures in CDF plots versus stable water / air temperature relationships in scatter plots implies *other positive feedback heating factors such as decreased streamflow and upstream cumulative heat loading contribute to upswings in stream heating during the very hottest summer*

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
				periods for the lower main stem, Packard Creek, and WPLT04. • *Potential downstream benefits of some cool stream reaches should also take into account their respective inflows' thermal loading for watershed planning implementation*, such as riparian plantings.
Fecal Coliform	• As expected, results varied widely, by up to five orders of magnitude. • On a wet and dry seasonal basis, across almost all monitoring locations both criteria were usually exceeded, often by substantial amounts (4.5 to 97 times criteria). • Of the 36 applicable evaluations (possible combinations of wet or dry season's dual criteria for 9 stations), only two stations exceeded at most one of the unique criteria combinations while seven locations exceeded both criteria for both seasons	• Monitoring location median fecal coliform counts range from 280 (WPLT080) to 830 (WPLT02). • Except for the uppermost tributary, all calculated main stem medians were lower than the tributary medians. • While not statistically significant, the overall spatial patterns show increasing medians from upstream to downstream within the main stem and tributary groups. • Boxplots for the more urban WPLT04 and rural Packard Creek tributaries suggest non-stormwater sources of fecal coliform • Calculated medians for dry season always higher than wet season with 5 of 9 significant • Calculated medians for storm flow always higher than for base flows with only 2 of 9 significantly higher • Nesting subgrouping of boxplots by season and flow type allows an evaluation of their synergistic impact on fecal coliform • The calculated medians for dry season storm flows were always the highest whereas those of the wet season base flow were the lowest (8 of 9 differences were significant) • The significant separation between wet season bae and storm flow medians suggests a reduced continuing bacteria sources between storms	• There is less seasonal effect on fecal coliform levels at the high wet and dry season concentrations than for lower concentrations especially for the lower and middle main stem stations • Among the tributaries, WPLT02 and WPLT04 have slightly more variability across both seasons and more commingling of seasonal points at higher concentrations which may reflect similar stormwater impacts for these two more developed subwatersheds	• *High fecal coliform levels are a watershed-wide issue since most locations exceeded both of the state standard's dual fecal coliform criteria.* • While differences in location medians were mostly not statistically significant, *the overall pattern in location medians showed lower calculated median fecal coliform levels on the main stem than on the tributaries except for WPLT04*. • Compared to other locations, the boxplot *analyses for the more urban WPLT04 and rural Packard Creek tributaries suggest non-stormwater sources of fecal coliform for these subwatersheds.* • *There are fairly consistent seasonality and flow influences on fecal coliform.* • More common significantly *higher main stem dry season medians than for tributaries may result from resident beaver and less dilution.* • *The consistent pattern of higher calculated storm flow than base flow fecal coliform medians (though not often statistically significant) across all monitoring stations strongly suggests surface runoff factors play an important role in bacterial levels.* • *Consistent patterns of high dry season storm flow medians versus very low wet season base flow medians likely are driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows.* • Unusually high wet season base flow fecal coliform variability at WPLT02 and *relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems*.

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
Dissolved Copper	• WPLT03 & WPLT04 both exceed chronic and acute criteria in 6% of samples. • PCK010 exceeds chronic in 11% and acute in 6% of samples	• Tends to be slight increases in calc. medians from down to upstream main stem and tributary stations. • Almost none of the stations have clearly significant differences in their median copper levels. • No seasonality. • Within stations' base flow calculated median copper was always lower than that for storm flow though often not statistically different.	• Consistently across watershed, base flow dissolved copper is usually less than that for storm flow but for some sites lower base and storm flow dissolved copper values do overlap • Generally is less difference between base and storm flow concentrations throughout their ranges for the main stem stations than for the tributary stations • Tributary stations storm flow's divergence from base flows at higher concentrations suggests tributaries are more susceptible to the effects of stormwater runoff	• *All dissolved copper state standards' criteria exceedances occurred during storm flows in just three mixed to more developed tributary subwatersheds.* • *There tends to be slight increases in calculated dissolved copper medians from down to upstream within groups of main stem and tributary stations.* • *Significantly higher storm flow dissolved copper medians for the most developed WPLT02 and WPLTO4 subwatershed stations supports storm first flush impact from developed areas.*
Dissolved Zinc	• Only WPLT03 exceeded either chronic or acute criteria and did so in only one sample or 6% of samples for both criteria	• Tends to be slight increases in calc. medians from down to upstream main stem and tributary stations. • Two lowest downstream stations main stem and tributary medians are significantly less than their corresponding most upstream main stem and three most upstream tributary stations. • No seasonality. • Within stations' base flow calc. median zinc was usually lower (except WPL010, WPL050, & WPLT01) than that for storm flow though often not statistically different.	• The lower main stem stations' unusually low storm flow dissolved zinc levels relative to base flow suggest impacts from pollutant travel time, downstream dilution, or instream pollutant reduction mechanisms • Generally is less difference between base and storm flow concentrations throughout their ranges for the main stem stations than for the tributary stations • Tributary stations storm flow's divergence from base flows at higher concentrations suggests tributaries are more susceptible to the effects of stormwater runoff	• *The single WPLT03 sample that exceeded both chronic and acute criteria suggests isolated occurrences of high dissolved zinc.* • *However, the tendency of increasing calculated dissolved zinc medians from downstream to upstream and associated Water Quality and Land Cover Relationships Report's findings of significant direct relationships between development and dissolved zinc suggest consistent widespread development related zinc pollutant impacts.* • *Significantly higher storm flow dissolved zinc medians for the most developed WPLT02 & WPLTO4 subwatershed stations supports the idea of first flush impacts from developed areas.* • *Relatively low storm flow dissolved zinc levels in the lower main stem suggest dilution, travel time factors, or instream pollutant reduction mechanisms taking place.*
pH	• Across all monitoring stations, only a very few (9 or 2% of all measurements) were slightly below (lowest value of 5.86) lower 6.5 criteria boundary. • WPL050 – 2.8%, WPL080- 4.7%, and WPLT02 3.2% of all their measured values were below 6.5 lower criterion.	• Only WPL010's and WPLT04's medians are significantly less than any of the other respective main stem or tributary medians. • Very little seasonality or flow type influences	• NA	• *Excessively low or high pH is not a substantial issue anywhere in the Whipple Creek watershed.*
Turbidity	• High turbidity is a widespread	• No significant difference in	• Strong flow type influences on turbidity	• *High turbidity is a widespread issue throughout the*

Water Quality Parameter	Unusual Patterns Over Time and Exceedances of State Standards Criteria	Most Parameters Boxplots	Temperature Scatter / CDF Plots and Other Parameters Probability Plots	Overall Observations (*most important italicized*)
	issue throughout the Whipple Creek watershed • 76% of watershed wide turbidity values exceeded criterion of 5 NTU above an estimated background level of 2 NTU • 55-95% of main stem station values exceeded criterion • 55-98% of tributary station values exceeded criterion	medians across stations. • No seasonality. • Storm flow median turbidity significantly higher than base flow median turbidity across all nine stations. • WPLT03 base flow turbidity most variable. • Packard Creek storm flow median turbidity highest calculated value and clearly significantly higher than WPL065 & WPL080 storm flow median turbidity	are consistently shown across watershed. • Storm flow low turbidity values overlap with base flow low turbidity values but separation increases dramatically with higher values	*Whipple Creek watershed with more than three-quarters of all monitored values substantially elevated above background levels.* • *Turbidity is almost always elevated with storm flows, often more than two orders greater than base flow for middle to high range values, likely due to soil erosion during surface runoff and instream channel erosion.* • Packard Creek storm flow turbidity tends to be highest.
Dissolved Oxygen	• Likely low dissolved oxygen levels frequently drop below the 8 mg/L minimum criterion given the pattern of mid-day monitored values across the watershed.	• NA	• NA	• *Low dissolved oxygen values likely occur over much of the watershed based on the high frequency of mid-day measurements approaching state standard's minimum criterion.*

Recommendations

The following are overall recommendations to protect or improve stream water quality during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures (i.e., WPL080) or excessive heating (i.e., WPLT04 and PCK010) as suggested by watershed wide baseline monitoring.
- After confirming the stream length extent of beneficial cooling or excessive heating, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loadings.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.
- Fecal coliforms generally greater sensitivity to flow type than seasonality suggests surface runoff factors play an important role in bacteria levels so both stormwater and rural/agricultural fecal coliform Best Management Practices (BMPs) should be pursued.
- Consistent fecal coliform patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows. These patterns are especially pronounced for Packard Creek, WPLT01, and WPLT03 so pursuing both stormwater and rural/agricultural fecal coliform BMPS should be a priority for them.
- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems so these potential sources would need further investigation.
- While the relatively few isolated state standards exceedances during storm flows for dissolved zinc and especially dissolved copper may suggest these metals are currently not substantial problems, their tendencies of increasing concentrations for storm flows over base flows (though usually not significant) and from downstream to more developed upstream subwatersheds suggest the need to address stormwater impacts.
- The Water Quality versus Land Cover Relationships findings of significant direct relationships between development and dissolved metals medians (dissolved zinc appears more sensitive than dissolved copper to development impacts) for the most developed subwatersheds supports likely stormwater impacts and the need to continue addressing especially zinc with stormwater BMPs.

- Given the predominant and consistent relationship patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations versus land cover strongly suggest the important role stormwater plays and the need to address this pollutant in the more developed subwatersheds.
- Preliminary linear regression analyses suggest with 95% confidence, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate. These local thresholds could serve to help inform and prioritize stormwater management efforts.
- Currently pH is not an issue that needs to be addressed in the Whipple Creek watershed.
- Wide spread high turbidity issues should be addressed by reducing soil and channel erosion.
- Apparent wide spread low dissolved oxygen issues can be addressed using the same management tools used for temperature.

Introduction

As required in the Permit's Section S5.C.5.c (Ecology, 2012), existing water quality conditions within the Whipple Creek watershed planning study area were assessed using available and sufficient stream water quality data. An additional important application of the assessment monitoring results is to help calibrate the water quality components of a continuous runoff model used to evaluate stormwater management strategies to support existing and designated stream beneficial uses. The Whipple Creek watershed plan water quality assessment includes this report and more detailed analyses summaries in its appendices "Whipple Creek Watershed Stream Temperatures" and "Water Quality and Land Cover Relationships".

Under sections 305 (b) and 303(d) of the federal Clean Water Act, Washington State is required to perform regular water quality assessments and list the status of waterbodies in the state (Washington Department of Ecology 303d web page). The state's 303 (d) list includes those waters that are in the polluted water category for which beneficial uses are impaired. Under this category, polluted waters require a Total Maximum Daily Load (TMDL) or other water quality improvement project. This category means Ecology has data showing that water quality standards have been violated for one or more pollutants, and there is no TMDL or pollution control plan. Based on a query using the Washington State Department of Ecology's 303d web page, approximately 1.4 stream miles of the main stem of Whipple Creek (Figure 2) downstream from Clark County's WPL050 site are identified within the latest 303(d) list from 2014 as falling under category 5 for bacteria, bioassessment, and water temperature. The state's listings are based on Clark County monitoring at WPL050 for bacteria from 2002 through 2010, for temperature from 2002 and 2006 through 2010, and for the bioassessment from 2001 through 2009.

This watershed planning assessment utilized more comprehensive and current water quality data sources. Requiring sources of known reliability, accuracy, and timeliness limited applicable monitoring results to three Clark County projects. The projects and their monitoring frequencies are: Long-term Index Site Program (LISP) – monthly for water quality starting in 2001 and for continuous temperature starting in 2002, Stormwater Needs Assessment Project (SNAP) – monthly during water year 2012 from October 2011 through September 2012, and the Whipple Creek Watershed Plan (WSPLAN) – monitoring targeted storm or base flows with up to three monitoring runs within a day from July 2014 through October 2015.

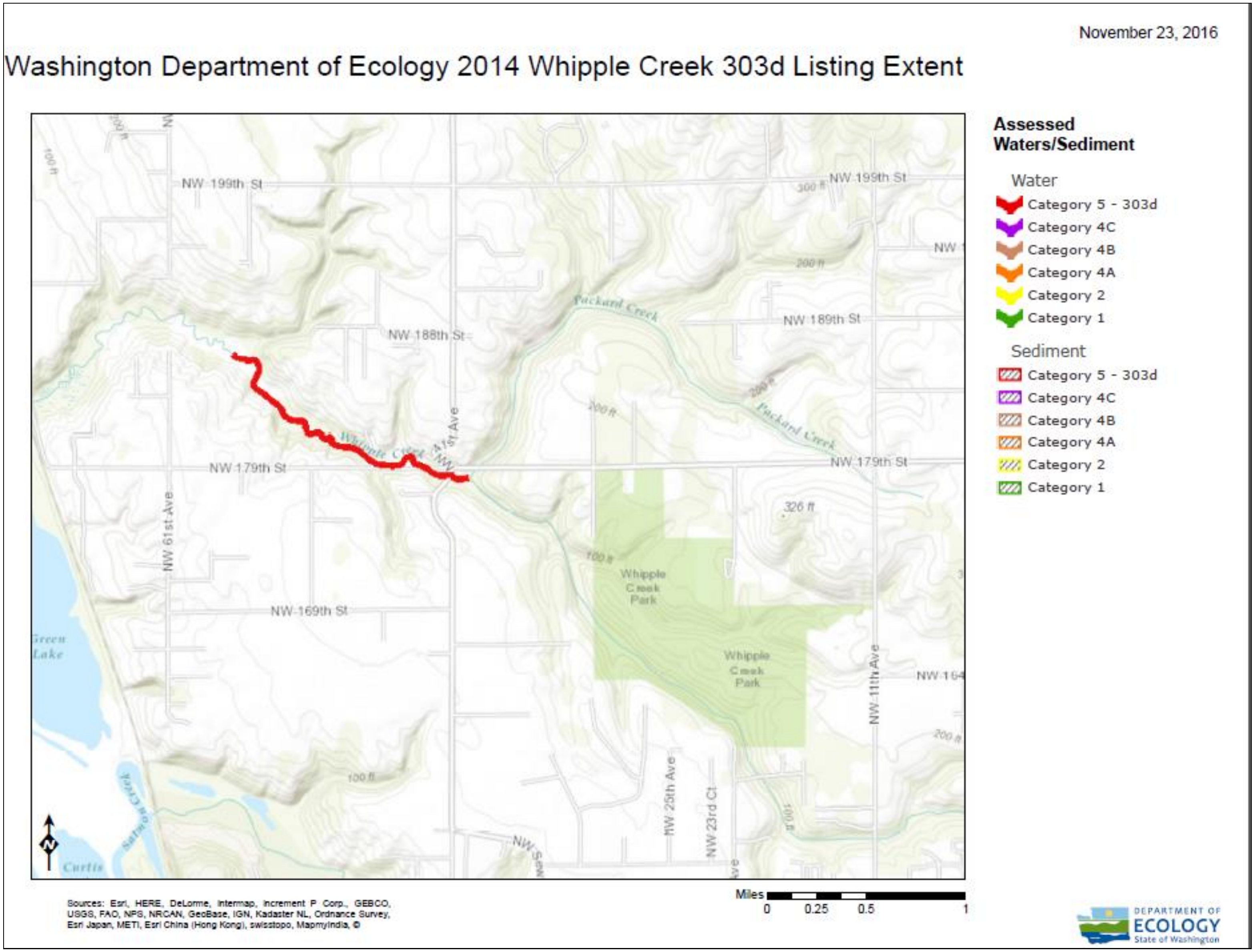

Figure 2 Washington State Department of Ecology web page map of 303d listed stream reaches within the Whipple Creek watershed

Methods

Monitoring Methods

The monitoring utilized specific quality assurance project plans (QAPPs), standard operating procedures (SOPs), and Washington State accredited laboratories for analyses of water samples. Monitoring locations were selected using best professional judgement (non-random) for targeting the farthest downstream location within selected areas of the Whipple Creek watershed to capture representative measurements and samples of upstream subwatershed water quality. Monitoring station names are based on the stream name and percent upstream from the stream's mouth (except plots' Packard Creek's WPLT00PCK010).

This report's assessment of existing water quality conditions used three Clark County project sources of monitoring results that utilized subsets of the same nine monitoring locations (Figure 3). The first is a relatively long-term (starting as early as August 2001 and running through June 2014) monthly data set from the central Whipple Creek watershed WPL050 main stem monitoring station. The second source utilized spans one year of monthly data (October 2011-September 2012) for the two main stem stations of WPL010 and WPL080 as well as the one Packard Creek (PCK010) tributary site. The third set includes up to sixteen months (July 2014-Oct 2015) of watershed-wide base and storm flow stream monitoring results from all nine monitoring locations including four main stem (WPL010, WPL050, WPL065, and WPL080) and five tributary (PCK010, WPLT01, WPLT02, WPLT03, and WPLT04) sites.

Figure 3 Whipple Creek watershed main stem and tributary water quality monitoring locations

All data is from county project monitoring performed by qualified and trained county staff using SOPs with prepared field and sampling equipment. Procedures were followed as described in applicable project quality assurance project plans (Clark County NPDES Long-term Index Site Project QAPP, 2004; Benthic Macroinvertebrate and Water Temperature Monitoring for Watershed Characterization in Clark County QAPP, 2004; Clark County Stormwater Needs Assessment Program Characterization Projects QAPP, 2011; and Clark County NPDES Whipple Creek Water Quality and Biological Assessment Project QAPP, 2014). Procedures included: calibration or pre- / post- checking of hand-held field meters, following SOPs for sampling and meters, utilizing lab prepared sample bottles for grab samples, transport of samples in ice filled insulated chests, timely sample delivery to a state accredited analytical laboratory, appropriate labelling and documentation for field trips and sample chain-of-custodies, etc.

Table 3 summarizes the monitoring methods used to collect this assessment's existing water quality data. At each monitoring location standard operating procedures were followed to minimize potential negative impacts on monitoring results. Monthly field meter measurements or samples were taken in approximately the same stream locations and sequence of locations during field trips. Handheld field meters' cable-end probes were placed in or grab samples were collected from the well-mixed center portions of the streams. WPL050's continuous temperature sensor / logger was also deployed to the same shaded stream reach annually for a period that included at least the warmest portion of each summer.

Data Evaluation Methods

This assessment first utilizes state water quality standards followed by statistical exploratory data analyses to evaluate existing stream water quality conditions in the Whipple Creek watershed. Table 4 presents the most applicable State water quality standards' designated uses and criteria (Ecology, 2011, pp. 55-58). Since Whipple Creek is not specifically listed otherwise in Washington State Water Quality Standard's Table 602, defaults apply for protecting an aquatic life designated use of salmonid spawning, rearing, and migration and human primary contact recreation. In addition to salmonid rearing and migration use, the most stringent key characteristic for spawning/rearing use is salmon or trout spawning and emergence that only occur outside of the summer season. Primary contact recreation use is intended to protect swimmers from waterborne disease. In order to consistently interpret results from a watershed-wide perspective, comparisons to state standard criteria mostly focused on the July 2014 through October 2015 period during which monitoring occurred at nine stations across the Whipple Creek watershed.

In addition to comparisons with state water quality standards, this assessment utilizes statistical exploratory data analyses through a range of graphs to help characterize water quality and gain further insights on watershed streams' potential pollutant sources. The watershed's stream water quality is systematically assessed and characterized through graphs primarily created using MINITAB® Release 14.1 statistical software (MiniTab, 2003) to compare and summarize watershed-wide results. Graphed results are presented and interpreted in the context of important factors that often influence water quality; including subwatersheds' relative location and general land covers, wet (October - April) or dry (May – September) seasonality, and base or storm flows. Where appropriate, the graphs show exceedances of applicable state water quality standards criteria. Given this assessment's relatively small sample sizes and resulting limited power to detect statistically significant differences in monitoring location or their subgroup parameter medians, noteworthy overall consistent patterns in calculated medians (without regard to significance of differences) were often emphasized since these may be of practical significance.

Table 3 Summary of water quality monitoring methods used for Whipple Creek watershed data assessment

Water Quality Parameter	Monitoring Frequency / Location Duration	Field Meter or Lab Sample	Method Reporting Limit	Accuracy	Lab Method Reference
Temperature	Summer Hourly Continuous / WPL050 - 12 yrs.	HOBO® Water Temp Pro Sensor /Logger	0.02°C	±0.21°C @ 25°C	NA
	Monthly / Others - WY2012	In-Situ Troll® 9500, YSI™ 6920, YSI™ 85	0.01°C	±0.1°C	NA
Fecal Coliform Bacteria	Monthly / WPL050 – 10 yrs., Others - WY2012	Lab Sample	2 CFU/ 100 mL	NA	Membrane filter SM 9222D
Dissolved Copper	Monthly / Start WY2013 (only WPL050)	Lab Sample	0.1 ug/L	25 % Error	EPA 200.8
Dissolved Zinc	Monthly / Start WY2013 (only WPL050)	Lab Sample	0.5 ug/L	25 % Error	EPA 200.8
pH	Monthly / WPL050 – 12 yrs., Others - WY2012	In-Situ Troll® 9500, YSI® 6920, YSI® 60	0.01 units	±0.1 pH units	NA
Turbidity	Monthly / WPL050 – 12 yrs., Others - WY2012	Hach® 2100P	0.01 NTU	±5% of reading	NA
Dissolved Oxygen	Monthly / WPL050 – 12 yrs., Others - WY2012	In-Situ Troll® 9500, YSI™ 6920, YSI™ 85	0.01 mg/L	±0.2 mg/L	NA

Table 4 Whipple Creek watershed streams' Washington State designated uses and water quality standards criteria

Parameter	Applicable Designated Use	State WQ Standard Criteria
Temperature	Aquatic Life: salmonid spawning, rearing, and migration	7-Day Average Daily Maximum (7-DADMax) of 17.5°C
Fecal Coliform	Primary contact recreation	< geometric mean of 100 colonies / 100 mL and <10% of samples: 200 colonies / 100 mL
Dissolved Copper	Aquatic Life – most sensitive biota : Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Dissolved Zinc	Aquatic Life – most sensitive biota : Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
pH	Aquatic Life: salmonid spawning, rearing, and migration	6.5 – 8.5 pH units
Turbidity	Aquatic Life: salmonid spawning, rearing, and migration	5 NTU over background
Dissolved Oxygen	Aquatic Life: salmonid spawning, rearing, and migration	1-day minimum of 8.0 mg/L once every 10 years on average

Water quality parameters were systematically evaluated using a series of plots contrasting subwatershed monitoring location and subgroup results. Depending on available data, graphs include water quality plots over time, boxplots often grouped by potential influencing factors, and sometimes probability plots. To help consistently interpret results from the most widespread and recent data available, all of the detailed boxplots and probability plots focused on the July 2014 through October 2015 period having watershed-wide water quality data. In order to further evaluate seasonality or flow type influences, probability plots provide a different perspective and more information across the full range of results beyond what is available through boxplots' limited summary statistics. Comparison plots used similar sample sizes. Log-normal probability plots and fitted distributions are used because most of the water quality variables have positively skewed distributions and their variabilities often increase with medians. In general, water quality observations often form a straight line (at least from about the 10 to 90 percentile points) on log-normal probability paper (Burton and Pitt, p. 585). Grouping of results in boxplots (Helsel and Hirsch, pp. 343-344, 423-424) and probability plots by location, wet or dry season, and sampled flow type helps visualize potential confounding or exogenous factors, evaluate their influence on water quality, and tease out likely contributing pollution sources. Where applicable, the analyses present up to four levels of factor subgroups based on monitoring location, season, relative flow, and nested combinations of these groups.

Plots are presented in a consistent order and appearance. Monitoring station names consist of a three-letter abbreviation of the monitored stream's name followed by a three number combination indicating its relative location as a percentage upstream from the stream month. Whenever possible, similar plot types use identical scale ranges to support their direct comparisons. Monitoring location values plotted over time and boxplot coloring use the same monitoring location specific colors as those in the Figure 1.

Each water quality parameter's exploratory data analyses starts with monitoring location values plotted over time to both provide historical context and show relative frequencies of state water quality standards exceedances. Next, descriptive statistics for each monitoring location or subgroup are depicted by boxplots': colored interquartile ranges (IQR or 25th - 75th percentiles), whiskers (vertical lines from the IQR to values falling within 1.5 times the IQR), outliers (colored asterisks of values beyond the whiskers), median values (numerically labeled horizontal lines), and 95% confidence intervals around the medians (grey shaded internal boxes). If the internal grey boxes' ranges overlap then their median values are not statistically different at the 95% confidence level and vice versa. Boxplots are not used to summarize water temperature and dissolved oxygen because differences for each of these two parameters may be substantially driven by the time of day at which they were measured.

If boxplots suggest widespread seasonal or flow type water quality influences then probability plots are used to explore these factors impact. Probability plots show monitoring location values plotted on log-normal axes with a straight-line log-normal distributions fitted to the data, curved lines of the distribution's 95% confidence intervals, and sometimes criteria reference lines. Probability plots can indicate possible range of the values expected, data variation, and their likely probability distribution type (Burton and Pitt, 2002, pp. 584-585). If plotted points form a straight line on a log-normal probability plot it suggests the data are log-normally distributed. Steeper probability plot slopes for the plotted points or their fitted distribution indicates less variability in the values and vice versa. Multiple data sets can also be plotted on the same plot (such as for different sites, different seasons, different habitats, etc.) to indicate obvious similarities or differences in the data sets. In comparing different data sets, similar variances are indicated by generally parallel plots of the data on the probability plots.

Results and Discussion

Background

Water quality monitoring from March 2002 through October 2015occurred across a wide range of flows as reflected by WPL050's water quality monitored flows spanning from less than1 to 213 cfs capturing both base and storm flows (Figure 4).

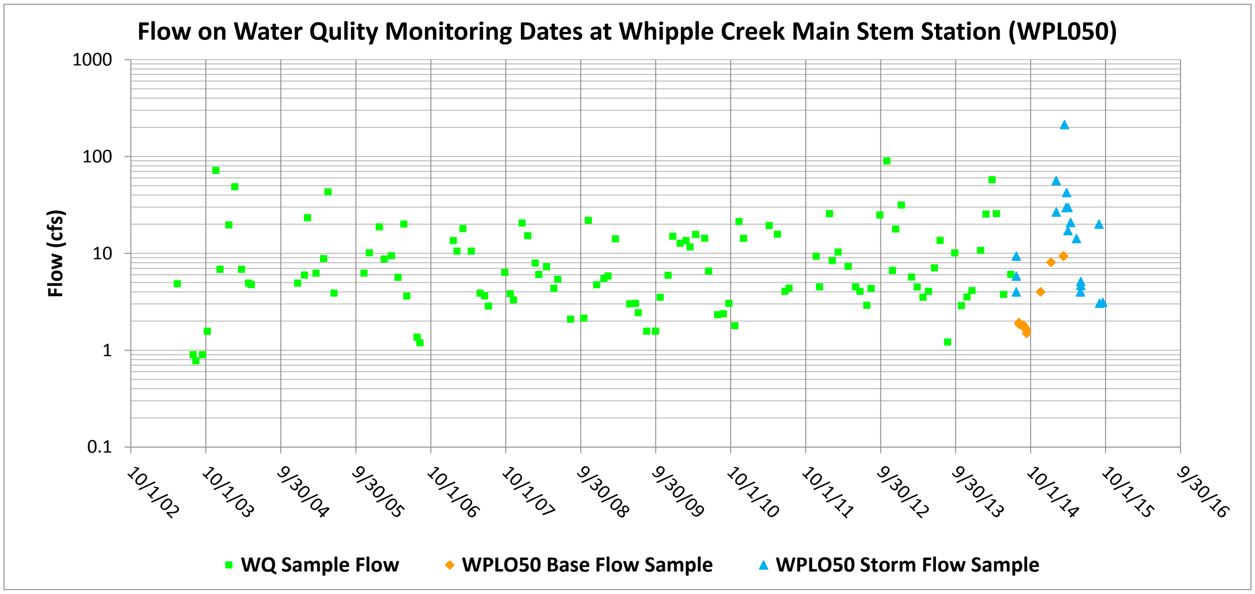

Figure 4 Flows at times of water quality monitoring for the mid-lower Whipple Creek watershed WPL050 monitoring station

The mid-lower watershed main stem monitoring location of WPL050 has by far the longest period of monthly data with some physical parameters' monitoring starting as early as 2002. Two additional main stem (WPL010 and WPL065) and Packard Creek locations' monthly data for water year 2012 (October 2011 – September 2012) is also included in the non-metal parameter plots of values over time. The farthest right portion of the time plots includes up to twelve base and eighteen storm flow monitoring results from July 2014 through October 2015 from nine watershed-wide locations. Often, the storm events include up to three samples per storm.

Stream Water Temperature

Appendix 1 presents the full assessment of the Whipple Creek watershed's stream temperatures.

Fecal Coliform

The scatterplot of Whipple Creek watershed fecal coliform (Figure 5) values over time includes all available County monitored fecal coliform results to provide historical context. As expected, the scatterplot shows that fecal coliform values varied widely (by up to five orders of magnitude) both over time and across monitoring stations. Generally, the long-term fecal coliform results for the mid-watershed WPL050 main stem monitoring location show that this station's monthly, random sampling date results prior to July 2014 were less variable and had comparatively fewer very high values than the subsequent watershed plan's targeted storm and base flow monitoring results across multiple main stem and tributary watershed locations.

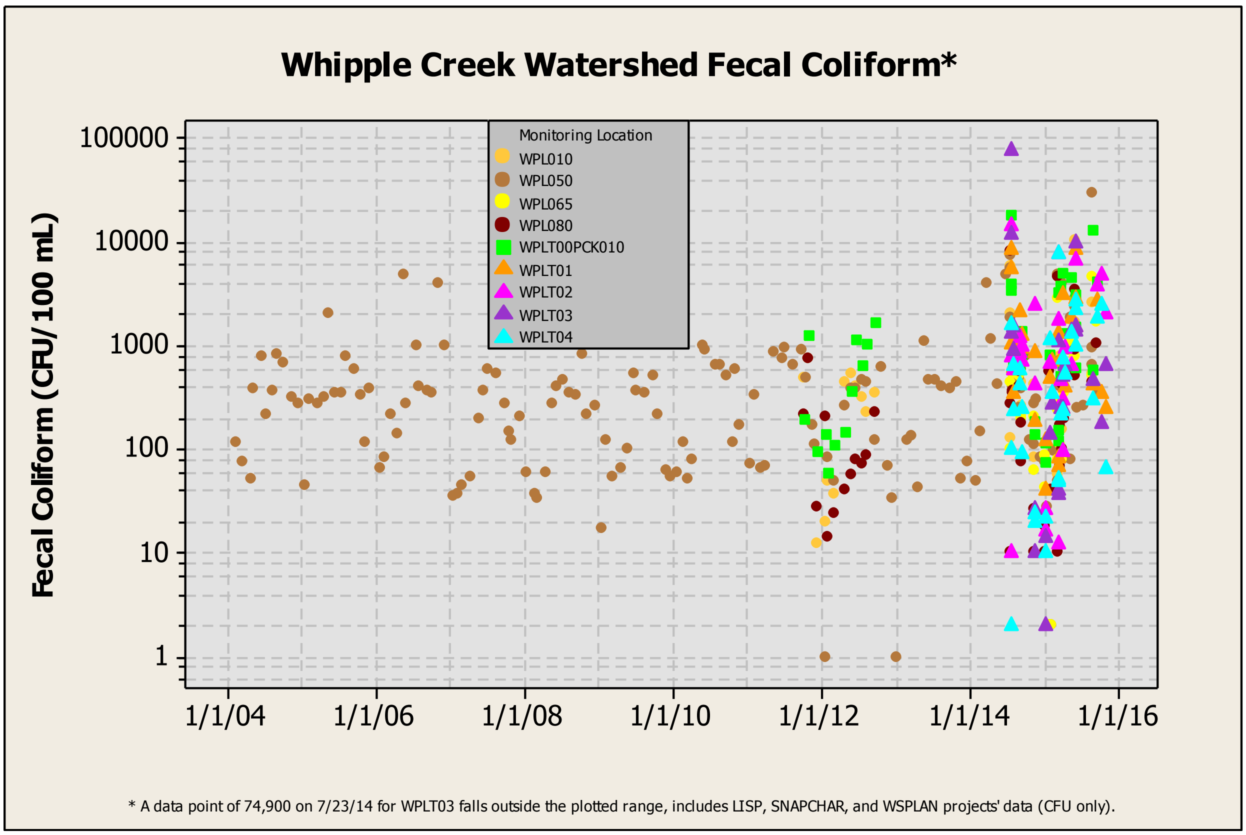

Figure 5 Scatter plot of Whipple Creek watershed monitoring stations long-term and recent fecal coliform levels

Following the state's preference for averaging fecal coliform values on a seasonal basis in applying state standards' fecal coliform criteria (Washington Department of Ecology, revised January 2012, p. 17), these analyses specifically used wet (October 1 – April 30) and dry (May 1 – September 30) seasons for evaluations. Figure 6 summarizes how each monitoring location's fecal coliform results for the July 2014 through October 2015 period compare to applicable Washington State standards' dual criteria. Overall, across almost all Whipple Creek watershed monitoring locations, both of the state's fecal coliform criteria were usually exceeded, often by substantial amounts. Based on the 36 assessments of nine monitoring locations compared across the four criteria of wet (October-April) or dry (May-September) season geometric mean or 10% criteria combinations, just two stations exceeded only one of the seasonal criteria while seven locations exceeded both criteria for the two seasons. Only seasonal values for the main stem monitoring stations of WPL065 (93) and WPL080 (75) were below the seasonal geometric mean criterion of 100 colonies / 100 mL and this only occurred for the wet season. All nine stations' 10% of samples (90th percentile of their respective station's log-normal distributions) seasonal criterion of 200 colonies / 100 mL were exceeded during both the wet and dry seasons. The level of exceedances were often quite substantial, ranging up to 4.5 times the wet season and 27 times the dry season geometric mean criterion as well as 27 times the wet season and 97 times the dry season 10% criterion.

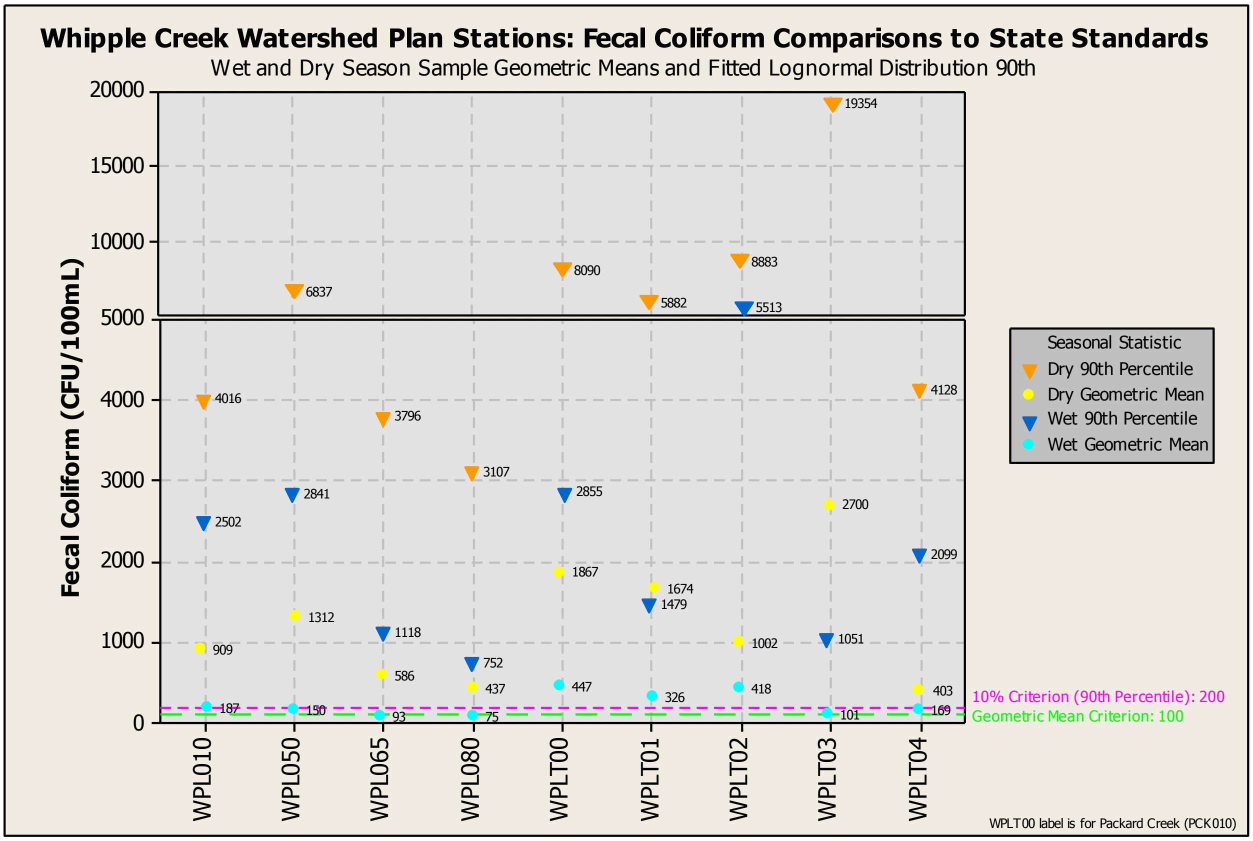

Figure 6 Whipple Creek watershed plan monitoring results comparison to state standards for fecal coliform

The following series of fecal coliform boxplots and probability plots present increasingly detailed perspectives by partitioning potentially important factors that could substantially impact stream fecal coliform levels. At the most general level comparing bacteria counts across the Whipple Creek watershed, the boxplots in Figure 7 display the central tendency (median) and variability (interquartile range or IQR) for each monitoring station and suggest potential differences. Median fecal coliform counts (i.e., colony forming units or CFUs) range from 280 for WPL080 to 830 for WPLT02. Overall, except for the uppermost WPLT040 tributary, all of the calculated main stem medians were lower than the tributary medians. All other factors held constant, this may be partly attributed to bacteria die off over time as fecal coliform are carried downstream. However, with the exception of low medians for WPL080 and WPL065, there appears to be no statistically significant difference in the median fecal coliform values for most of the monitoring stations as demonstrated by their boxplots' internal grey shaded boxes overlapping ranges (i.e., medians' 95% confidence intervals). The few non-overlapping internal boxes show Packard Creek's median (750) is significantly higher than that of both WPL080 (280) and WPL065 (315) while WPLT02's median (830) is only higher than that of WPL080.

Figure 7 boxplots' colored inter-quartile-ranges (IQR or 25th through 75th percentiles depicting one perspective on variation), also show the spread for the middle 50% of stations' fecal coliform values generally expands with increasing values of location medians. The smallest IQRs are associated with WPL080 and WPL065 stations that have the lowest value medians while wider IQRs are found for higher median valued stations and especially for the more variable Packard Creek. While not statistically significant, the overall spatial pattern depicted in the monitoring location boxplots suggests fecal coliform levels generally increase from upper to lower main stem reaches and from upper to lower watershed tributaries (even though these tributaries do not drain into each other). Interestingly, the tributary with the lowest median and smallest IQR for fecal coliform is for the small tributary WPLT04, which has one of the most densely developed subwatersheds (Figure 1). Conversely, the large, mostly rural Packard Creek tributary subwatershed has a one of the higher medians and a greater portion of relatively higher fecal coliform values (as shown by the higher upper extent of its IQR). These patterns suggest possible non-stormwater conveyance sources of fecal coliform for these two subwatersheds.

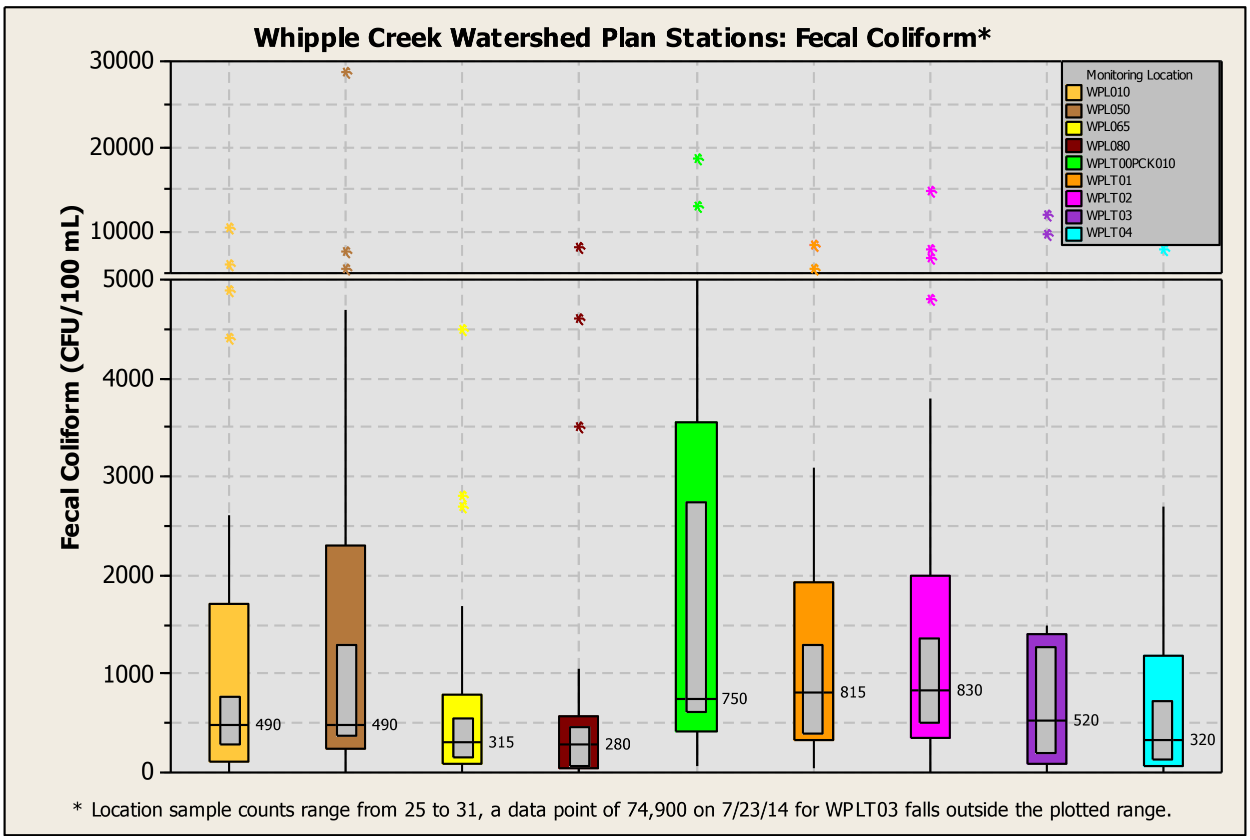

Figure 7 Boxplots of Whipple Creek watershed plan stations' fecal coliform results

There appears to be fairly consistent seasonality and flow components to the fecal coliform results across the watershed (Figure 8 and Figure 9). Dry season fecal coliform medians and IQRs are often substantially higher than wet season values. All monitoring locations' dry season fecal coliform calculated medians were higher than their respective wet season medians (average dry season median 4.3 times that of wet season) with five of the nine locations being significantly higher statistically (on average 6 times as much). Similarly, these same five locations' dry season IQRs were higher such that there was no overlap with their respective wet season IQRs. As shown by narrower wet season IQRs for all locations except for WPLT02, there also was less variability in wet season fecal coliform levels than for the dry season results. For main stem versus tributary seasonal medians, three of the four main stem (75%) and only two of five tributary (40%) stations' dry season medians were significantly higher than their corresponding wet season medians. The more common significantly higher main stem dry season medians may result from resident beaver and lower dry season flows resulting in less dilution of bacteria levels.

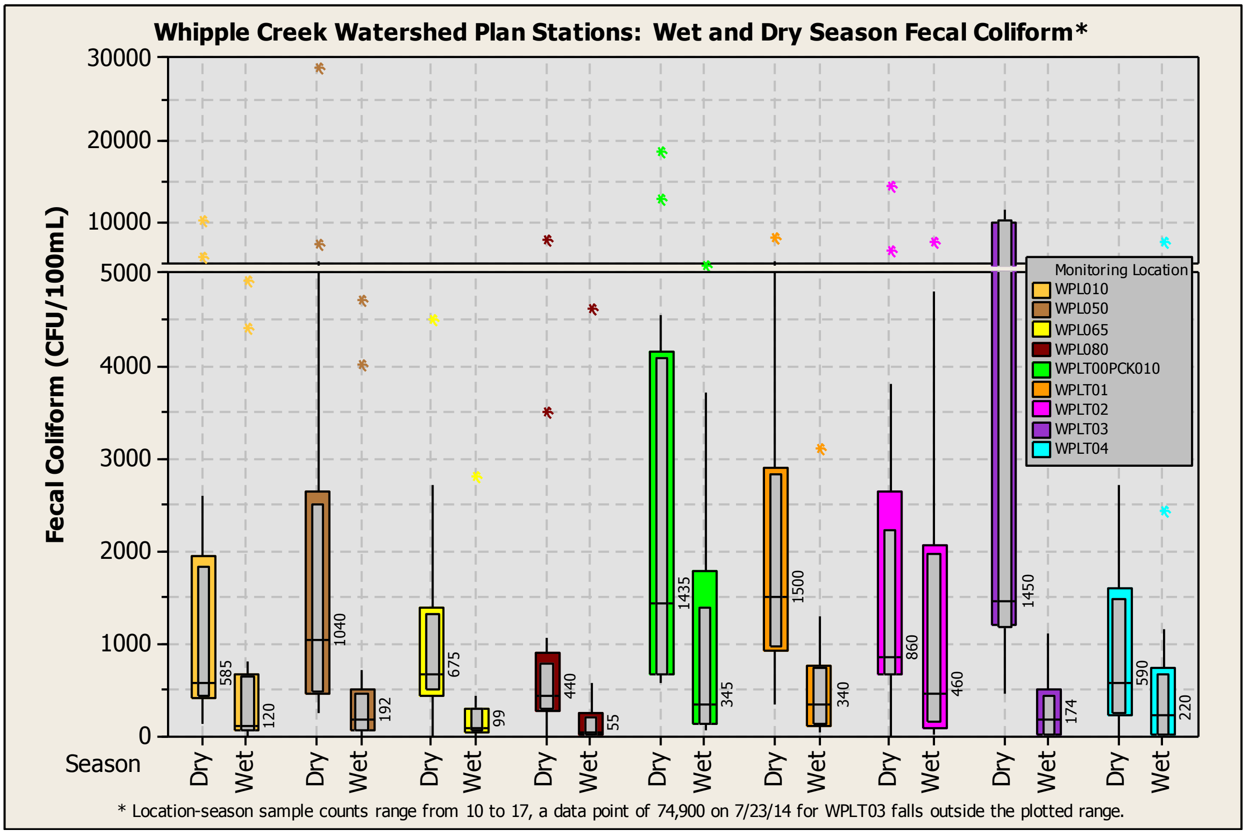

Figure 8 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by season

Like the overall dry season median pattern, storm flow fecal coliform calculated medians were always higher than those for their respective base flows (on average four times as much). However, statistically only two of the nine locations' (WPL050 and WPLT00PCK010 / Packard Creek) storm flow medians were significantly higher (on average 7.5 times as much) than their respective base flow medians with no overlap in both their median confidence intervals and IQRs (Figure 9). The generally lower base flow fecal coliform results also showed less variability (having narrower IQRs) than those for storm flows. The overall consistent pattern of higher calculated medians and IQRs for storm versus corresponding base flows across all monitoring stations strongly suggest surface runoff factors play an important role in bacteria levels in the monitored streams.

The most detailed boxplot partitioning of fecal coliform monitoring results utilizes sequentially nested grouping by flow type within season within monitoring location (Figure 10). This figure zooms in on the narrower range of results from zero to 10,000 to highlight some of the differences at the lower portion of concentrations where most of the values fall. By nesting these groups by factors that have already been shown to likely influence median fecal coliform concentrations their synergistic influences can be evaluated.

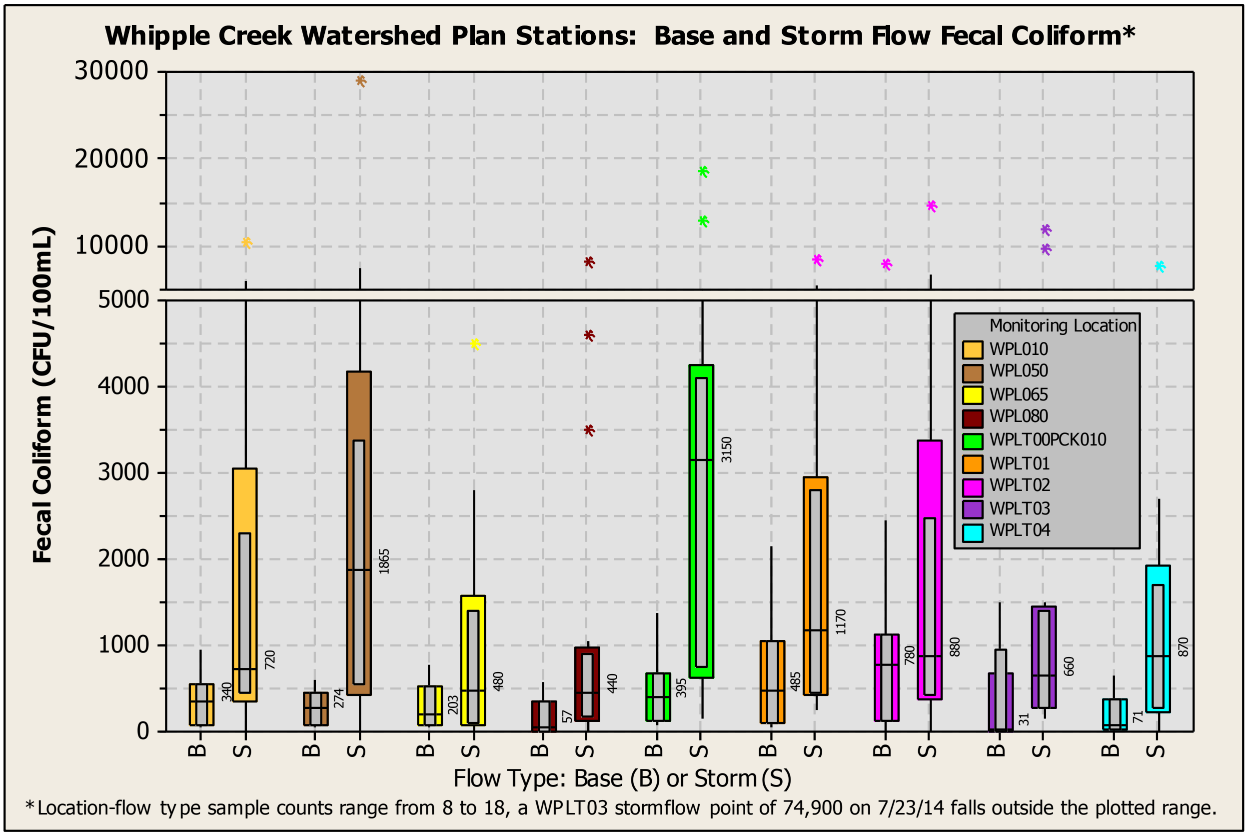

Figure 9 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by flow type

Several consistent patterns and unique features emerge in the detailed fecal coliform boxplots of Figure 10. Across all the monitoring locations, the calculated fecal coliform medians (red circles in the figure) for dry season storm flow were the highest whereas their medians for the wet season base flow were the lowest. Within monitoring locations, the dry season storm flow medians were always significantly higher than their wet seas base flow medians except for station WPLT02. Additionally, dry season base flow calculated medians were always greater than their corresponding within monitoring location wet season base flow medians. Within any monitoring location, the smallest difference between the relatively high dry season storm flow medians and the next closest subgroup medians was 250 CFU at WPLT03 while that for the relatively low wet season base flow was 116 CFU for WPL065. The relative impact on fecal coliform concentrations from flow type is much greater than from season as depicted by within monitoring locations' much larger differences between base and storm flow boxplots compared to corresponding pairs of base or storm flow boxplots for a location's dry and wet seasons.

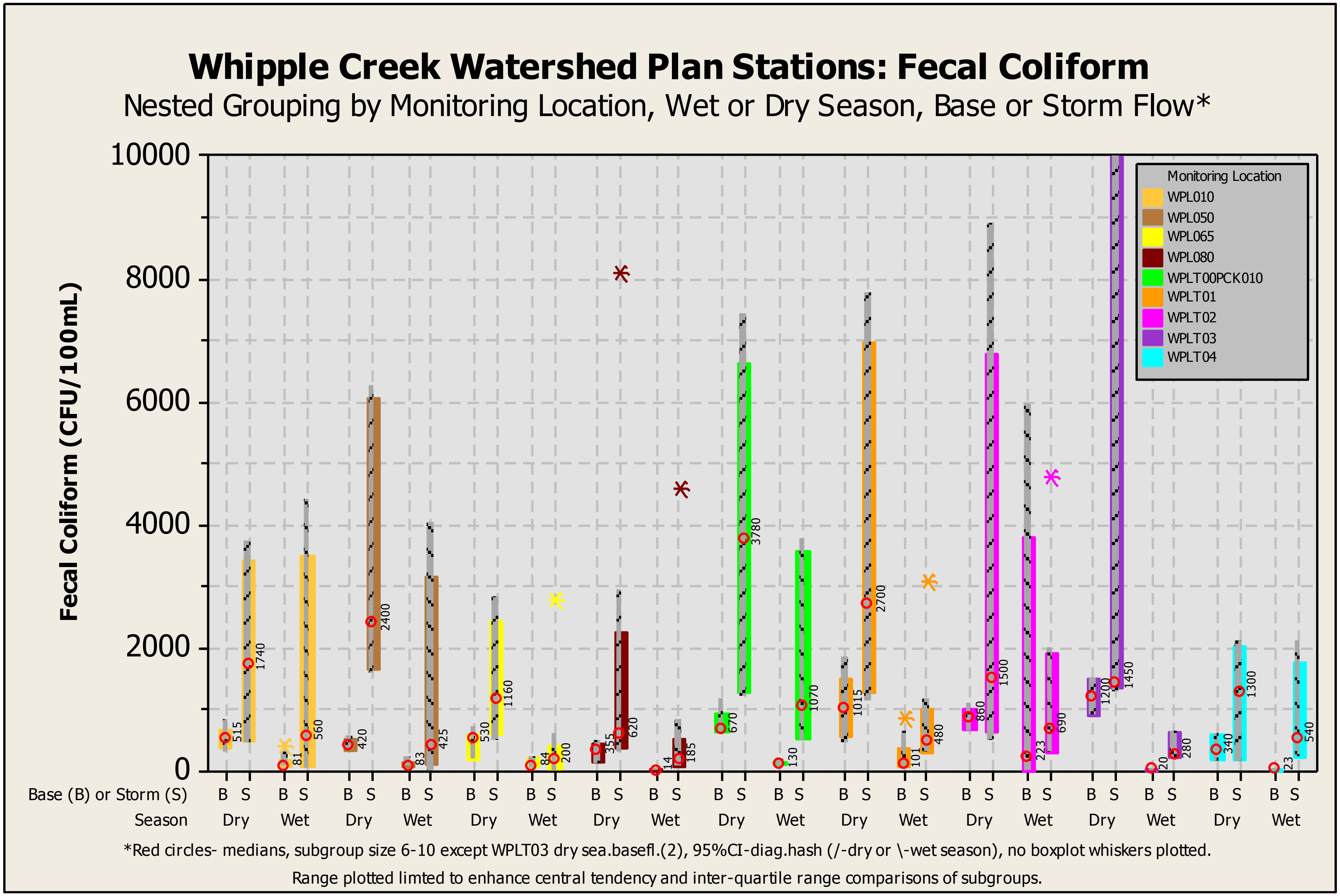

Figure 10 Boxplots of Whipple Creek watershed plan stations' fecal coliform results grouped by flow type nested within season

From a statistically significant perspective of within station subgroup medians, none of the high dry season storm flow medians was different from at least one other same station subgroup median but there were four low wet season base flow subgroup medians that were different (Figure 10). The statistically significant separation (based on separation between their median's applicable 95% confidence boundaries) for the four wet season base flow medians from the nearest other within location subgroup medians always occurred with its corresponding wet season storm flow subgroup. However, the magnitude of the four differences is sequentially wider from the upper main stem (WPL080) to the upper tributaries (WPLT03 and WPLT04) to the Packard Creek tributary. This spatial pattern and magnitude of the significantly lower medians for these wet season base flow subgroups suggests a lack of continuing bacteria sources between wet season storm flow events for these headwater tributaries and especially for Packard Creek. Not only are the wet season base flow fecal coliform group medians the lowest for within station subgroups but their 95% confidence intervals and IQR's are also generally the narrowest by far (except for WPLT02) which suggest very little variability in most of their values. Given that the within monitoring location subgroup sizes consist of at most ten samples, it is not surprising that many of these subgroups' median 95% confidence intervals overlap. Larger sample sizes could provide more power to statistically test the significance of meaningful differences between the subgroup medians especially for highly variable parameters such as fecal coliform.

These detailed nested boxplot patterns (especially for the consistent patterns in calculated high and low group medians) may be due to a combination of storm runoff of accumulated nonpoint source bacteria from hard surfaces during dry season storms and dilution due to larger wet season base flows with shorter pollutant accumulation periods between storms. The Washington Department of Ecology notes in their "White Salmon River Watershed Fecal Coliform Bacteria Attainment Monitoring Study" (Ecology, 2011, p. 20) that "The critical conditions for nonpoint sources generally occur during high-rainfall periods, particularly during the start of a rainfall event when bacteria are 'flushed' from surface soils into the streams" (cited reference not listed in the report's reference list). The low wet season base flow medians could also be partly attributed to dilution of any relatively constant fecal coliform sources (e.g., failing septic systems, beavers, etc.) during the wet season. WPLT02's generally higher medians and wider ranging IQR suggest unusual fecal coliform sources impacting it over a wide range of seasonal and flow conditions. The very unusual WPLT02 fecal coliform wet season base flow subgroup results (whose median is 93 higher and IQR is bar far wider than that of the next highest similarly grouped median) would need further investigation as to the potential pollutant sources. The unique pattern in the WPLT02 boxplots, especially for the unusually high variability wet season base flows, suggests potential ongoing impacts from nearby resident beavers and waterfowl living in a large upstream pond / wetland or a relatively large continuous manmade source of fecal contamination. Additionally, the relatively high median fecal coliform values (>1,000 CFU / 100 mL) during dry season base flow conditions for the tributary monitoring locations of WPLT01 (mostly rural land cover subwatershed) and WPLT03 (mixed land cover subwatershed but median based on just two samples) also suggests possible wildlife, livestock, or human sources such as failing septic systems contributing bacteria.

The common general patterns of fecal coliform asymmetric distributions, increasing variability (as shown by the boxplot IQRs) with increasing fecal coliform median values, seasonality, and the interpretation of a state water quality standards 10% criterion on a seasonal basis suggest the need to evaluate fecal coliform results using log-normal probability distributions for further insights. The Washington State Department of Ecology Environmental Assessment Program uses a stream's 90^{th} percentile of its log-normal distribution of sampled fecal coliform results to calculate and assess a stream's attainment of the state fresh water standard's 10 percent criterion of 200 fecal coliform colonies / 100 mL (Ecology, 2011, p.17).

Figure 11 presents a series of identically scaled fecal coliform log-normal probability plots fitted with wet (green) and dry (orange) season straight-line log-normal distributions and their corresponding 95% confidence intervals for each of the nine Whipple Creek watershed monitoring locations. Also superimposed on each plot are the 90th percentile values along each season's fitted log-normal distribution which match their equivalent calculated 90th percentile values presented in Figure 6. That most of each plot's seasonal values fall within their corresponding fitted log-normal distribution's 95% confidence intervals suggest that the log-normal distribution is a reasonable overall statistical model to use on the data across all the monitoring locations. The greatest difference in an individual monitoring location's 90th percentile seasonal values is, by far, for WPLT03 (depicted on Figure 11 by blue labels and vertical dashed lines dropping to the horizontal log scale) similar to that in Figure 6 (depicted parallel to the broken non-log vertical scale).

Most of the monitoring locations' probability plot seasonal subgroups (Figure 11) contain similar sample sizes (all within three of each other except for five more for WPLT03's wet season) allowing direct evaluations of differences in the spread of their seasonal values. Similar to the observations made for the seasonal boxplots, almost all of the equivalent percentile wet season values tend to be lower than (to the left of) their corresponding percentile dry season values. Five stations (four of which are for the wet season) have at least one very low result likely at the laboratory reporting limit for fecal coliform. The generally steeper slopes of the fitted dry season log-normal lines relative to their wet season lines implies slightly less variability for the dry season. However, at many locations' higher values their fitted lines and confidence intervals either approach or cross over each other and conversely there is greater separation at lower values. This high value overlap is especially true for the main stem locations and Packard Creek. However, there is considerable seasonal overlap throughout the full range of values for WPLT02 and WPLT04 which reinforces the lack of seasonal effects seen in the boxplots for the two locations. The greatest separation in fitted log-normal lines and their confidence intervals throughout the full range of seasonal values is for the WPLT03 monitoring location. These probability plot patterns suggest that there is less seasonal effect (less separation and more comingling of points) at the higher wet and dry season concentrations especially for the lower main stem of Whipple Creek and WPLT02 and WPLT04 tributaries. Much of the main stem locations' probability plots clearer seasonal separation at lower concentrations may be due to their consistent lower base flow and higher storm flow concentrations during the both seasons also shown in the nested seasonal-flow boxplots of Figure 10. Compared to the other subwatersheds, the slightly flatter slopes of WPLT02's and WPLT04's fitted log-normal distributions for both the wet and dry seasons suggest more variable fecal coliform across both seasons for these more developed subwatersheds.

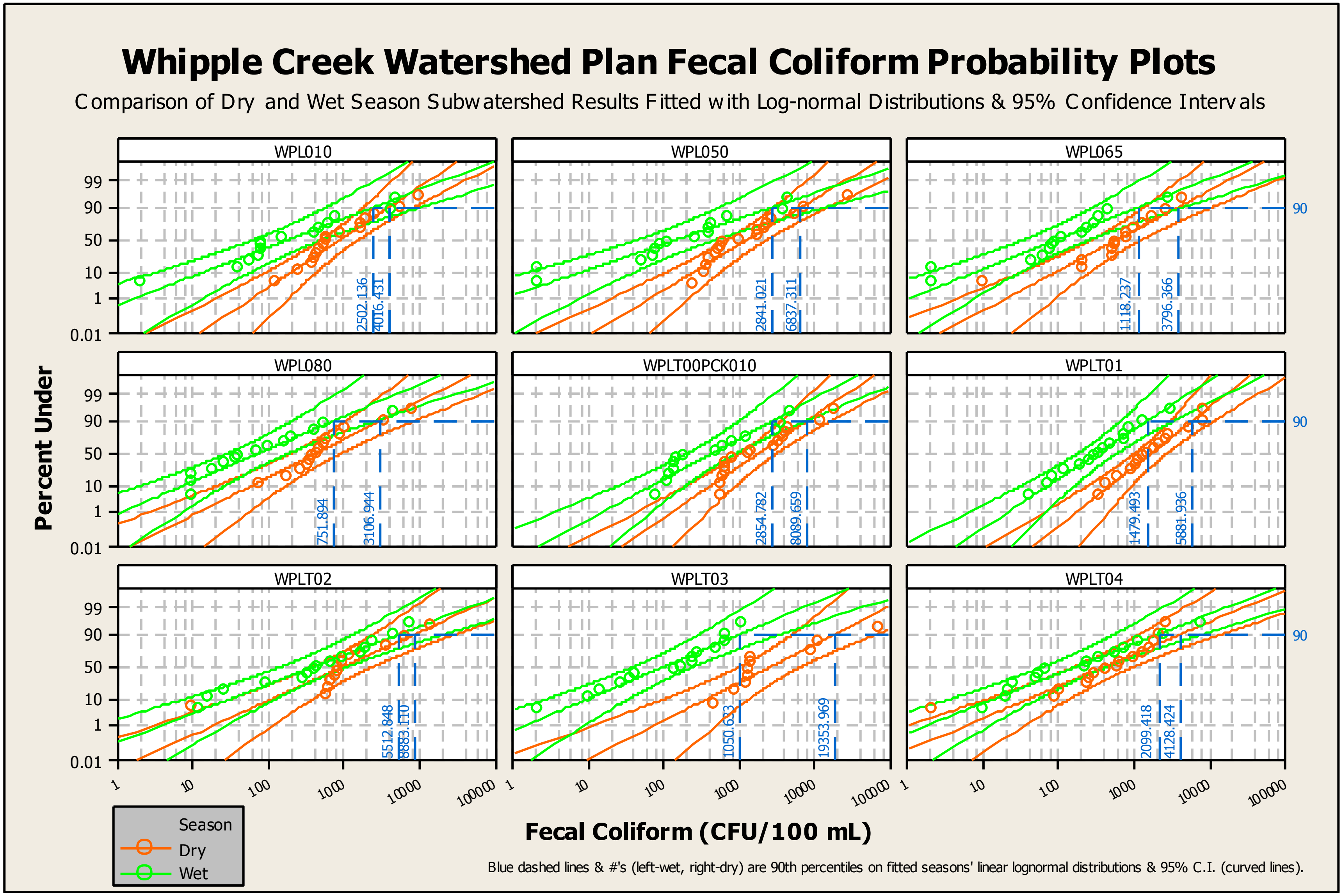

Figure 11 Log-normal probability plots of Whipple Creek watershed plan stations' fecal coliform results grouped by season

Dissolved Copper and Dissolved Zinc

This summary of Whipple Creek watershed dissolved copper and dissolved zinc monitoring results compares and contrasts levels of these two metal pollutants across multiple main stem and tributary watershed locations and suggests factors likely influencing them. The scatterplots of Whipple Creek watershed dissolved copper (Figure 12) and dissolved zinc (Figure 13) present historical context by showing the range of their values over time. The scatterplots show that the mid-watershed main stem WPL050 long-term monitoring location's monthly, (randomly selected sampling dates) dissolved copper and zinc values were comparable (both mostly below 2 ug/L) prior to the start of watershed-wide monitoring in July of 2014. The subsequent watershed plan's higher frequency, targeted storm and base flow monitoring showed both dissolved metals varied much more widely throughout the watershed than they did during the prior monthly WPL050 monitoring. Generally, watershed-wide dissolved zinc values were both higher and varied more than dissolved copper levels.

Possible exceedances of applicable state freshwater quality standard's acute and chronic criteria were evaluated for both dissolved copper and dissolved zinc where simultaneous water hardness values were available during the watershed plan's targeted base and storm flow monitoring period of July 2014 through October 2015. Both dissolved copper and dissolved zinc each had 266 applicable pairs of dissolved metal and corresponding hardness values for evaluation. The applicable state water quality standards (Ecology, revised 2012, p.26-30) include language for the acute and chronic criteria that suggest the need for more frequent monitoring than performed for the watershed plan. For dissolved copper and zinc, the state's criteria language specifically state for acute "A 1-hour average concentration not to be exceeded more than once every three years on the average" and for chronic "A 4-day average concentration not to be exceeded more than once every three years on the average". Therefore, the application of the water hardness specific numeric criteria is only to provide relative context even though exceedance terms are used in these analyses.

As shown in Figure 12, Whipple Creek watershed plan (WSP) monitoring locations exceeded dissolved copper acute criterion three times (across three stations, 1.1% of all WSP samples, and 6% of these individual stations' samples) and chronic criterion four times (across three stations, 1.5% of all WSP samples, and from 6 to 11% of these individual stations' samples). Figure 13 shows only one exceedance each for dissolved zinc acute and chronic criterion (both for WPLT03, 0.4% of all WSP samples, and 6% of this station's samples for each criterion). The dissolved copper exceedances ranged from 117% to 449% for acute and 126% to 634% for chronic criteria. The dissolved zinc exceedances were 303% of acute and 332% of chronic criteria. All of the exceedances for both dissolved metals occurred during storm flow events across a combination of wet and dry seasons.

Whipple Creek watershed plan monitoring location boxplots for dissolved copper (Figure 14) and dissolved zinc (Figure 15) show central tendencies, distributions, and contrasting patterns for the concurrently collected and equivalent sample sizes for these two metals across the watershed. All the distributions for both metals are asymmetrical and skewed toward high values with most monitoring locations having at least one high outlier above the plotted whiskers. An extreme dissolved copper outlier of 39.8 ug/L for Packard Creek is four times higher than the uppermost plotted range of all the other dissolved copper values. Falling above the plotted range of most dissolved zinc values are the three extreme outliers of 17.3 ug/L for WPLT02 as well as two for WPLT03 of 27.7 ug/L and 202 ug/L (more than thirteen times higher than the top of the plotted range).

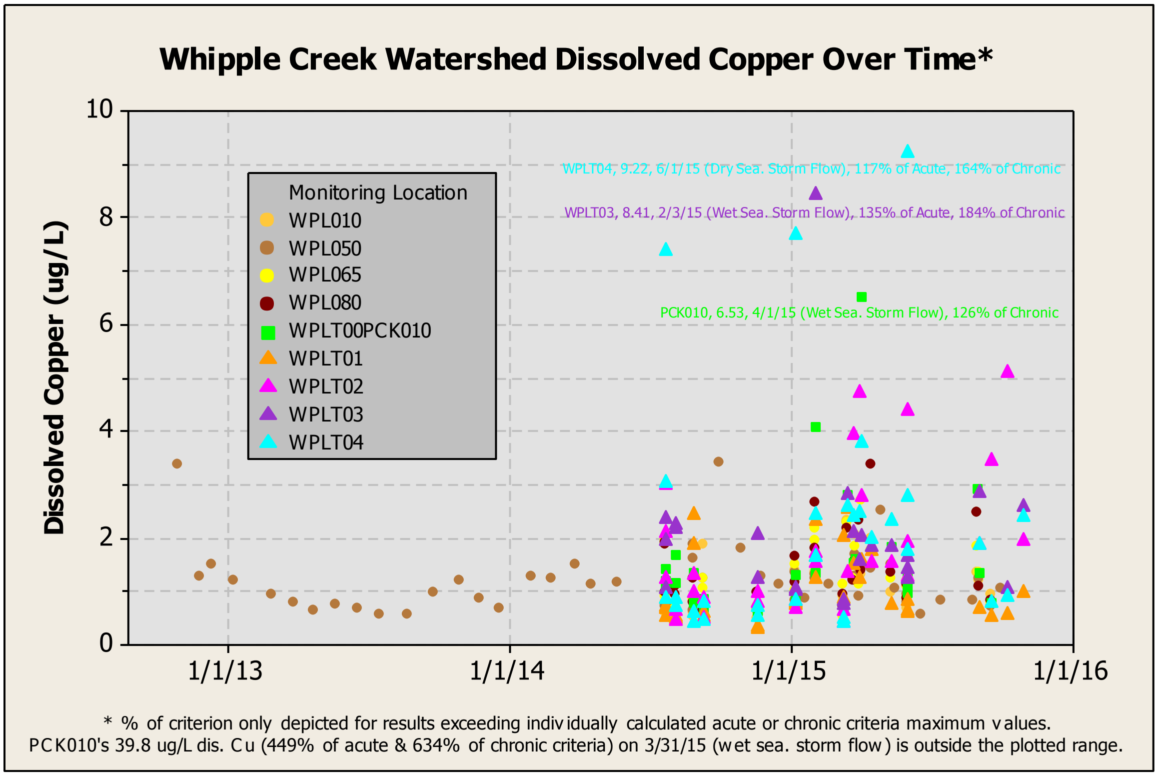

Figure 12 Whipple Creek watershed dissolved copper levels over time and exceedances of state standards

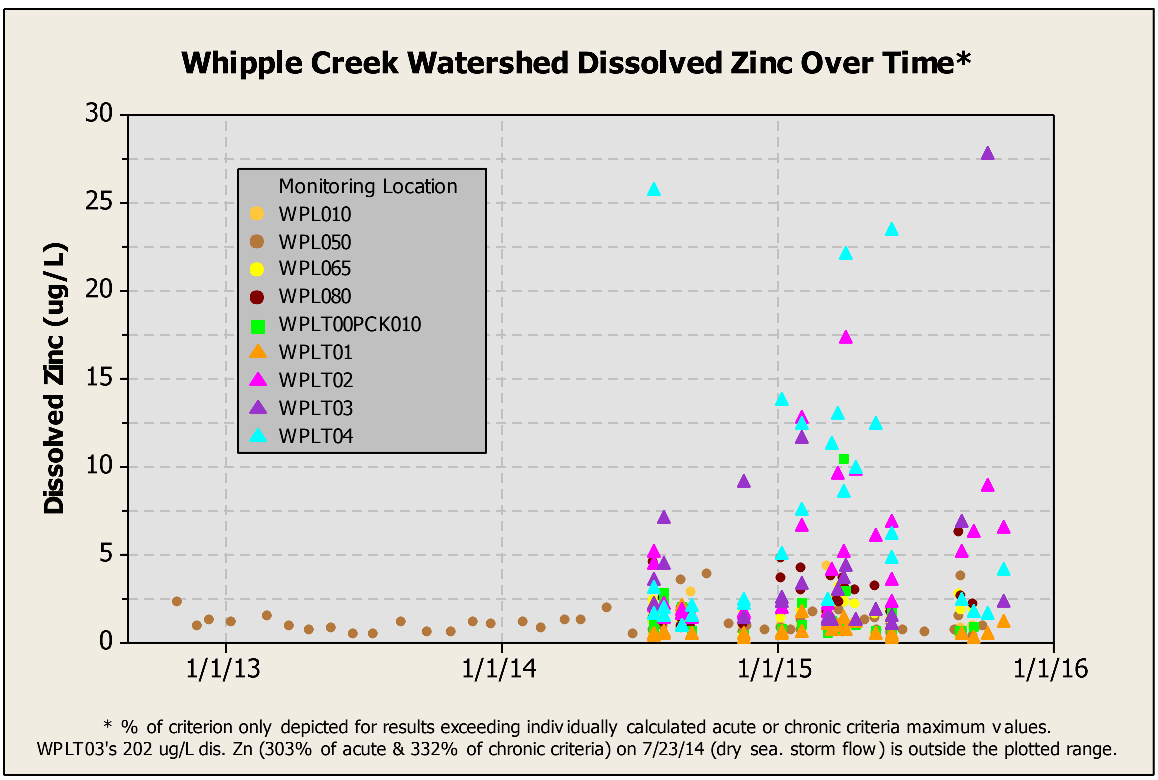

Figure 13 Whipple Creek watershed dissolved zinc levels over time and exceedances of state standards

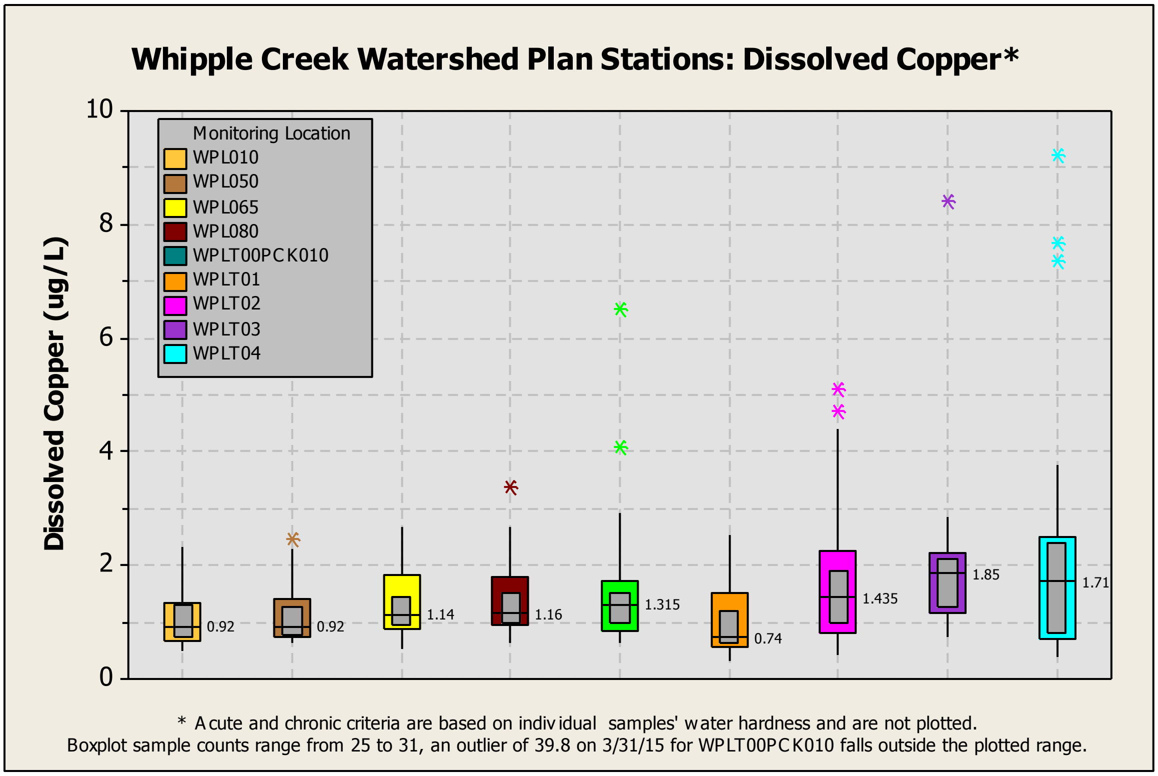

Figure 14 Boxplots of Whipple Creek watershed plan stations' dissolved copper results

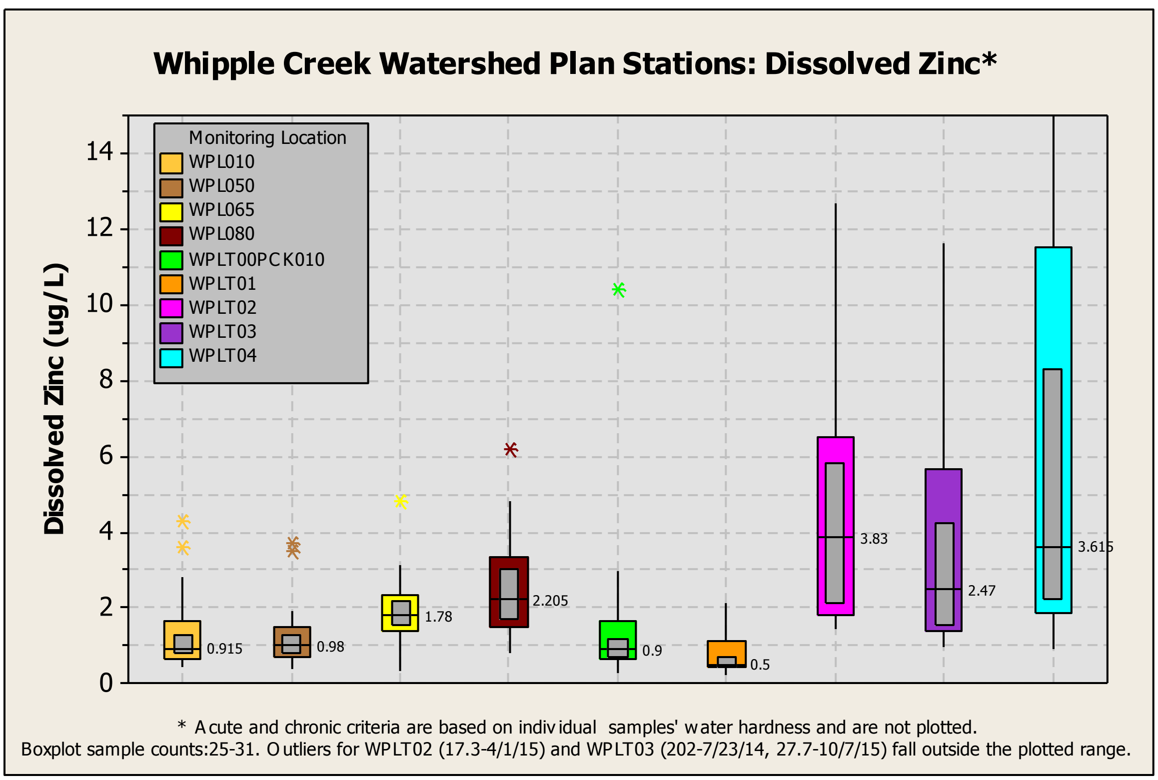

Figure 15 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results

From a watershed wide perspective, there tends to be slight increases in the calculated medians and interquartile ranges from downstream to upstream for the main stem and tributary monitoring locations (as shown from left to right within these subgroups in Figure 14 and Figure 15 except slight decreases for WPLT01) but most of these increases are not statistically significant. In fact, for dissolved copper, the only statistically significant difference in monitoring location medians is that the WPLT01 median of 0.74 ug/L is significantly less than the WPLT03 median of 1.85 ug/L (all the other dissolved copper boxplots' internal grey 95% confidence interval boxes overlap). For dissolved zinc, both of the two most downstream main stem and tributary monitoring stations' medians were significantly less than those for the most upstream main stem and three most upstream tributaries. The overall watershed wide pattern of decreasing dissolved metals from upstream to downstream (especially for dissolved zinc) suggests that higher concentrations are driven by increased development impacts in the upper tributaries and main stem headwater subwatersheds with dilution of concentrations likely occurring further downstream.

The potential impact of seasonality on dissolved metal concentrations was evaluated by the grouping of results in seasonal boxplots. The evaluation utilized two seasons, consisting of a wet season running from October through April and a dry season running from May through September. As depicted in both Figure 16 for dissolved copper and Figure 17 for dissolved zinc, the nearly consistent overlap between the pairs of dry and wet season internal grey boxes for each monitoring location indicates no significant difference between the within monitoring location seasonal medians. The only exception to this pattern is for dissolved copper at WPLT01, but even this site's confidence intervals around their medians almost overlap so the significance of their differences in medians is likely marginal. Therefore, it is concluded that seasonality is not an important factor in the concentrations of these two dissolved metals and is not incorporated in further analyses of dissolved copper and zinc.

The influence of base and storm flow factors on Whipple Creek watershed dissolved metals was also evaluated. Paired base and storm flow boxplots of dissolved metals concentrations for each monitoring location are presented in Figure 18 for dissolved copper and in Figure 19 for dissolved zinc. Within each monitoring location, the base flow calculated dissolved copper median (labeled values on boxplots) was always lower (though often not statistically different) than the median for its storm flow. Similarly, within location base flow calculated dissolved zinc medians were always lower than their corresponding storm flow medians except for the two most downstream main stem (WPL010 and WPL050) and the WPLT01 tributary site.

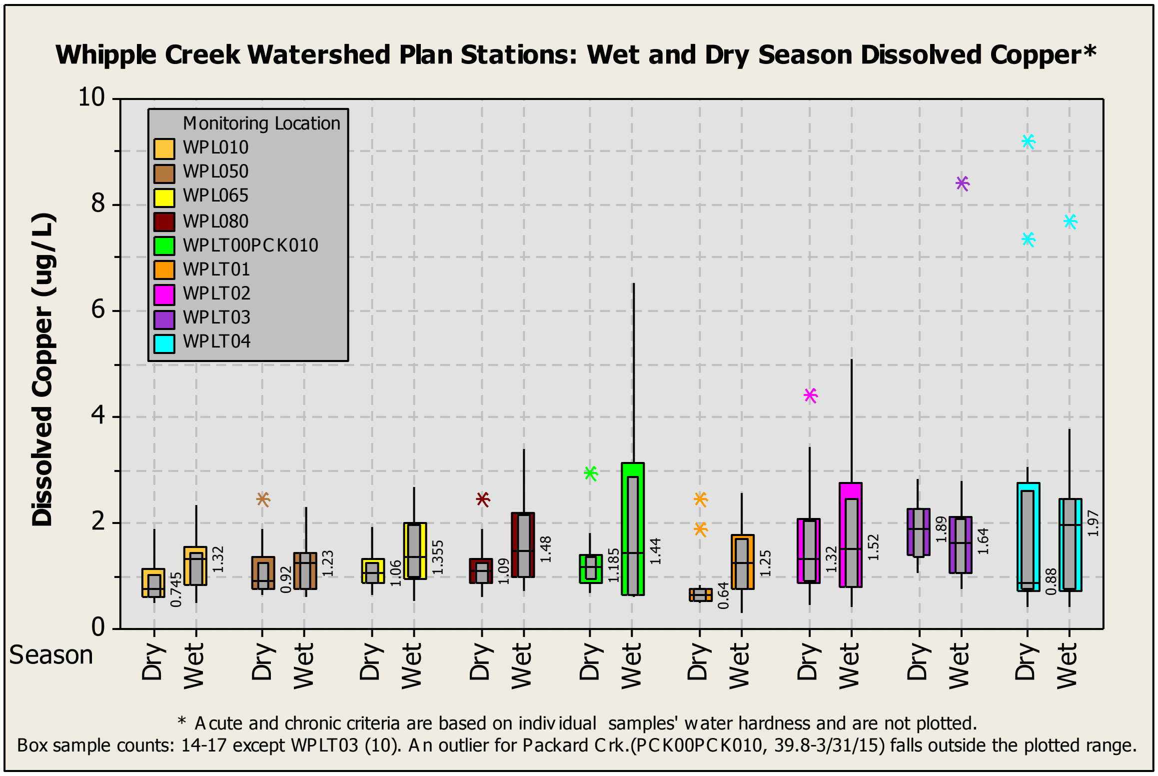

Figure 16 Boxplots of Whipple Creek watershed plan stations' dissolved copper results grouped by season

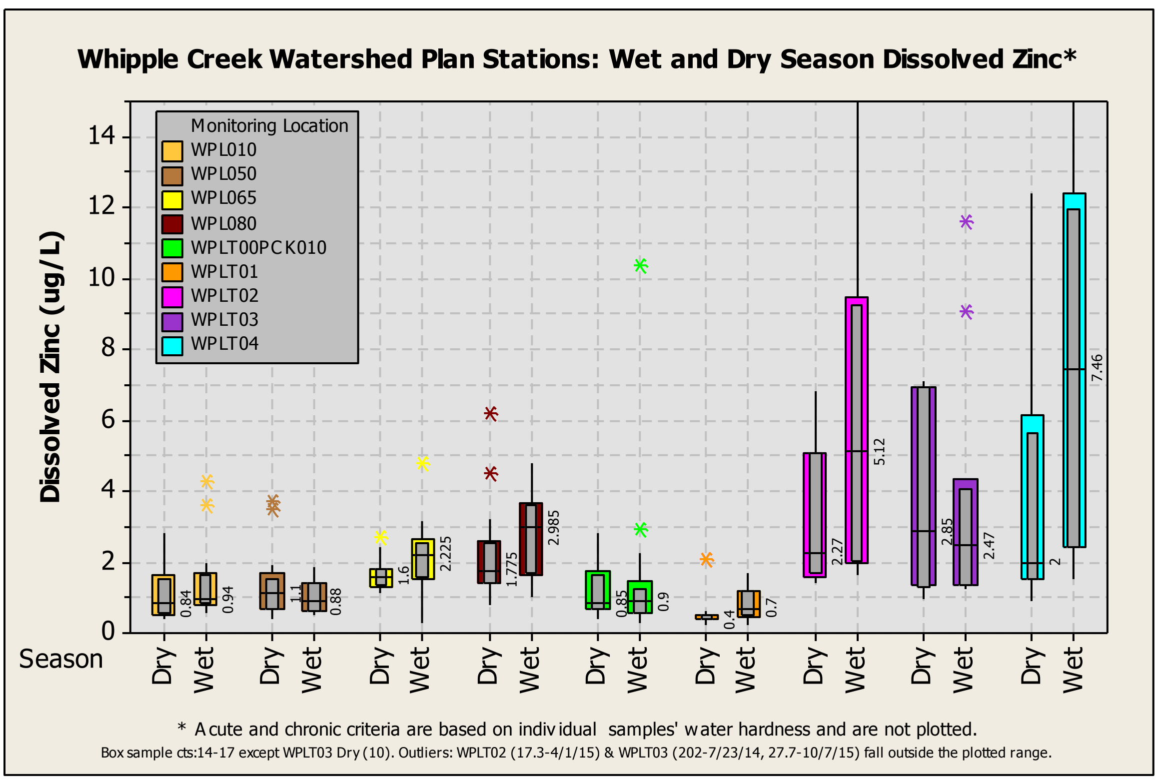

Figure 17 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results grouped by season

Significant differences in median dissolved metal concentrations between base and storm flow for individual monitoring locations is much more common for flow type than it was for wet and dry seasons. Of the nine locations monitored, base and storm flow median dissolved copper levels (Figure 18) were not significantly different for five sites (three main stem and two tributaries) but were significantly different for four sites (two each for main stem and tributary sites). However, of the four significant differences in median dissolved copper levels, only two tributary sites' medians were clearly different (as depicted by clear separation of the base and storm flows' internal grey boxes for WPLT02 and WPLT04) in which both had significantly higher storm flow medians compared to base flow medians. There is a very similar overall pattern across monitoring locations for significant differences between base and storm flow median dissolved zinc levels (Figure 19). Across the same nine monitoring locations, base and storm flow median dissolved zinc levels were not significantly different for six sites (three main stem and three tributaries) but were significantly different for three sites (one main stem and two tributary sites). Again, there were only clear significant differences in the dissolved zinc medians for the same two tributary sites of WPLT02 and WPLT04, which both had significantly higher storm flow medians compared to base flow medians.

Compared to WPL050's relatively constant monthly dissolved metals levels, the more variable and higher watershed-wide dissolved metals concentrations (Figure 12 and Figure 13) after July 2014 are likely largely due to the more frequent targeted storm and base flow monitoring. Specifically, the preferential targeting of storm flows likely captures the higher concentration of metals often associated with the first flush of pollutants from impervious surfaces during the beginning of a storm. Some of the lower values are likely during base flow conditions when dissolved pollutants have already passed downstream and concentrations become diluted. The common pattern of higher storm than base flow calculated dissolved metals medians, especially significantly higher storm flow medians for the most developed subwatersheds of WPLT02 and WPLT04, strongly supports that there are first flush dissolved metal impacts from the more developed areas.

Whether dissolved metal concentrations were generally increasing or decreasing between the first and second samples (averaged five hours apart) within a base or storm sampling event were briefly evaluated. Patterns would provide insights on departures from expectations and mechanisms operating within the watershed. One surprising pattern for both metals during base flow monitoring events was that increases occurred over time much more often on the lower main stem (except WPL050) while more decreases usually occurred for the tributaries. This within sampling event pattern suggest pollutant travel time downstream may play a more important role by increasing downstream concentrations even during base flows when decreasing concentrations over time would typically be expected throughout the watershed. Storm flow concentrations would be highly dependent on when sampling occurred within an event.

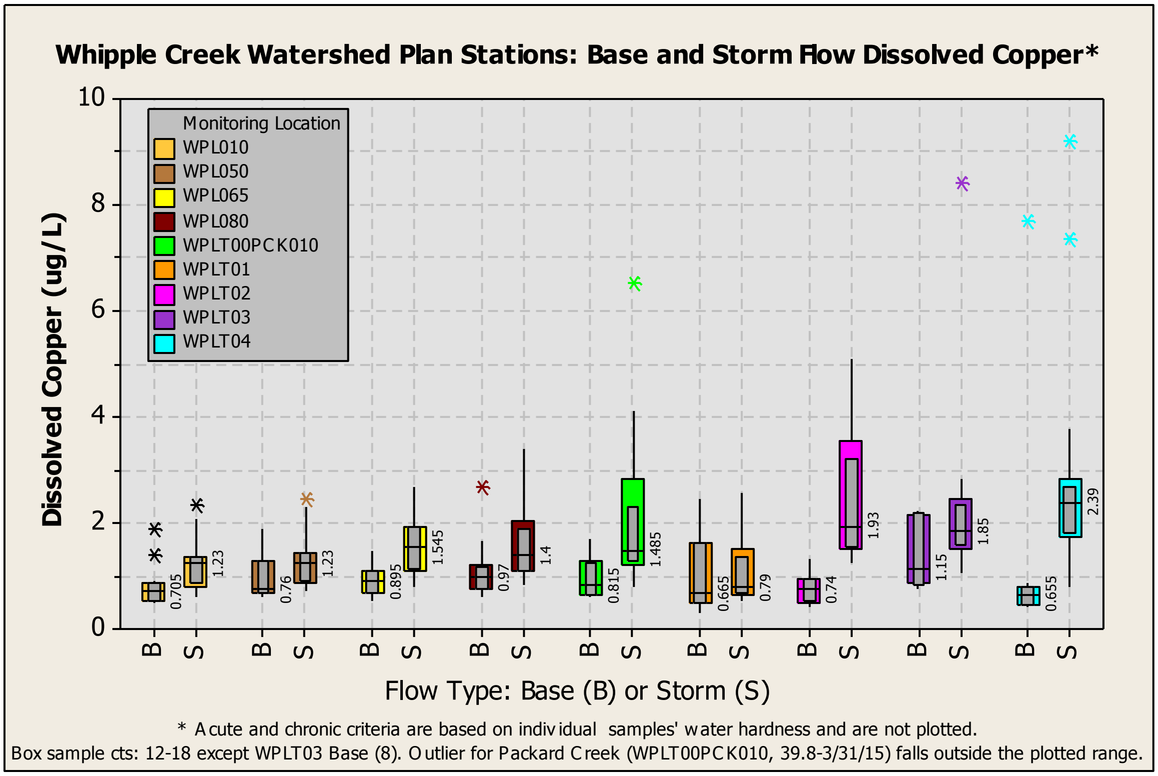

Figure 18 Boxplots of Whipple Creek watershed plan stations' dissolved copper results grouped by flow type

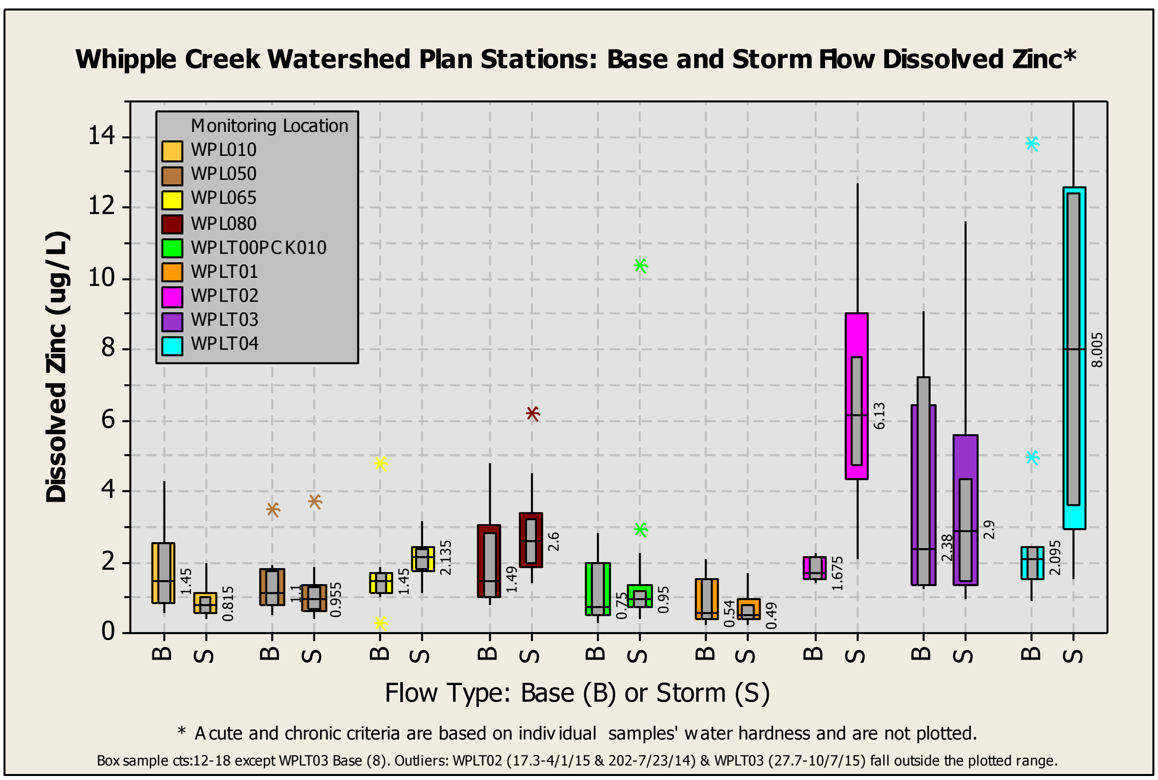

Figure 19 Boxplots of Whipple Creek watershed plan stations' dissolved zinc results grouped by flow type

Figure 20 and Figure 21 present Whipple Creek watershed plan monitoring locations' paired base flow and storm flow probability plots fitted with straight-line log-normal distributions and 95% confidence intervals. These plots show that most of the monitoring stations dissolved metals concentrations fit log-normal distributions fairly well, storm flow concentrations are usually higher (to the right) but often overlap with those of base flow at their lower levels, and the variability (shown by the slope of the straight line distributions) differs considerably for some of the sites.

Overall, for both dissolved metals, there generally is less difference between base and storm flow concentrations throughout their ranges for the main stem locations than for the tributaries (as depicted by the relatively wider separation between base and storm flow distributions for individual tributaries in Figure 20 and Figure 21). The general pattern in both dissolved metals' tributary storm flow probability plots of usually having both flatter slopes and more divergence at higher concentrations (except for WPLTPCK010 – Packard Creek's dissolved zinc) from their base flows suggests that the tributaries are more susceptible to the effects of stormwater runoff especially during the short term periods of stormwater runoff.

Interestingly, while the main stem dissolved zinc probability plots' slopes (variability) remain relatively constant, the horizontal position of their storm flow distributions (and their plotted blue points) appears to gradually shift to the right from downstream to upstream main stem locations (Figure 21). This gradual shift suggest a general increase in storm flow dissolved zinc values from downstream to upstream along the main stem of Whipple Creek. WPL050 and especially WPL010 have unusual horizontal positions in their storm flow dissolved zinc probability plots in that they are mostly less than (to the left of) their corresponding base flow distributions. This switch from the usual pattern of higher storm flow values suggests these lower main stem sites' zinc levels are affected by pollutant travel time (also see above interpretation of within sampling event increasing or decreasing patterns), overall dilution, or some instream mechanism that reduces dissolved zinc levels as they travel downstream.

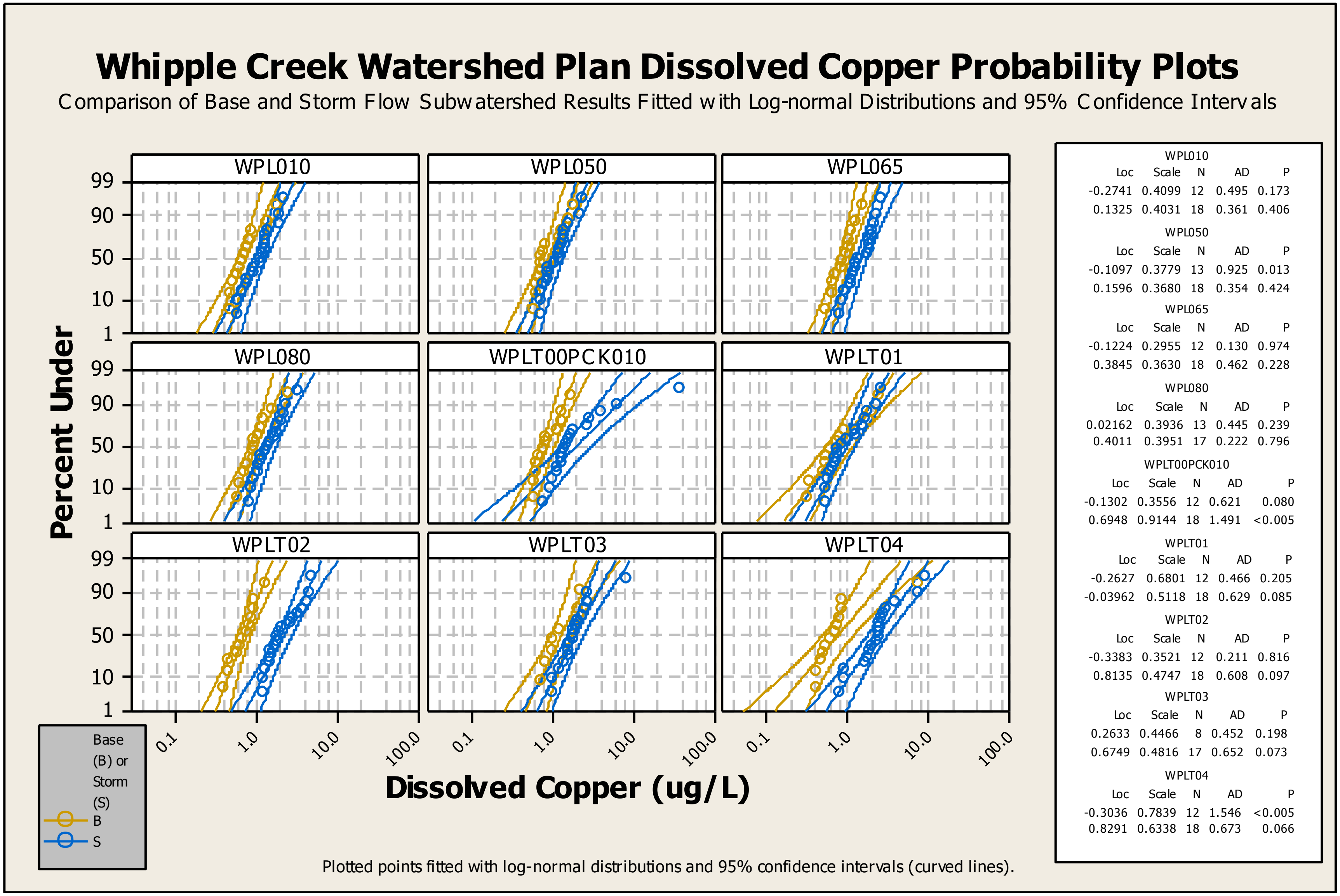

Figure 20 Log-normal probability plots of Whipple Creek watershed plan stations' dissolved copper results grouped by flow type

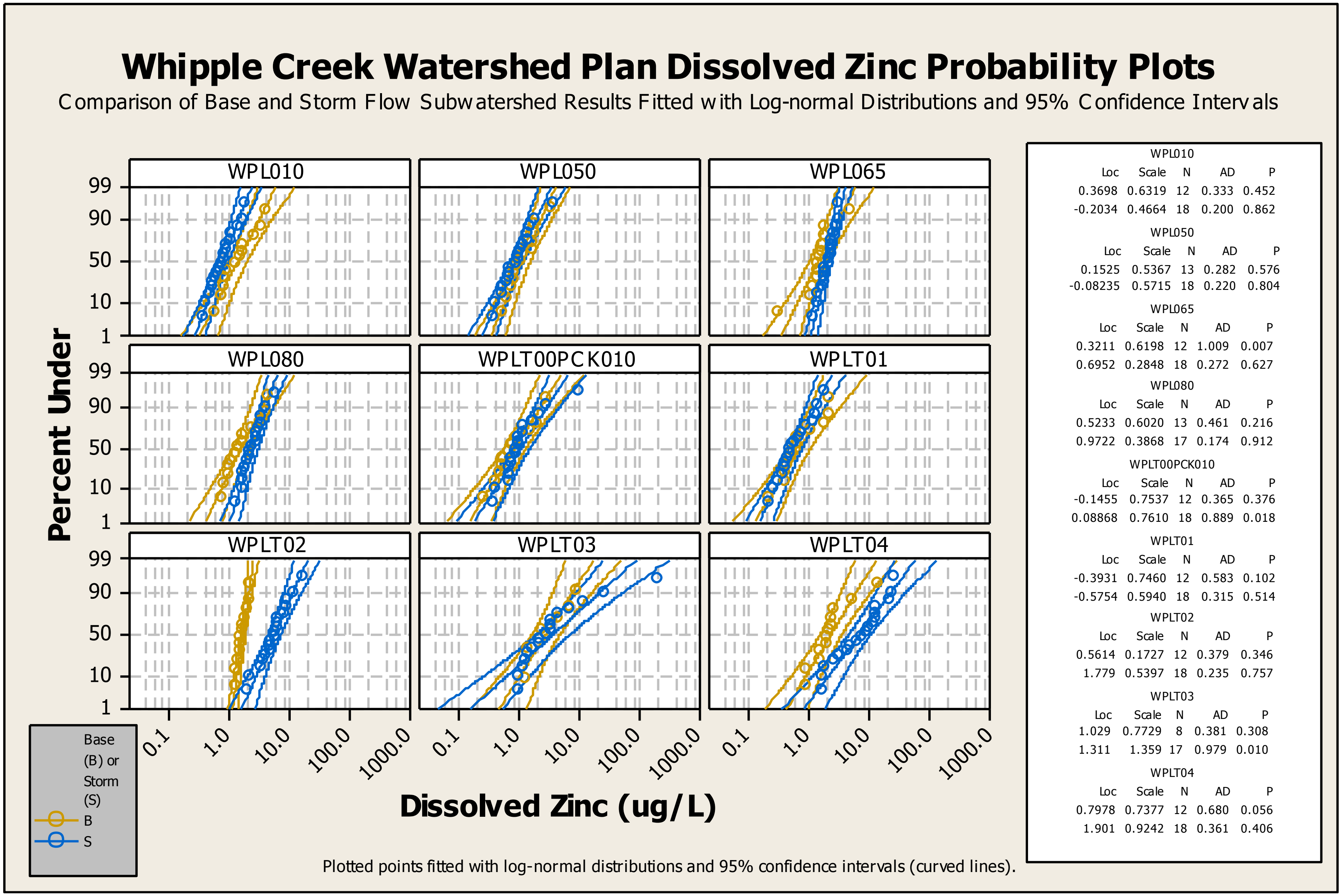

Figure 21 Log-normal probability plots of Whipple Creek watershed plan stations' dissolved zinc results grouped by flow type

pH

The Whipple Creek watershed scatterplot (Figure 22) shows that the vast majority of monitored pH values across all monitoring stations fell within the applicable state standard's pH criteria range of 6.5 to 8.5. Only nine pH values (or 2%) of all measurements fell slightly below the lower criteria value of 6.5. On a station basis, the counts and percentages of all monitored pH values less than 6.5 were: WPL050 – five (2.8%), WPL080 – two (4.7%), and WPLT02 – one (3.2%). The lowest pH value of 5.86 (for WPL050 on 11/25/13) may be of questionable accuracy but could not be eliminated outright based on review of other applicable information.

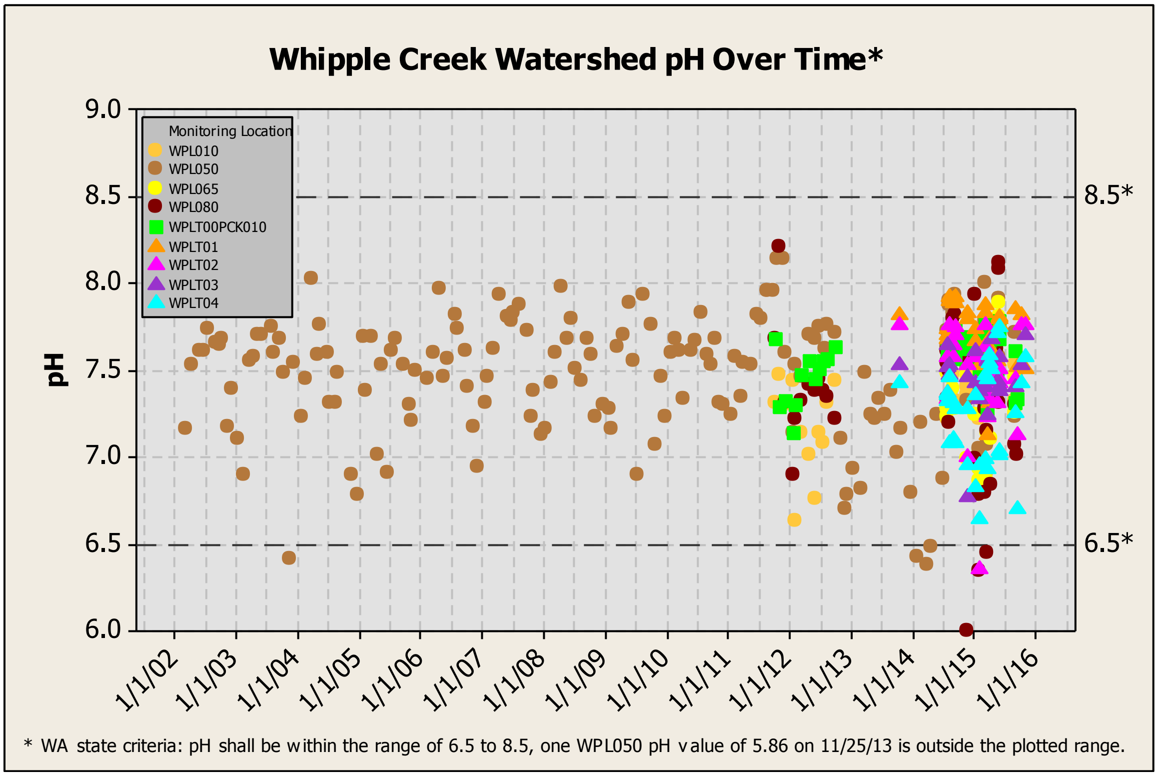

Figure 22 Whipple Creek watershed pH over time and exceedances of state standards

Each of the main stem and tributary group monitoring locations' respective calculated median pH values gradually decrease with distance upstream except for the relatively lower medians for the most downstream main stem (WPL010) and tributary (Packard) stations (Figure 23). However, the only statistical difference in any of the main stem stations' pH medians is that WPL010's is significantly less than WPL050's. Among the tributaries, only WPLT04's median is significantly less than any of the other tributary medians.

There is very little seasonal and flow type influence on median pH values across the Whipple Creek watershed. This is shown by the overlap within the monitoring locations' pairs of internal grey shaded boxes for eight of the nine monitoring locations' paired wet and dry season pH boxplots (Figure 24) and seven of the nine base and storm flow pH boxplots (Figure 25).

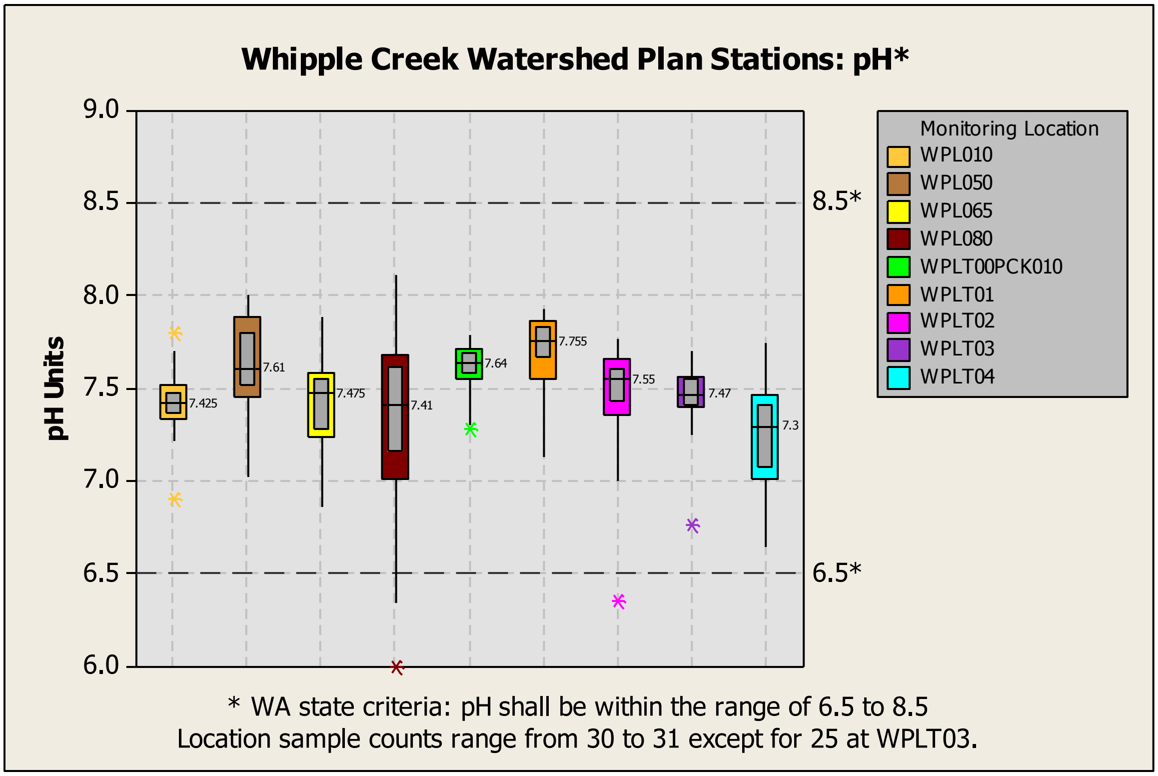

Figure 23 Boxplots of Whipple Creek watershed plan stations' pH results

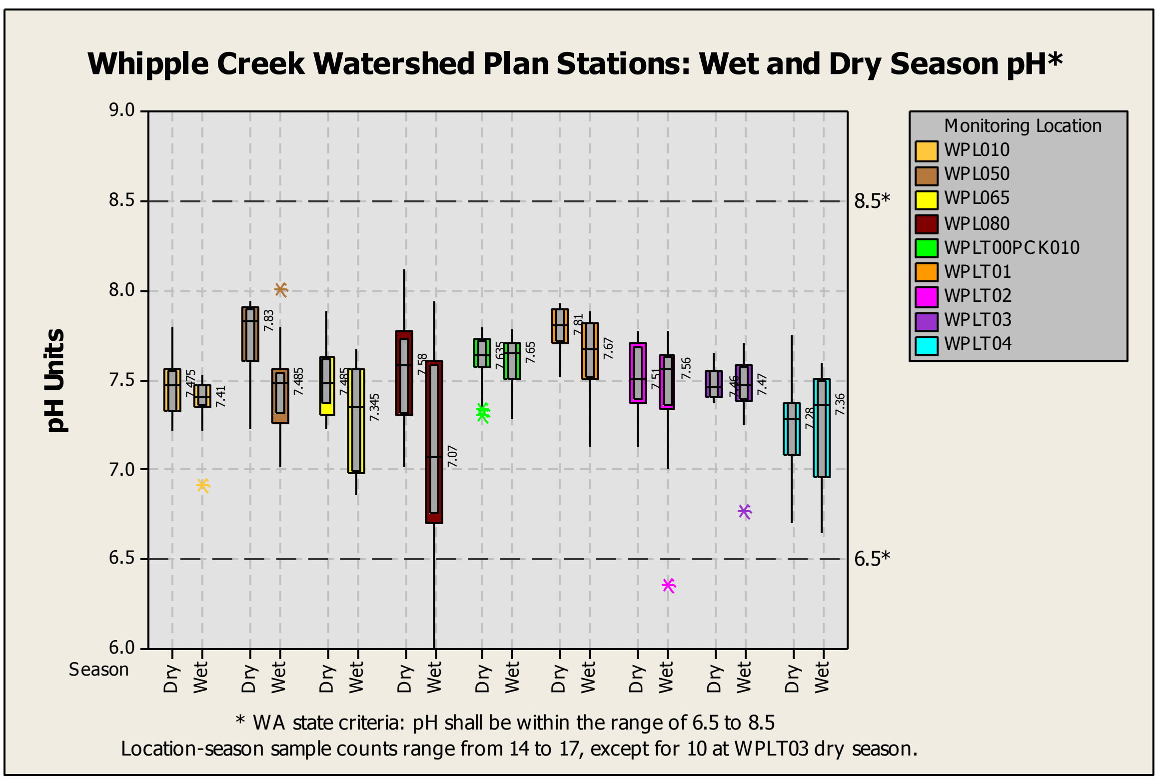

Figure 24 Boxplots of Whipple Creek watershed plan stations' pH results grouped by season

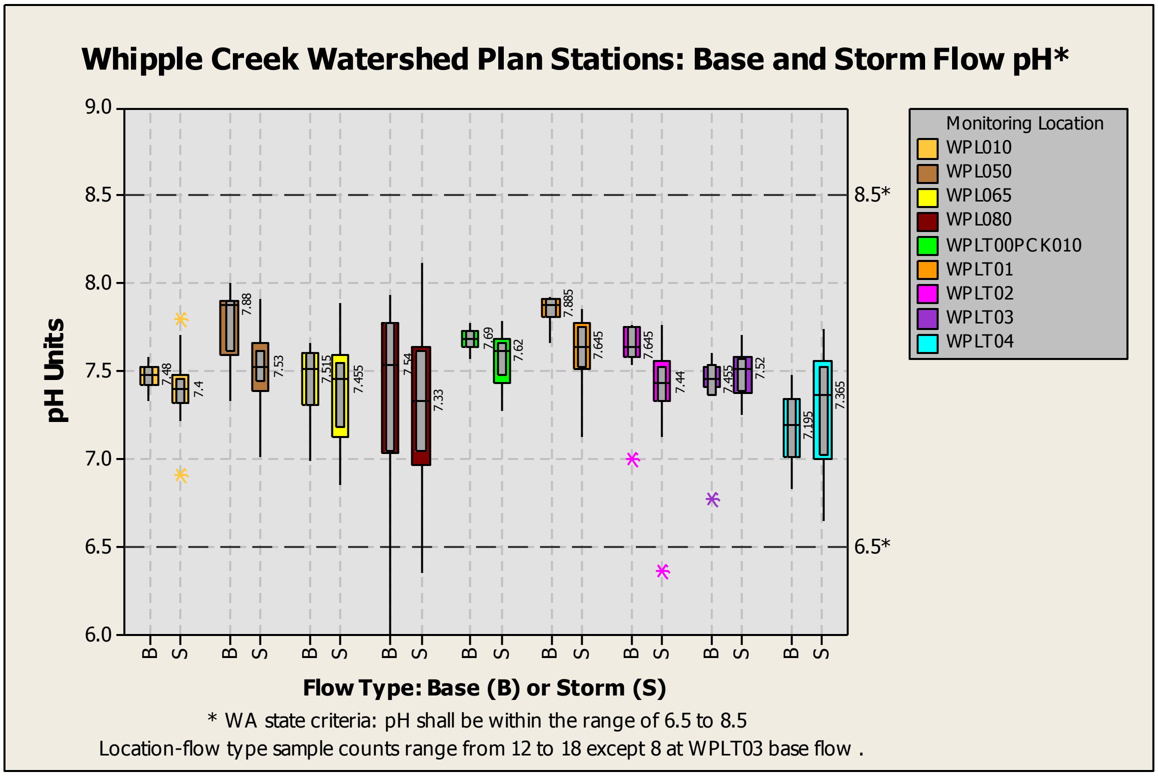

Figure 25 Boxplots of Whipple Creek watershed plan stations' pH results grouped by flow type

Turbidity

High turbidity is a widespread issue throughout the Whipple Creek watershed based on the applicable state criterion of "Turbidity shall not exceed 5 NTU over background when the background is 50 NTU or less" (Ecology, revised 2012, p.13). Figure 26 shows, in fact, the majority (76%) of all Whipple Creek watershed monitoring location turbidity values exceed 7 NTU when an estimated background turbidity level of 2 NTU is used. On an individual monitoring location basis, the percentages of turbidity values greater than 7 NTU range for the main stem stations from 55% (WPL080) to 95% (WPL010) and for tributary stations from 55% (WPLT02) to 98% (Packard Creek). Even the state's alternative criterion of "10% increase in turbidity when the background turbidity is more than 50 NTU" is commonly exceeded.

There are no statistically significant differences in median turbidities across all the Whipple Creek monitoring stations (Figure 27). Similar to pH, there is little seasonal influence on median turbidity values across the Whipple Creek watershed since all of the within monitoring locations' pairs of dry and wet season internal grey boxes overlap (Figure 28). However, just the opposite pattern exists for monitoring location base and storm flow median turbidity values where strong flow type influences are shown by no overlap for all within monitoring location flow type pairs' internal grey boxes (Figure 29). This is likely due to soil erosion during surface runoff and instream channel erosion. WPLT03's base flow turbidity is the most variable across the base flow boxplots. Packard Creek has the highest calculated storm flow median turbidity value but is only significantly higher than the two most upstream main stem storm flow medians for WPL065 and WPL080. The strong influence of flow type on turbidity values is also evident in all the monitoring locations' probability plots where there is an expanding separation with increasing turbidities between the base and storm flow fitted log-normal distributions and plotted points (Figure 30).

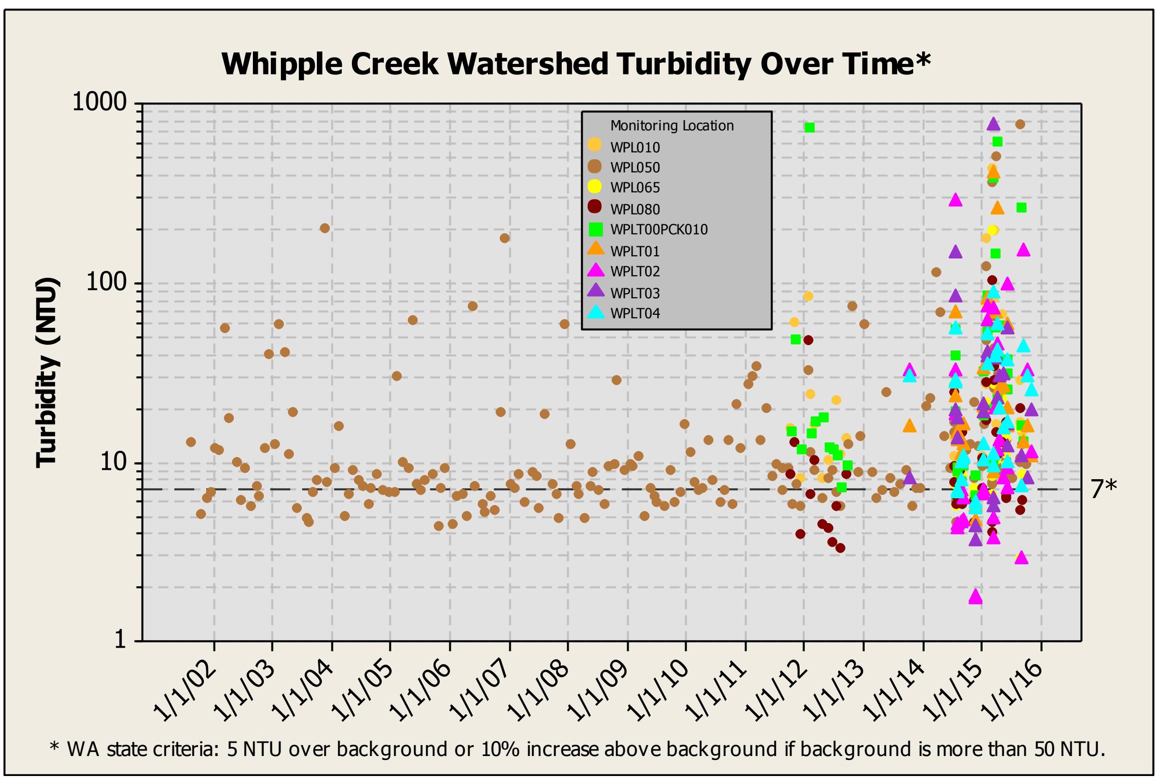

Figure 26 Whipple Creek watershed turbidity over time and exceedances of state standards

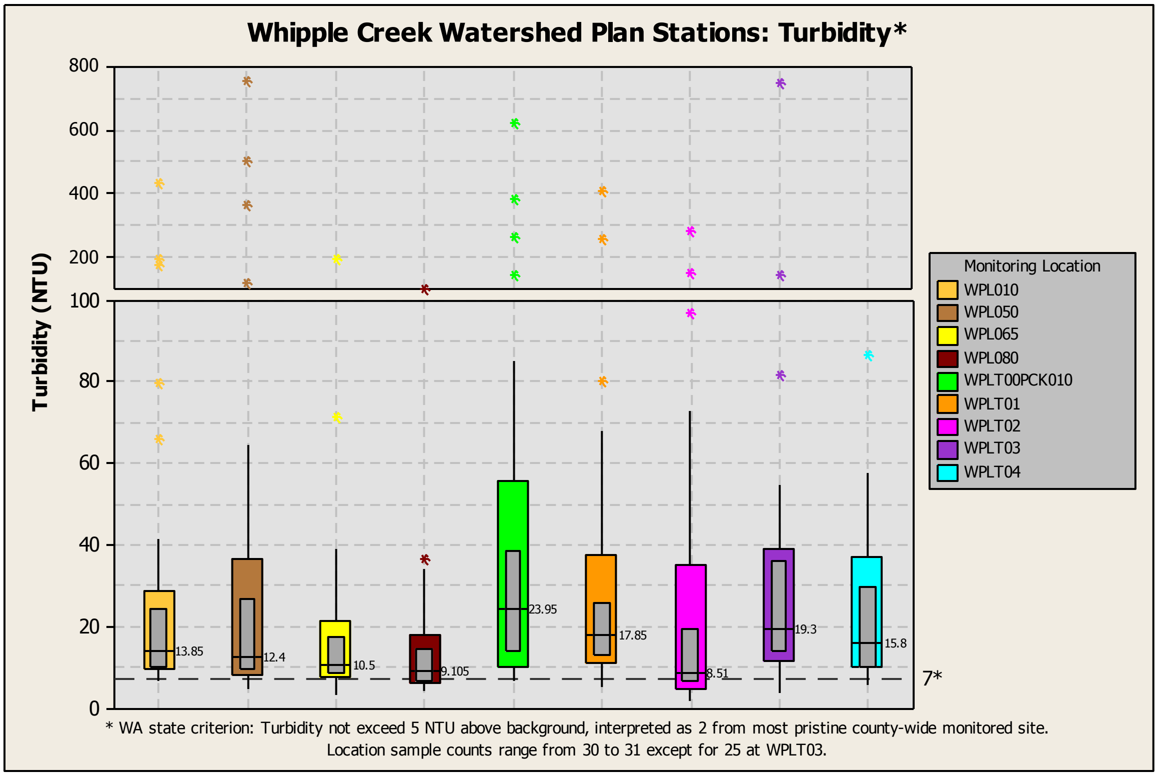

Figure 27 Boxplots of Whipple Creek watershed plan stations' turbidity results

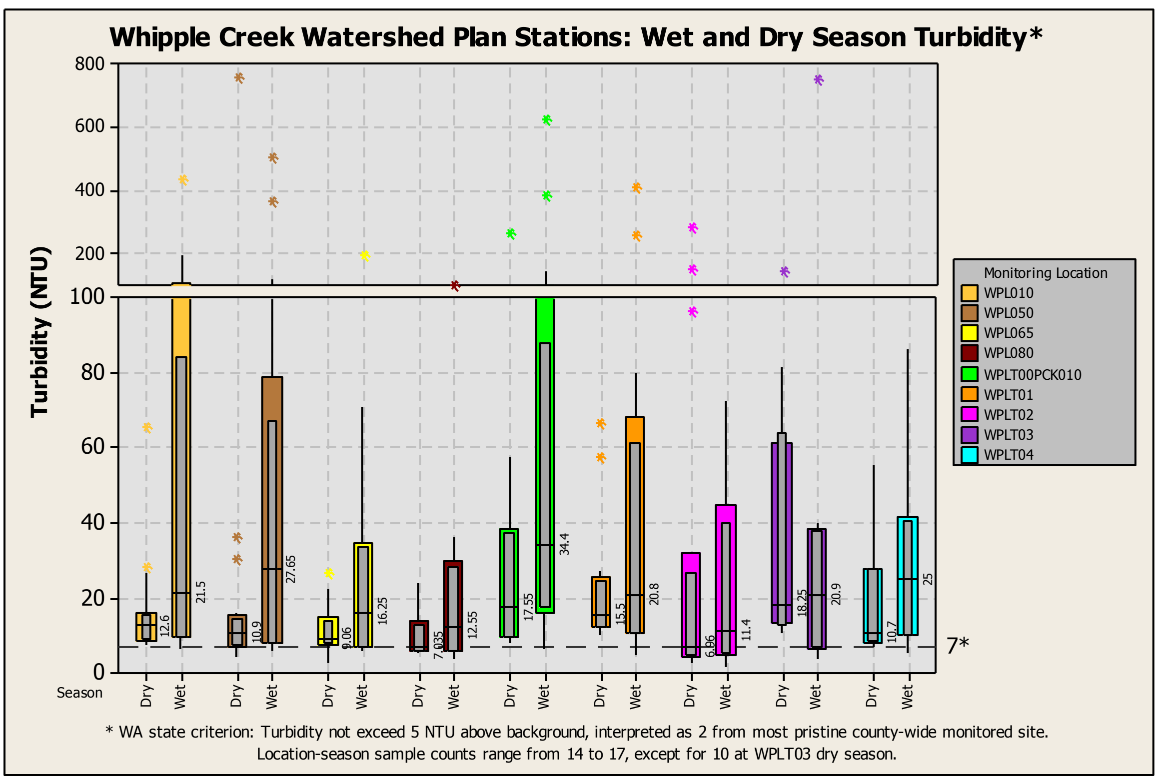

Figure 28 Boxplots of Whipple Creek watershed plan stations' turbidity results grouped by season

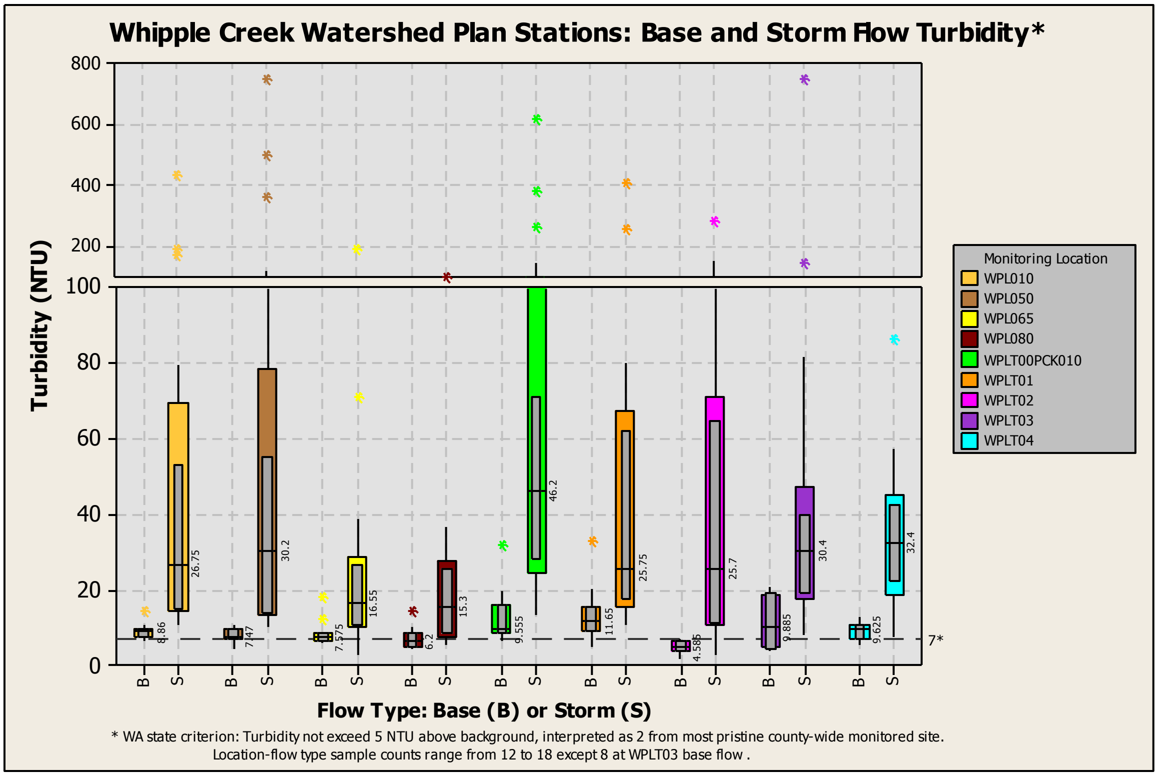

Figure 29 Boxplots of Whipple Creek watershed plan stations' turbidity results grouped by flow type

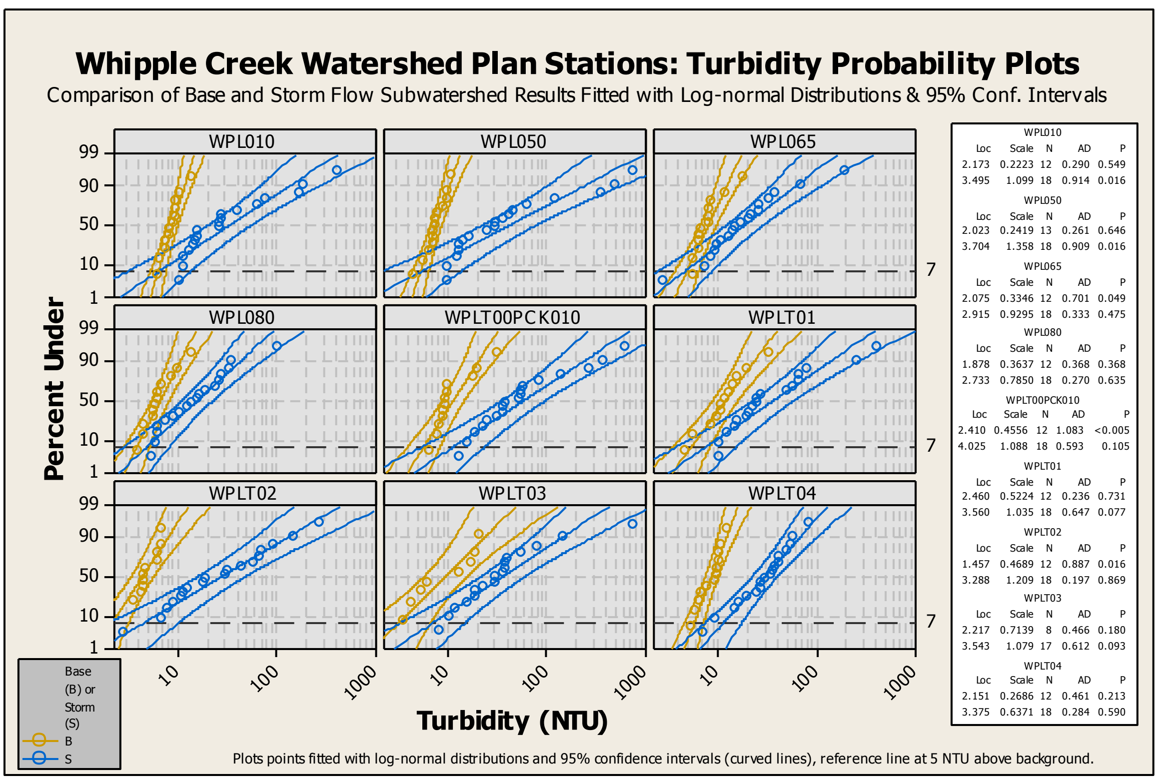

Figure 30 Log-normal probability plots of Whipple Creek watershed plan stations' turbidity results grouped by flow type

Dissolved Oxygen

Based on very limited available data, only a general overview is presented here on the dissolved oxygen conditions for streams in the Whipple Creek watershed. Figure 31 shows existing mid-day dissolved oxygen readings on random dates each month at up to four Whipple Creek watershed stream monitoring locations. Washington State's applicable criterion is included in the plot only for context.

Importantly, Figure 31 does not reflect daily dissolved oxygen minimums since the plotted points represent levels measured close to the middle of the daylight period. Daily dissolved oxygen minimums typically occur near sunrise after over-night respiration depletes oxygen levels and prior to the start of daylight driven photosynthesis potentially increasing dissolved oxygen. Many factors impact dissolved oxygen levels including, among others, biochemical oxygen demand, water temperature impacts on oxygen solubility, localized light intensity, and sunlight duration. The values for many of plotted dissolved oxygen points may be closer to daily peak oxygen levels given the mid-day timing of their measurements. Even with these values likely being closer to daily maximums, six (3%) of all the values (all for WPL050) are below the state 1 day minimum criterion. Given the pattern of many values being within 1 mg/L of the 8 mg/L minimum criterion, it is highly likely that exceedances of the applicable criterion occur especially for the lower main stem watershed locations of WPL010 and WPL050. No further exploratory analyses is performed due to the lack of available diurnal stream dissolved oxygen values and the above noted limitations for interpretation.

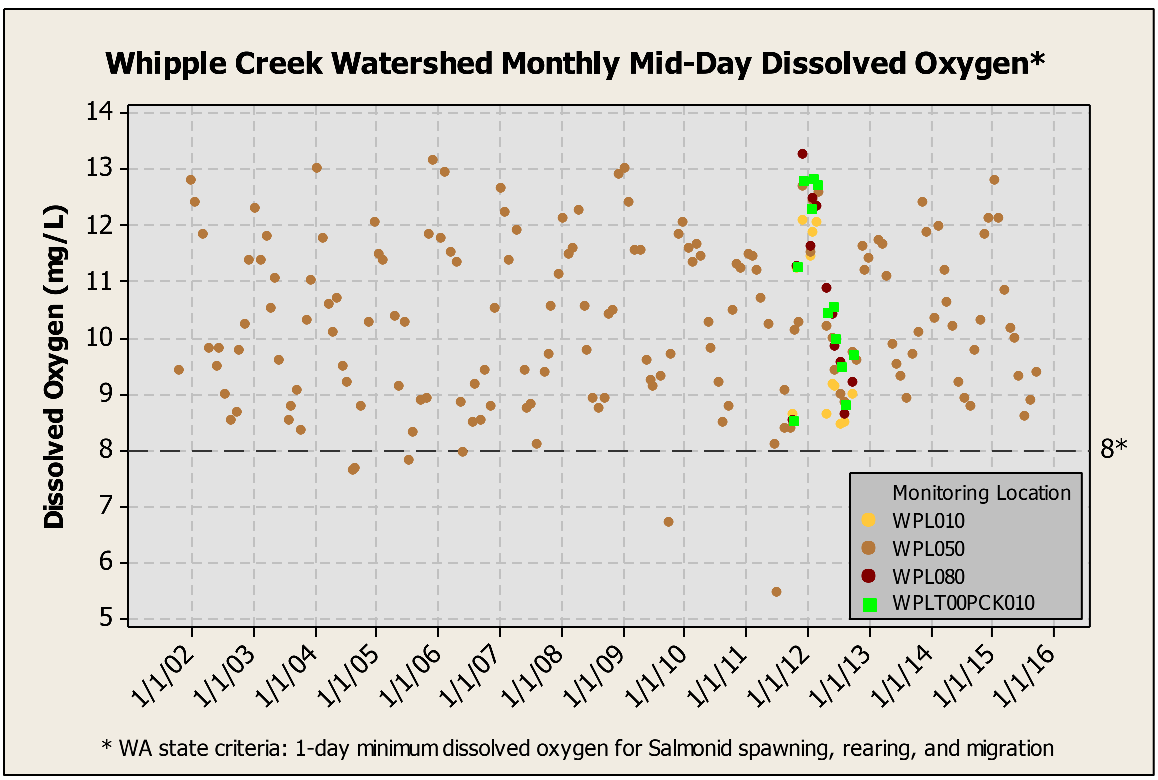

Figure 31 Whipple Creek watershed monthly mid-day dissolved oxygen levels over time relative to state standards criteria

Conclusions

This report and its appendices partially address Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit watershed-scale stormwater planning requirement to assess existing water quality conditions within the county selected Whipple Creek watershed. It summarizes conditions and likely general pollutant sources in the watershed based on recent, reliable Clark County water quality monitoring project data and land cover data. Exploratory data analysis was systematically applied to enhance perspectives and gain insights on potential stormwater impacts to inform watershed planning.

This assessment evaluated the Whipple Creek watershed's water quality condition based on state standards for surface waters, general pollutant sources suggested by data patterns revealed through exploratory data analyses, and water quality versus land cover relationships. The most applicable state designated uses to be protected for the watershed's surface waters are: 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use of primary contact recreation such as swimming.

This assessment concludes that the Whipple Creek watershed's existing water quality is substantially degraded. The latest watershed-wide data indicate four of the seven evaluated standards' parameters were often exceeded throughout much of the watershed; including water temperature, fecal coliform, turbidity, and dissolved oxygen. Only the state standards' criteria for dissolved copper, dissolved zinc, and pH were mostly met throughout much of the monitored watershed. The highest frequency and severity of state standards exceedances generally occurred for warm temperatures on Whipple Creek's middle to lower main stem and developed WPLT04 subwatershed whereas high fecal coliform bacteria and turbidity occurred throughout most of the watershed. Fairly consistent patterns between water quality results for the long-term, lower-mid watershed WPL050 station and more recent results from most watershed- wide stations suggest that some water quality parameters (especially stream temperature, fecal coliform bacteria, turbidity and likely dissolved oxygen) have probably been an ongoing watershed-wide issue for at least several years.

Recommendations

The following are overall recommendations to protect or improve stream water quality during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures (i.e., WPL080) or excessive heating (i.e., WPLT04 and PCK010) as suggested by watershed wide baseline monitoring.
- After confirming the stream length extent of beneficial cooling or excessive heating, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loadings.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.

- Fecal coliforms generally greater sensitivity to flow type than seasonality suggests surface runoff factors play an important role in bacteria levels so both stormwater and rural/agricultural fecal coliform Best Management Practices (BMPs) should be pursued.
- Consistent fecal coliform patterns of high dry season storm flow medians versus very low wet season base flow medians are likely driven by a combination of storm runoff of accumulated nonpoint source bacteria between dry season storms versus more dilution of constant bacteria sources such as failing septic systems during wet season base flows. These patterns are especially pronounced for Packard Creek, WPLT01, and WPLT03 so pursuing both stormwater and rural/agricultural fecal coliform BMPS should be a priority for them.
- Relatively high dry season base flow fecal coliform medians for WPLT01 and WPLT03 suggest ongoing contribution of bacteria from wildlife, livestock, or failing septic systems so these potential sources would need further investigation.
- While the relatively few isolated state standards exceedances during storm flows for dissolved zinc and especially dissolved copper may suggest these metals are currently not substantial problems, their tendencies of increasing concentrations for storm flows over base flows (though usually not significant) and from downstream to more developed upstream subwatersheds suggest the need to address stormwater impacts.
- The Water Quality versus Land Cover Relationships findings of significant direct relationships between development and dissolved metals medians (dissolved zinc appears more sensitive than dissolved copper to development impacts) for the most developed subwatersheds supports likely stormwater impacts and the need to continue addressing especially zinc with stormwater BMPs.
- Given the predominant and consistent relationship patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.
- The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations versus land cover strongly suggest the important role stormwater plays and the need to address this pollutant in the more developed subwatersheds.
- Preliminary linear regression analyses suggest with 95% confidence, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate. These local thresholds could serve to help inform and prioritize stormwater management efforts.
- Currently pH is not an issue that needs to be addressed in the Whipple Creek watershed.
- Wide spread high turbidity issues should be addressed by reducing soil and channel erosion.
- Apparent wide spread low dissolved oxygen issues can be addressed using the same management tools used for temperature.

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Appendices

Appendix 1 Whipple Creek Watershed Stream Temperatures

Whipple Creek Watershed Stream Temperatures

Introduction

This document addresses the important stream temperature component of Clark County's Whipple Creek watershed assessment of existing water quality conditions. The assessment is required for watershed-scale stormwater planning by the NPDES Phase I Municipal Stormwater Permit (WA Dept. of Ecology, 2012).

Under sections 305 (b) and 303(d) of the federal Clean Water Act, Washington State is required to perform regular water quality assessments and list the status of waterbodies in the state (Washington Department of Ecology 303d web page). The state's 303 (d) list includes those waters that are in the polluted water category for which beneficial uses are impaired. Under the state's latest 303 (d) listing from 2014, approximately 1.4 stream miles of the main stem of Whipple Creek downstream from the WPL050 site is listed for high water temperatures under category 5. Under this category, polluted waters require a Total Maximum Daily Load (TMDL) or other water quality improvement project. This impaired water body's category means Ecology has data showing that water quality standards have been violated for one or more pollutants, and there is no TMDL or pollution control plan. The state's listing is based on unpublished 2002 and 2006 through 2010 Clark County stream temperature data from station WPL050.

Recent county watershed-wide monitoring during the summers of 2014 and 2015 demonstrate individual streams' relative susceptibility to heating. Susceptibility is suggested by patterns in the spatial distribution, duration, and magnitude of concurrent average peak summer stream temperatures. Stream locations showing anomalies from the general pattern, such as sites with extended periods of unusually warm or cold average values, often are of the most interest for watershed management activities.

Differences across streams' concurrent average peak summer stream temperatures take into account the net effect of multiple heating factors on individual stream reaches while muting confounding seasonal variability. Important summer heating or cooling factors on stream reaches include: the amount of solar radiation versus shading; heat transfer between stream water and the air or exposed streambed rocks; the combined thermal loading effects from previous warm days / nights and varying flows and temperatures of upstream reaches; and the relative contributions from fairly constant temperature cooler groundwater. Typically, the highest Whipple Creek watershed stream temperatures occur during consecutive very warm summer days that have a cumulative heating impact on streams during very low flows.

The patterns in concurrent maximum stream temperature can help spatially and temporally target permanent long-term through temporary short-term specific watershed management activities to both protect relatively cool thermal refuges and mitigate warmer stream reaches. Future long-term actions could include permanent conservation easements along existing beneficial cooler stream reaches or warmer stream reaches targeted for streamside tree planting. Promoting low impact development and continued implementation of stormwater best management practices improves wet season stormwater infiltration and cooler groundwater contribution to summer base flows. Summer heatwaves could trigger short-term water releases from relatively cooler depths of specifically designed stormwater detention facilities to reduce peak temperatures on targeted heat stressed stream reaches. Recent cellular communication and control technology allows for offsite monitoring and remotely controlled releases from targeted facilities based on weather forecasts. Maximum stream temperature patterns should be taken into account in targeting flexible designs of future stormwater facilities and management actions.

Methods

There are several background items common across all monitoring results presented. Each monitoring station name consists of a three-letter abbreviation of the monitored stream's name followed by three numbers indicating its approximate location as a percentage upstream from the stream mouth. Most of the stream temperature analyses use 7-Day Average Daily Maximum (7-DAD Maximum) water or air temperatures. The 7-DAD Maximum represents a moving average of seven daily maximum temperatures centered on day four. The 7-DAD Maximum water temperatures are compared to Washington's criterion of 17.5 degrees Celsius that is applicable to the Whipple Creek watershed's streams.

Monitoring locations were chosen to provide representative temperature measurements along targeted areas of the Whipple Creek main stem or tributary stream mouths. Stream temperatures were monitored continuously during the summers of 2014 and 2015 at up to ten Whipple Creek watershed sites (Figure 32). These sites included five along the main stem (i.e., WPL010, WPL050, WPL065, WPL080, and WPL090) and five on tributaries (i.e., PCK010, WPLT01, WPLT02, WPLT03, and WPLT04). The tributary site WPLT04 was monitored only during the summer of 2015.

Clark County staff monitored stream temperatures following standard operating procedures (Clark County, 2003, pp. 19-22). In situ stream temperature measurements were automatically logged every hour using programmed Onset HOBO® Water Temp Pro v2 combination temperature sensors / loggers. Within each targeted stream reach, field staff found locations primarily with adequate water depth and secondarily with representative shading. Steel rebars hammered into the streambed secured PVC pipe-protected / shaded Water Temp Pros at a submerged depth near the streambed. Specific locations were flagged using color tape and photographed to make them easier to find later (Figure 33). At least annually, stream temperature data were downloaded in the field from the loggers to an Onset HOBO® Optic USB Base Station data shuttle.

After two summers of data collection, Clark County staff compiled, manipulated, and analyzed temperature data. Following field trips, stream temperature data were uploaded from the data shuttle into Microsoft Excel 2010 ® spreadsheets to store and initially review the data. Air temperature data were compiled from National Weather Service web sites. Stream and air temperature 7-DAD Maximums were also calculated using the spreadsheets. Maps were created using ESRI ARC MAP 10.2.2®. All graphs were created using MINITAB® Release 14 Statistical Software.

The Whipple Creek watershed's large summer stream temperature data set is summarized in a series of graphs and figures that include bar charts, a map, time series plots, cumulative distribution function plots, and scatter plots fitted with Lowess smoother lines. The bar charts show counts of the monitored streams' exceedances of applicable state stream temperature criterion. The map depicts the watershed wide spatial distribution of exceedances grouped by count categories overlaid, for context, on an aerial image of land cover. The time series plots compare two summers of concurrent daily values for multiple sites' average maximum stream temperatures (i.e. 7-DAD Maximums), the lower Whipple Creek's flows at WPL050, and air temperature ranges. The cumulative distribution function plots show how each site's 7-DAD Maximum results change over different percentages of the sorted results. The scatterplots depict the relationship between concurrent 7-DAD Maximum stream versus air temperatures.

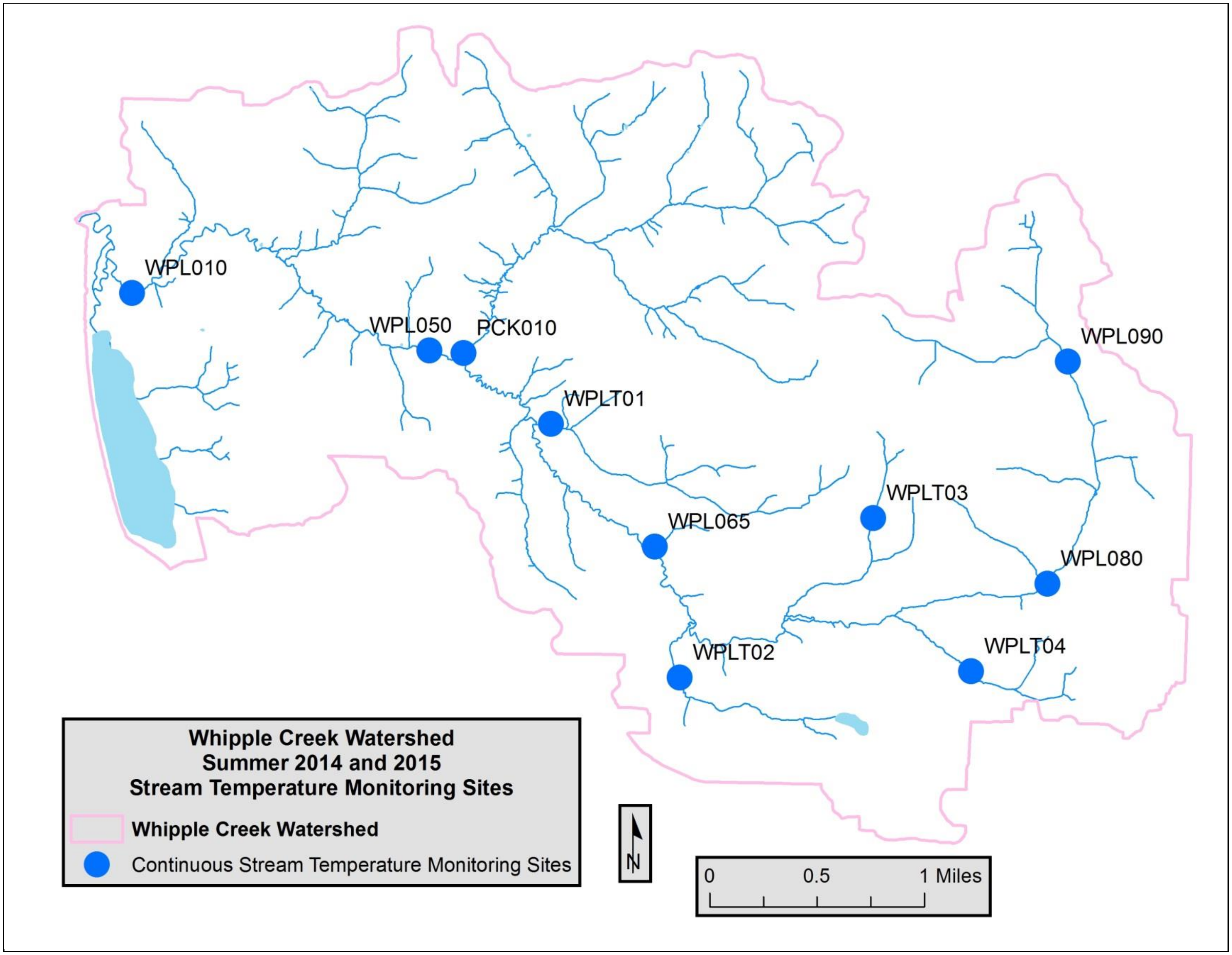

Figure 32 Whipple Creek Watershed stream temperature monitoring sites

Figure 33 Example of temperature logger location with flagging tape as shown for Packard Creek (PCK010)

Results and Discussion

Weather During Watershed Monitoring

Since weather can be a major driver of stream temperatures, the following presents a summary of 2014 and 2015 summer daily temperature and precipitation data from nearby long-term weather stations concurrent with most of the presented stream temperature results. Overall, the summer of 2014 was somewhat warmer over most of the summer months with fairly typical precipitation but the summer of 2015 was unusually hot and dry (National Weather Service Annual Climate Reports for Portland, Oregon, 2016, online at WEATHER.GOV/PORTLAND).

Table 5 summarizes the amount of departure from normal (derived from weather station daily mean temperature or total precipitation values for the 1980-2010 normal comparison period) for the primarily targeted 2014 and 2015 summer months' daily mean air temperature or total precipitation values. The five-month total departures from normal reflect the cumulative impact over each year's entire summer from unusual air temperatures or precipitation. The five-month average departure represents the typical monthly departure over the five summer months. The five-month total departures show that 2015's cumulative temperature departure of +16.6 ° F was 70% more than 2014's already above normal cumulative departure of +9.7 ° F. Conversely, the very dry 2015 five-month cumulative precipitation departure was more than 17 times lower than that of 2014.

More specifically, the National Weather Service Portland Oregon office reports both downtown Portland (monitored since 1874) and the nearby Portland International Airport weather station (i.e., PDX monitored since 1940, with normals based on the latest three decade period 1980-2010) broke several heat and no rainfall period records during the summer of 2015. In 2015, downtown Portland had the most June days having at least 80° F. (18 days) and the second most days in June with no rain (27 days). For the 2015 warm season, PDX set records of 88 days with high temperatures of at least 80 ° F (normal is 54 days) and 29 days with high temperatures of at least 90 ° F (normal is 12 days) while also having two days in July over 100° F. On a monthly basis during 2015 for PDX: June had the warmest daily average highs, lows, and means; most days above 90 ° F (9 days); and most consecutive days with no rain (24 days); July was the second warmest July; August was on the warmer side but was more normal; and September had near normal temperatures and rainfall.

Table 5 PDX weather station mean monthly values departures from normal

	PDX Weather Station Monthly Values Departures From Normal			
	Mean Temperature (° F)		Total Rainfall (inches)	
Month	2014	2015	2014	2015
May	+2.4	+2.8	-0.08	-1.88
June	-0.4	+6.7	+0.63	-1.30
July	+2.1	+4.7	+0.40	-0.08
August	+3.0	+2.9	-0.66	-0.01
September	+2.6	-0.5	-0.49	-0.21
5 Month Total	+9.7	+16.6	-0.20	-3.48
5 Month Avg.	+1.9	+3.3	-0.04	-0.70

2014 and 2015 Summer Stream Temperature Monitoring Results

The two summers of simultaneous continuous stream temperature monitoring across multiple Whipple Creek watershed sites allows more in-depth comparisons of how this important water quality parameter varies throughout the watershed over biologically stressful warm periods. These detailed monitoring results support: analyses at a higher temporal and spatial resolution, greater confidence in capturing a representative range of temperatures, interpretation across a broader context of weather conditions, and accounting for location factors in addressing subwatershed or stream reach susceptibility to heating.

Comparisons of the two consecutive summer stream temperature data sets enhances an evaluation of the relative cumulative impact from or resistance to heating at each site assuming that other location factors have not dramatically changed over this timeframe. Many subwatershed scale and site-specific factors, such as degree of shading and relative groundwater contributions to base flow, can substantially affect an individual stream site's summer temperature regime or pattern. However, usually the cumulative impact of these site-specific location factors on summer stream temperature regimes is relatively consistent year over year unless there is a dramatic landscape change at the monitoring site or upstream of it. Even if landscape changes occurred at one site, it is unlikely to occur similarly across all monitoring sites. Therefore, the magnitude of stream temperature differences at corresponding portions of consecutive summers and the cumulative differences in their summer regimes is more likely the net result of each site's relative resistance to the two summers' heating.

For 2014 and 2015 watershed wide stream temperature context, Figure 34 shows that the lower Whipple Creek main stem (monitored at WPL050) has a long history from at least 2002 through 2015 of exceeding the state's applicable stream temperature criterion multiple times per year during the summer. Historically, most WPL050 exceedances occurred during the months of July and August.

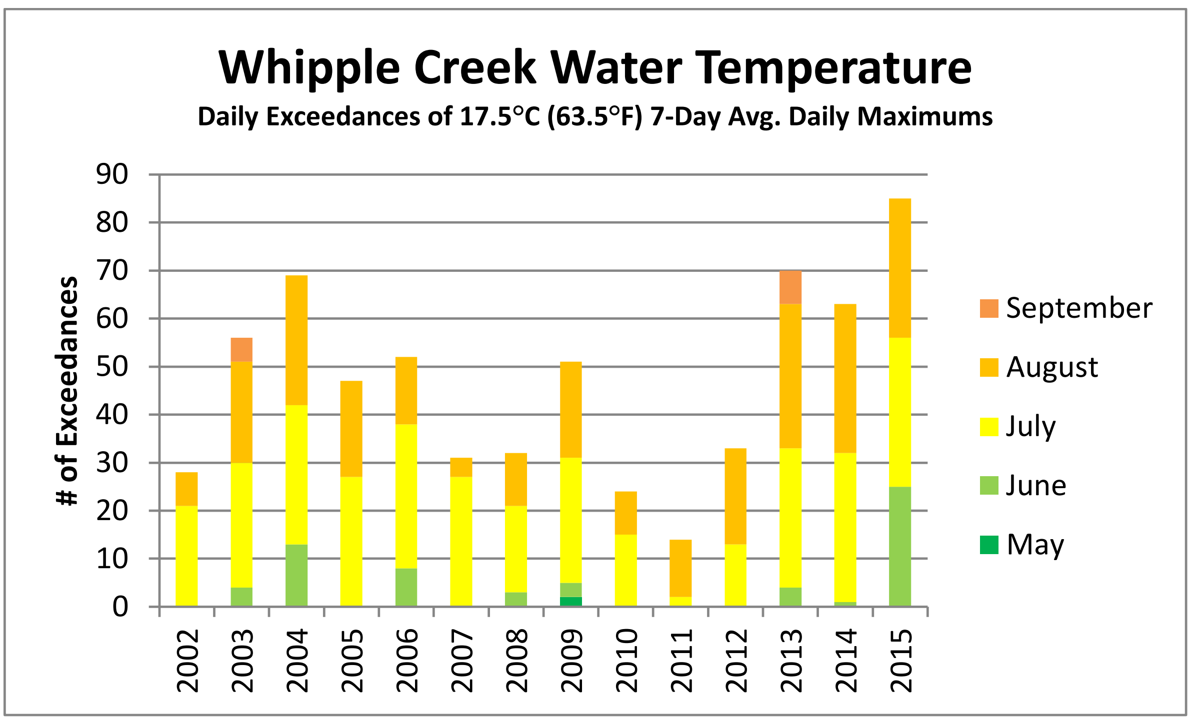

Figure 34 Lower Whipple Creek WPL050 main stem sites long-term exceedances of state temperature criterion

Figure 35 summarizes more recent information from the summers of 2014 and 2015 on the frequency of state criterion temperature exceedances across the Whipple Creek watershed. Similar to the earlier pattern shown for WPL050, most exceedances also occurred during the warmest months of July and August on the lower main stem sites, more urbanized WPLT04 tributary, and the large mid-watershed Packard Creek (PCK010) tributary. The lower main stem's and Packard Creek's relatively low riparian shading and cumulative upstream heat loading impacts probably contribute to their common exceedances. WPL050's summer 2015 count of 85 exceedances was the most recorded (an increase of about 21% over the previous 2013 high count of 70) for this location, likely reflecting the very warm heating early in the summer of 2015.

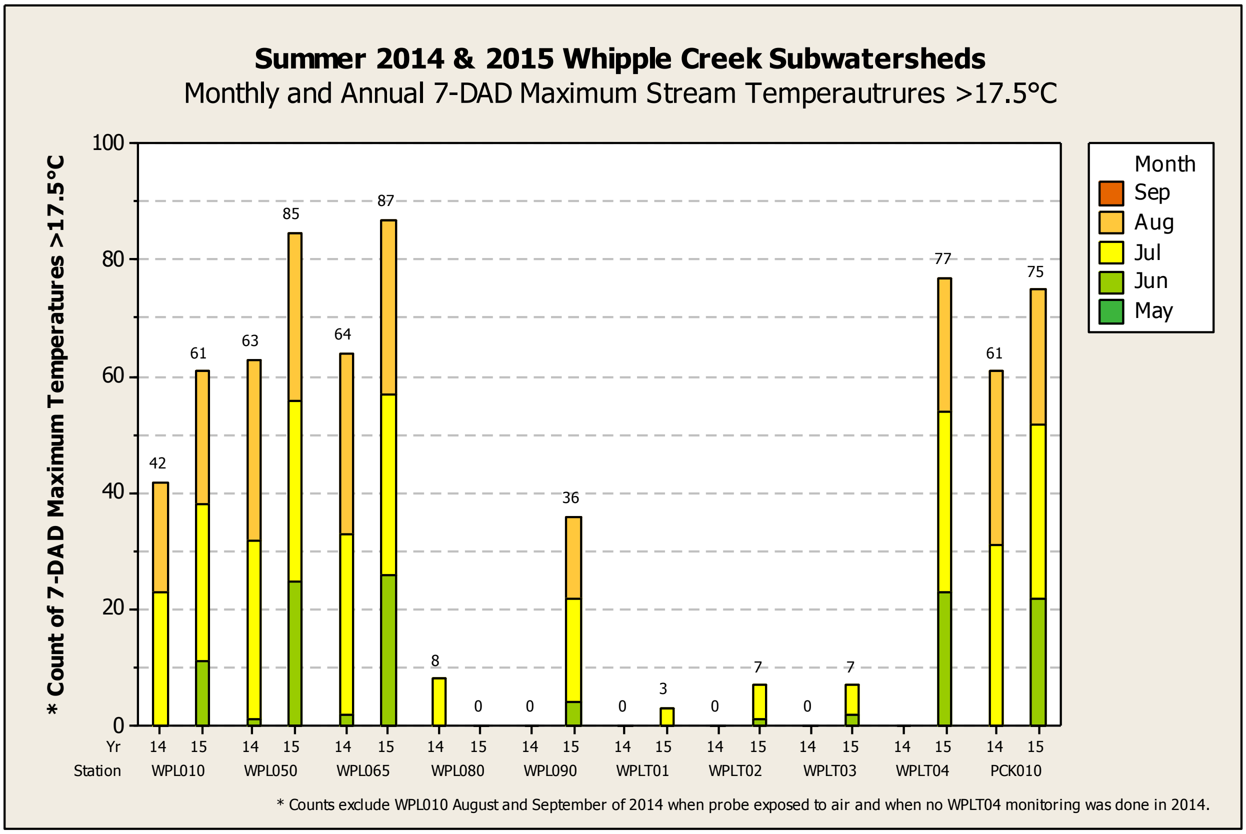

Figure 35 Whipple Creek subwatershed monthly/annual counts of 7-DAD maximum stream temperatures greater than 17.5 °C

Figure 36 shows, for the exceptionally warm summer of 2015, the distribution across the watershed of stream temperature exceedances (grouped into categories of counts) in the context of land cover depicted by an aerial image from 2013. Relatively little riparian shading (as suggested by the lack of or very narrow bands of dark green vegetation areas adjacent to stream reaches) is more pronounced especially along Whipple Creek's lower main stem and above WPLT04. These reaches with reduced riparian cover are consistent with their higher number of exceedances. Conversely, most of monitored tributary stream sites with more forested riparian areas and less urbanized watersheds (i.e., WPLT01 and WPLT03) tend to have fewer exceedances.

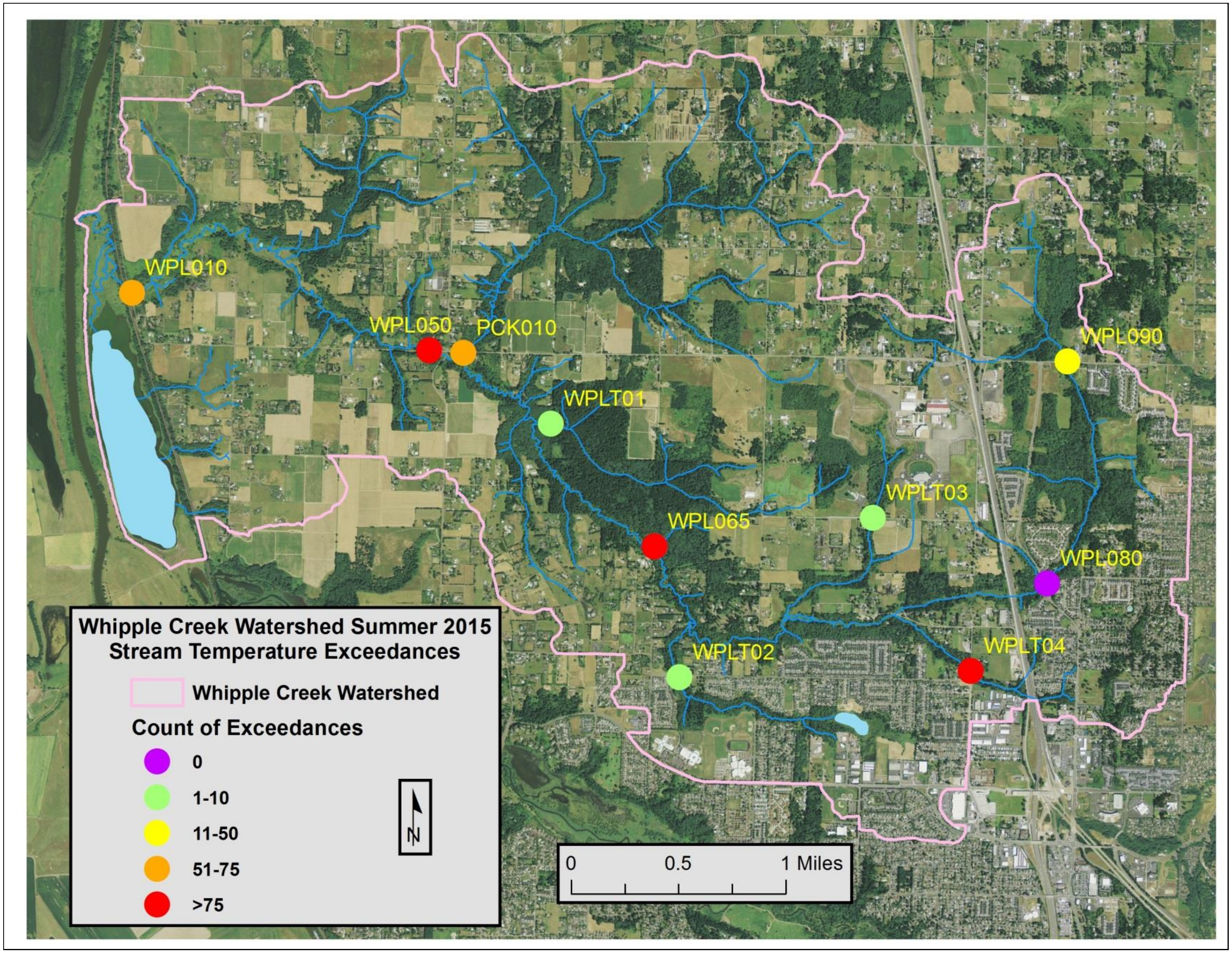

Figure 36 Whipple Creek watershed stream temperature exceedances of state temperature criteria

While recognizing the caveat that relatively small differences in stream temperatures can be driven by site-specific conditions, several general patterns did emerge in the Whipple Creek watershed data. Figure 37 and Figure 38 present, respectively, summer 2014 and 2015 daily time series of: each Whipple Creek monitoring sites' 7-DAD Maximums, the lower main stem Whipple Creek (WPL050) mean daily flows, and a nearby National Weather Service station's (Portland, Oregon Airport – PDX) daily air temperature maximums, minimums, and departures from normal.

Compared to 2014, the summer of 2015's unusually warm air temperatures are shown by the much more common and longer duration of above normal daily mean air temperatures (dashed green lines) shown in the lower graphs of Figure 37 and Figure 38. However, if warming climate trends continue, the 2015 air temperatures may be more typical of future biologically stressful summer conditions.

As would be expected, many of the summer WPL050 flow peaks shown in Figure 37 and Figure 38 approximately coincide with dips in the 7-DAD Maximums. This overall pattern likely reflects the cooling effect on stream temperatures from relatively colder summer storm rainfall, overcast periods' reduced direct solar heating, and possibly more cool groundwater remaining in the streams due to less evapotranspiration. Given the multiple day moving average calculation of the 7-DAD Maximums, corresponding dips in daily mean stream temperatures would have been more substantial. Contrasting with the other monitoring stations, WPL080's unusual stream temperature increases (medium dark blue solid line) immediately around and after the first late summer storms (with large antecedent dry periods) suggest that this site's likely groundwater dominated, previously consistently cool base flow becomes overwhelmed and heated by warmer stormflow.

Interestingly, most of the main stem 7-DAD Maximums (solid color lines) track together fairly tightly until they start to exceed the state criterion of 17.5 degrees Celsius in early July of 2014 and early June 2015. The lower main stem (i.e., WPL010, WPL050, and WPL065) temperatures still generally parallel each other after the start of July 2014 while after early June 2015 they tend to diverge further apart, especially during the warmest months of July and August. Summer 2015's one-month earlier rise above the criterion and larger divergence of temperatures likely are due to the unusually warm and dry summer of 2015 and varying stream heating susceptibility. Reflecting its headwater character similar to tributaries, the uppermost main stem site WPL090 temperatures stay well below those of all the other main stem sites.

During both summers, the upper main stem site WPL080 temperatures track tightly with the other main stem sites until they rise above the criterion, after which WPL080 substantially diverges from them staying mostly below the criterion during both summers. WPL080 temperatures tended to actually decline slightly during the warmest months as the other main stem stations' temperatures tended to increase and bounce around at much warmer temperatures.WPL080's cooler temperatures could reflect an increasing proportion of its flow coming from typically consistent cooler groundwater. Ground water temperatures, as measured from a nearby (Latitude 45 44 06 N, Longitude 122 40 50 W, approximately 1.25 miles west of WPL080) 196 foot deep well on May 16, 1988 suggest ground water temperatures of about 13 degrees Celsius (USGS, Turney, 1990, pp. 54-55). WPL080's decreasing temperatures are unlikely due solely to slight increases in riparian plant cover because shading would likely be fairly constant during the summer.

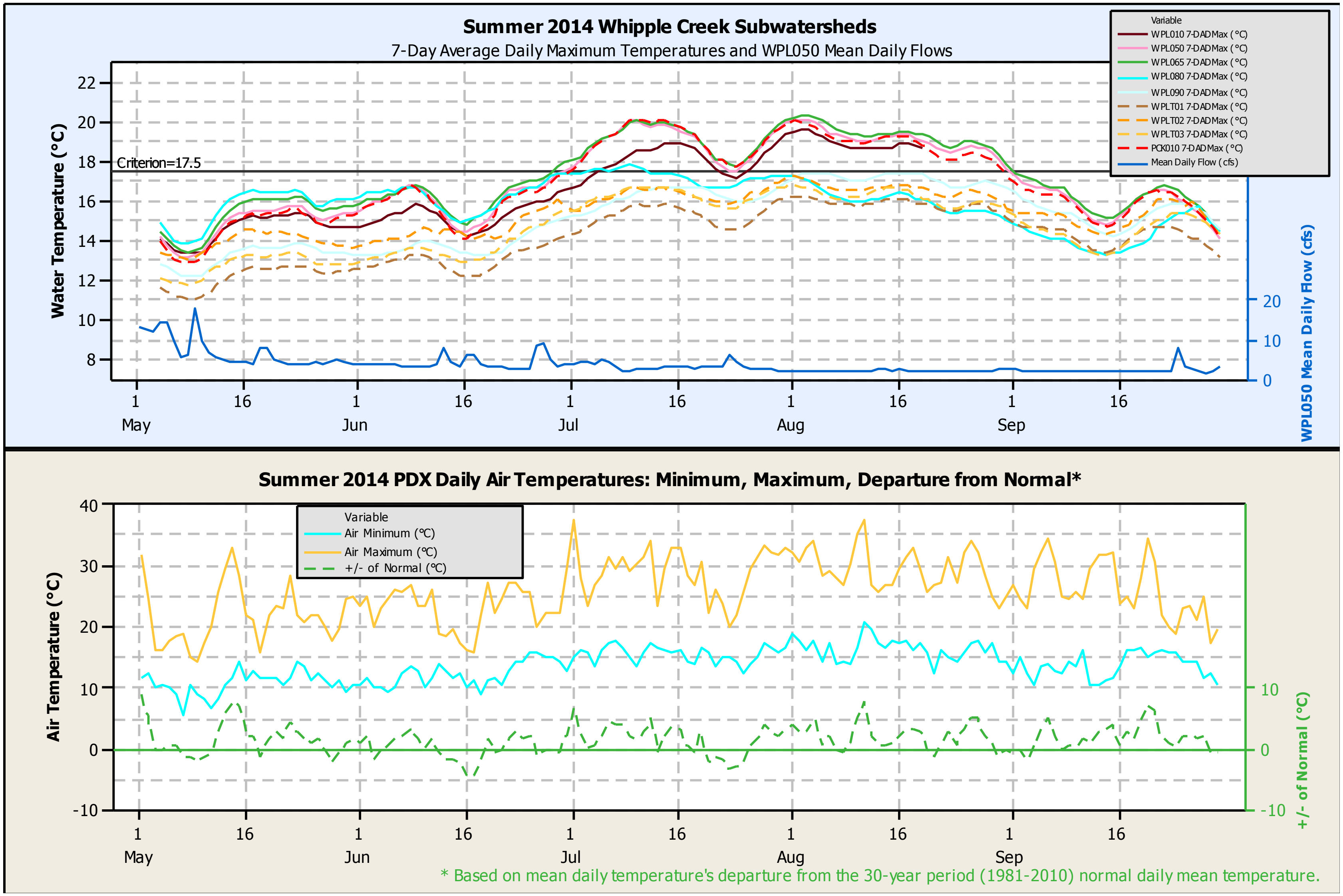

Figure 37 Summer 2014 Whipple Creek Subwatersheds 7-DAD Maximum Water Temperatures and PDX Daily Air Temperatures

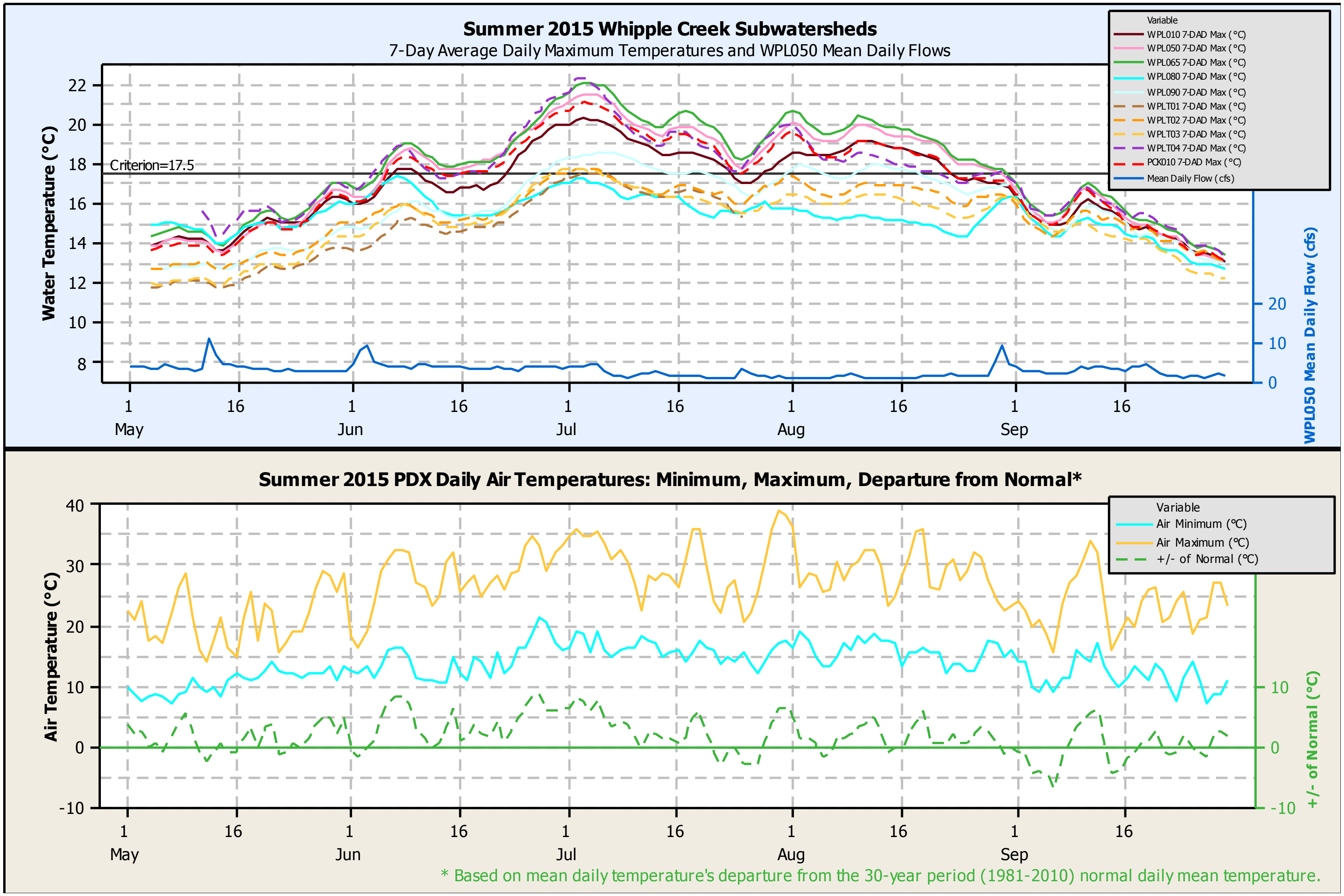

Figure 38 Summer 2015 Whipple Creek Subwatersheds 7-DAD Maximum Water Temperatures and PDX Daily Air Temperatures

Given the likely very similar daily weather influences across the relatively small distances between the monitoring stations (less than five miles), the spatial order and the relative timing pattern for these streams' temperatures hints at their susceptibility to summer heating. Many of the tributary and upper main stem streams represent headwater areas where the majority of summer stream water is probably recently derived from relatively cool groundwater sources. Whereas, the lower main stem waters are more likely to have been exposed to either indirect or direct sunlight for extended periods of time during which heating could be occurring and as well as impacted by already heated flows from upstream. As shown in Figure 37 and Figure 38, many of the higher and larger peaks in the 7-DAD Maximums coincide with the highest air temperature peaks especially those air temperature peaks of longer duration.

Cumulative Distribution Function (CDF) plots of Figure 39 and Figure 40 present a different perspective on the 2014 and 2015 May through September summer maximum stream temperatures. Both figures show increasing separation of the lower main stem 7-DAD maximum temperatures from those of the watershed tributaries and main stem headwater reaches. During both summers, only a very small percentage of some of these tributaries and headwater reaches 7-DAD maximums consistently exceeded the criterion except for WPL090's 25 percent during 2015. However, during both summers, from 40 to 60 percent of the lower main stem sites' 7-DAD maximums exceeded it. Importantly, the summer 2015 CDF slopes of most lower Whipple Creek main stem and WPLT04 and PCK010 tributaries drop consistently for the warmest 7-DAD Maximums above the 90th percentile in Figure 40. This suggests, during very hot summer days and nights (less stream cooling at night), a greater rate of heating susceptibility for these monitored stream reaches. Specifically, during 2015 periods that include the hottest ten percent of 7-DAD Maximum stream temperatures, the intensity of their stream water heating increases compared to the rest of the temperature range.

WPL080's CDF plotted lines in Figure 39 and Figure 40 are very different from all the other monitoring locations, especially during 2015, in that they cross over many of the other stations' plotted lines. These unusual WPL080 temperature patterns appear to be valid based on a review of field notes and similar temperature readings from a secondary thermistor located in a nearby flow gaging station. The pattern of WPL080's relatively large percentage of sustained cooler temperatures (as indicated by similar steeper slopes in both of its summer CDF plots) supports that a substantial part of its summer flows come from relatively cold year-round groundwater associated sources in this stream reach.

The general relationships between concurrent 7-Day Average Daily Maximum Whipple Creek watershed stream and nearby weather station air temperatures are shown in the scatterplots with Lowess smoothing lines in Figure 41, Figure 42, and Figure 43. The 7-DAD maximum air temperatures started about one degree Celsius warmer at the low end and ended about three degrees warmer at the high end during the summer of 2015 compared to the summer of 2014. Over both summers, almost all the monitored streams' 7-DAD maximum temperatures increased at fairly constant rates of about 1 degree Celsius water temperature for every 2.5 to 3 degree rise in 7-DAD maximum air temperature. Importantly, this relatively stable relationship during very different air temperature regime summers, suggest that these streams react similarly over a range of energy inputs but the duration and magnitude of heat impact how warm they get on the hottest days of summer. The previously described unusual WPL080 stream temperatures patterns are very pronounced in these figures.

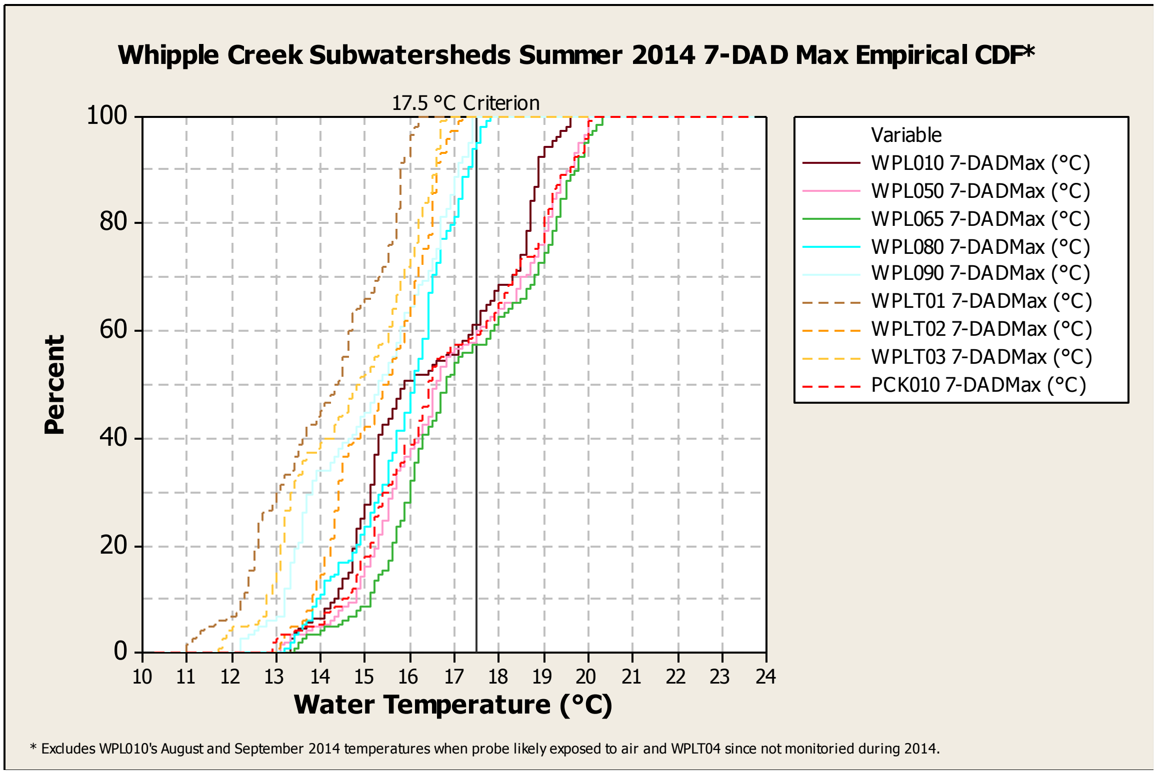

Figure 39 May–Sept. 2014 Whipple Creek subwatersheds 7-DAD Max. water temperatures cumulative distribution function (CDF)

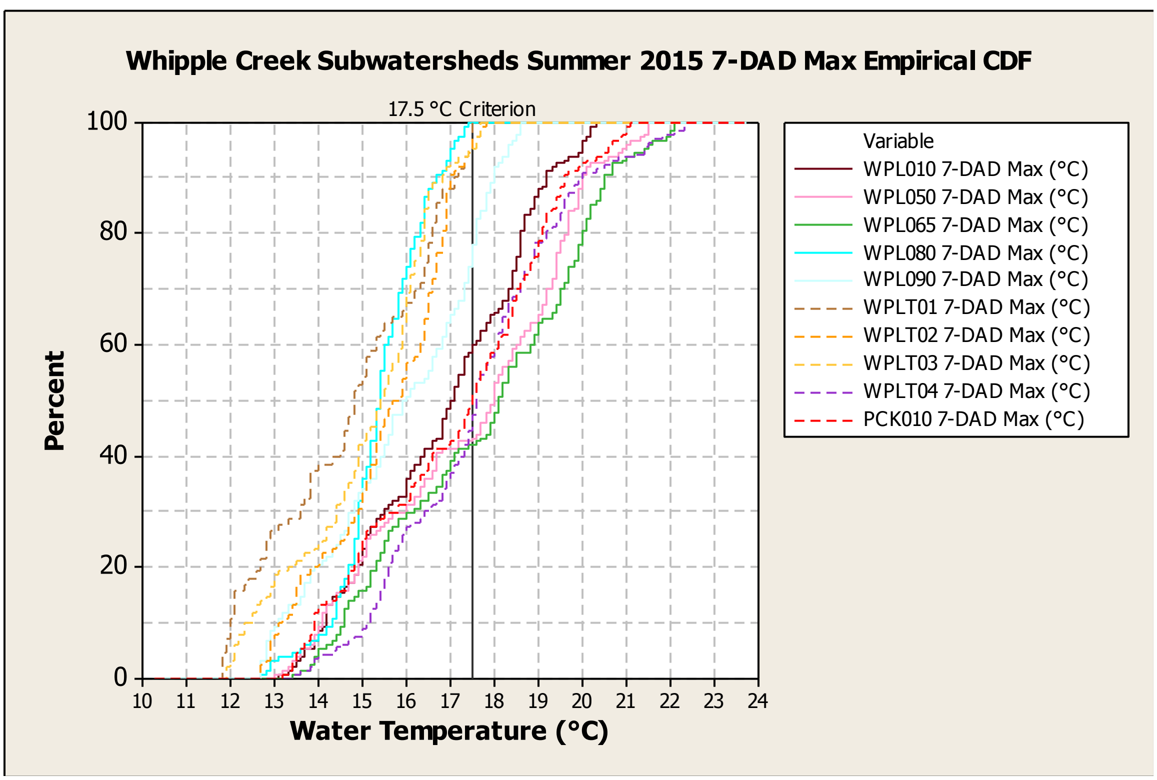

Figure 40 May–Sept. 2015 Whipple Creek subwatersheds 7-DAD Max. water temperatures cumulative distribution function

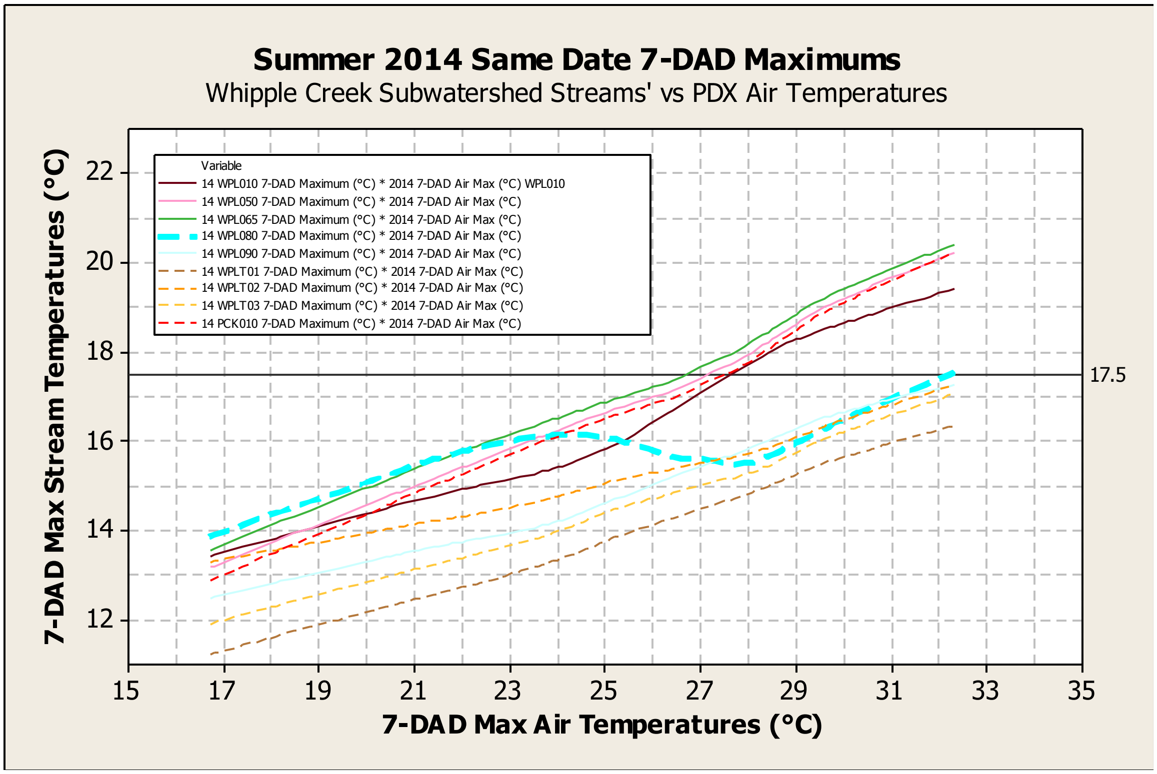

Figure 41 Whipple Creek subwatershed summer 2014 7-DAD maximum stream versus air temperatures

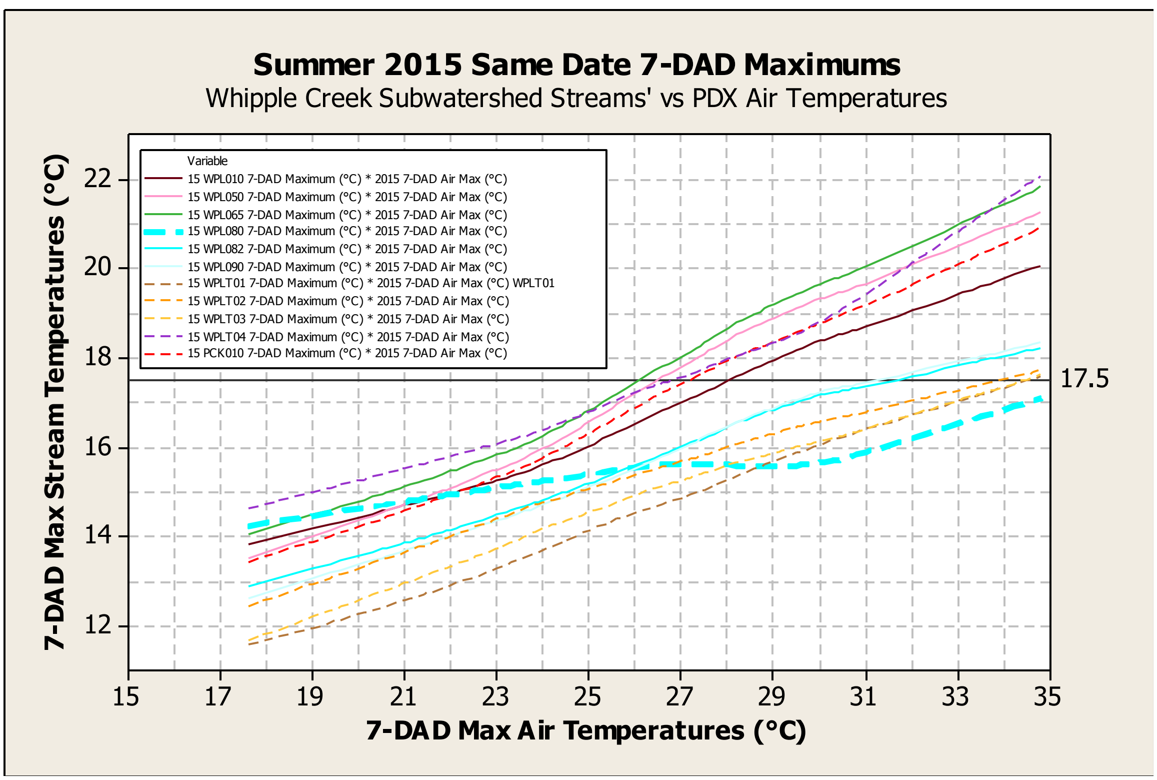

Figure 42 Whipple Creek subwatershed summer 2015 7-DAD maximum stream versus air temperatures

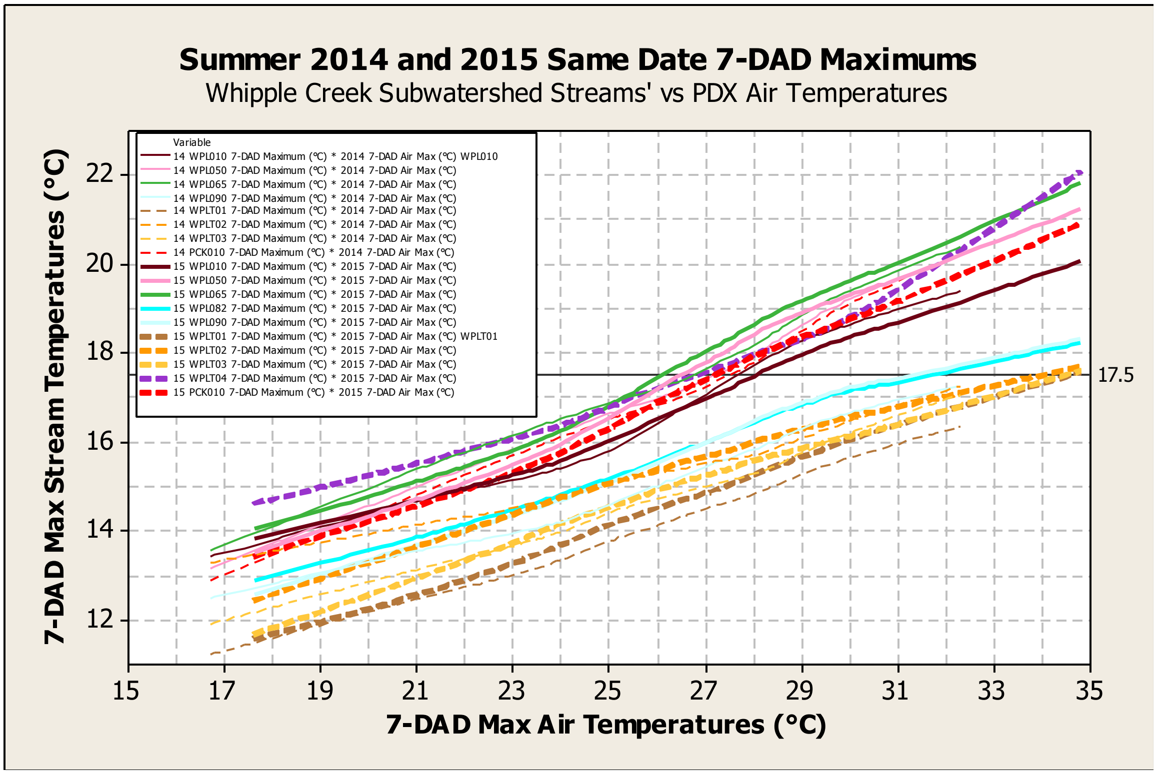

Figure 43 Overlay of Whipple Creek subwatershed summer 2014 and 2015 7-DAD maximum stream versus air temperatures

During the single summer of 2015 for which stream temperature was monitored for WPLT04, it exhibited a steeper slope for 7-DAD maximum stream temperatures above 30 degrees Celsius air temperature. This change in slope suggests that this stream site may heat up even more rapidly than others with increasing maximum air temperatures and may need more temperature mitigation actions implemented.

The 7-DAD Maximum CDF plots and scatterplots of Figure 39 through Figure 43 suggest that other factors beyond just air temperature related factors are contributing to the intensity of stream heating for the hottest 10 percent 7-DAD Maximum stream temperatures of the lower main stem and WPLT04 and PCK010 tributaries in Figure 40. Given only WPLT04 shows a substantial upswing in its 2015 scatter plot slope (above 30 Celsius air temperature in Figure 42 suggesting it may be the most susceptible to direct heating), implies other positive feedback heating factors such as decreased stream flow and upstream cumulative heat loading contribute to non-linear stream heating during the very hottest summer periods.

Relative Flow Context

Flow was continuously monitored during 2015 at three stations within the Whipple Creek watershed: WPL048 – the long-term flow monitoring station (just downstream from water quality monitoring station WPL050) near the intersection of NW179th Street and 41st Avenue; WPL082 – just east of Interstate 5 and adjacent to Union Road; and PCK012 - near the mouth of tributary Packard Creek just upstream from WPL048. The minimum, median, and maximum of mean daily flows (in cubic feet per second) across the five dry season summer months of 2015 (from May 1 through September 30) were, respectively: WPL048 = 0.92, 3.1, 10.9; WPL082 = 0.30, 0.43, 1.21; and PCK012 = 0.05,0.33, 1.62. The median summer measured flows for WPL082 and PCK012 represent approximately 14% and 11%, respectively, of that for WPL048.

Table 6 shows HSPF continuous flow modeled estimated median summer flows for most of the Whipple Creek watershed streams' temperature monitoring stations or nearby flow monitoring stations (excludes WPL090) and calculated summer medians flows for sites with flow monitoring. The averages of the 2014 and 2015 summer HSPF modeled medians (dark shaded table cells) match relatively well with the summer 2015 medians of actual monitored flows (dark shaded table cells) for WPL048, WPL082, and PCK012. The HSPF 2015 summer WPL050 and WPL080 medians were about a third lower and PCK010 was half again higher (light shaded in the table) than those based on actual monitoring. It is understandable that summer low flow estimated and monitored flows show some degree of differences given the inherent uncertainty, low precision, and error in both estimating and measuring very low flows.

From a heat loading perspective, the estimated percent of total Whipple Creek watershed flow (second from last row) of Table 6 gives some idea of the potential beneficial impact from cooler Whipple Creek watershed stream reaches. Combining the relative differences of concurrent peak summer 7-DAD maximum temperatures for the various stream reaches (depicted in Figure 37 and Figure 38) with their estimated percentage of the total watershed flow (Table 6) can give an idea of how much each cooler stream reach is benefiting downstream warmer reaches. More detailed analyses would be needed to calculate individual stream reach heat or cooling impacts. For example, the five degree Celsius difference in the warmest summer 2015 7-DAD maximum temperatures (during early July 2015, WPL065's 22°C versus WPL080's 17°C) needs to be put in the relative dilution context of each reaches' percentage (respectively, 37% and 13%) of the entire watershed's flow. The relative cooling benefits of stream reaches could then be weighted, prioritized, and utilized for watershed planning. Conversely, Packard Creek's (PCK010) generally very warm, large flow contribution (22%) combined with the similarly warm WPL065 and WPL050 waters appear to be somewhat temperature mitigated by the time their waters reach WPL010. An example application of this prioritization approach could be to promote riparian plantings along Packard Creek given its very warm temperatures, relatively large flow contribution, and potentially shade benefited narrow width.

Table 6 Whipple Creek subwatershed summer flow medians: 2014 and 2015 medians of HSPF estimated flows and 2015 monitored flows

Median Summer Values: Monitoring Station's HSPF Estimated and 2015 Monitored Flows – cfs (based on mean daily flow estimates)										
Flow	**Period**	**WPL010**	**WPL050**	**WPL065**	**WPL080**	**WPLT01**	**WPLT02**	**WPLT03**	**WPLT04**	**PCK010**
HSPF	**Summer 2014**	3.5	3.0	1.3	0.46	0.27	0.24	0.05	0.16	0.79
	Summer 2015	2.3	1.9	0.8	0.29	0.17	0.15	0.03	0.11	0.49
	Summer Averages	2.9	2.5	1.1	0.37	0.22	0.20	0.04	0.13	0.64
	% of Total Watershed Flows	100%	86%	37%	13%	8%	7%	1%	5%	22%
Actual	**2015 Monitored Flows**	NA	3.1 (WPL048)	NA	0.43 (WPL082)	NA	NA	NA	NA	0.33 (PCK012)

Future Stream Temperature Monitoring Recommendations

At a minimum for future temperature monitoring, consistently record continuous stream temperatures from May 1 through October 1 across the full range of targeted representative stream monitoring sites. It is important that the timing and magnitude of daily maximums be captured not only during the hottest summer periods but also in the transition period from spring to summer to identify year-to-year differences in both the timing and rate of changes in daily maximums.

By the following spring after the first summer of continuous stream temperature monitoring at baseline stations, perform exploratory data analyses on the 7-DAD Maximum stream temperature data similar to the graphical analyses presented above. These analyses should include: time series plots, cumulative distribution plots, scatter plots of 7-DAD maximum stream temperatures versus 7-DAD maximum air temperatures based on a nearby National Weather Service station, approximate thermal loading summaries, etc. Anomalies in average temperature patterns could suggest sites having either net beneficial cooling factors or excessive heating impacts that may need further investigation.

Early exploratory data analyses will provide adequate time to plan targeted, follow-up field reconnaissance monitoring of peak summer stream temperatures and related factors. This planning should utilize a prioritization process based on continuous temperature patterns, scope specific targeted stream reaches using GIS aerial images to review riparian land cover, and schedule follow-up fieldwork. Schedule fieldwork for monitoring teams based on forecasted windows of extended hot weather during July or August to measure near simultaneously peak stream temperatures across multiple targeted stream reaches.

Both upstream and downstream reaches from continuous baseline stations with excessive or cooler peak summer water temperatures should be targeted for reconnaissance monitoring to approximately identify the spatial extent of heating factors or verify potential beneficial base flow groundwater influences. The follow-up monitoring should be limited to relatively simple, quick spot measurements and direct observations of reach specific factors during short duration fieldwork. The fieldwork duration should last at most a couple of hours at a single stream reach during late afternoon peak temperatures to minimize confounding additional heating during the fieldwork. Preference should be given to monitoring over the full length of a targeted stream reach rather than overly detailed measurements or observations. Splitting the monitoring effort into concurrent work by staff teams would facilitate timely capture of data. Fieldwork monitoring should use handheld meters for spot stream temperature and conductivity measurements (if severe lack of mixing is obvious then measure across applicable stream cross-sections at various depths), visually estimate flow rates, measure air temperatures above the stream, record GPS locations, as well as visually approximate shading and streambed exposure. All data should be recorded on standardized field sheets / field computer input forms.

Whipple Creek Watershed Plan Implementation Recommendations: Stream Temperature

The following are overall recommendations specific to protecting or improving stream temperatures during implementation of the Whipple Creek watershed plan:

- Perform stream temperature confirming follow-up field reconnaissance on stream reaches identified as having potentially beneficial cooler temperatures or excessive heating as suggested by patterns in the 7-DAD maximum temperature analyses of the two-year screening period of watershed-wide baseline continuous stream temperatures.
- For more detailed stream temperature field reconnaissance, target those reaches draining to the WPL080 site for cool waters and the WPLT04 and PCK010 for excessive heating.
- Follow the recommended stream temperature field reconnaissance procedures in the "Future Stream Temperature Monitoring Recommendations" section above during the hottest extended periods of summer.
- After confirming the stream length extent of beneficial cooler waters or excessive heating, as needed, follow up with more detailed field measurements of stream / air temperatures and flow for thermal loading analyses and energy inputs.
- Based on the detailed thermal loading analyses consider reach specific combinations of management options such as: targeted stream side tree planting, property conservation easements along naturally cool stream reach refugees, and using hot weather forecasts to alter the timed release of cool stormwater stored in existing or future flexibly designed stormwater detention facilities to reduce peak stream temperatures. Perform downstream continuous stream temperature monitoring to confirm / calibrate possible temperature mitigation.
- Evaluate potential stream heating impacts from open water, beaver ponds, and low shading above WPL010, WPL050, WPL065, WPLT04, and PCK010.

Whipple Creek Stream Temperature Analyses References

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Washington State Department of Ecology 303d web page, accessed on 7/20/2016 (http://www.ecy.wa.gov/programs/wq/303d/index.html).

Washington State Department of Ecology. August 1, 2012. *Phase I Municipal Stormwater Permit National Pollutant Discharge Elimination System (NPDES) and State Waste Discharge General Permit for discharges from Large and Medium Municipal Separate Storm Sewer Systems*. Olympia, WA 74 p.

Appendix 2 Whipple Creek Watershed Water Quality and Land Cover Relationships

Introduction

Exploratory statistical analyses was performed on the relationships between Whipple Creek subwatersheds' water quality and general land covers to support the stormwater planning assessment of existing local water quality conditions, screen for broad potential pollution sources, and provide insights for water quality modeling. For nonpoint source pollution analysis and watershed management, linear regression is often used to determine the extent to which water quality (dependent variable) is influenced by hydrological or land use factors (independent variables) such as the percentage of land treatment (EPA, 1997, pp. 1-4). Practical applications of these regression results include the ability to predict water quality impacts due to changes in the independent variables.

Stormwater management planning encompasses a wide range of site-specific issues including understanding local problems and pollutant sources that monitoring can help identify (Burton and Pitt, 2002, p. 10). Discharge from storm drainage systems includes warm weather stormwater, snowmelt, base flows, and inappropriate discharges to the storm drainage that all may be important to consider when evaluating alternative stormwater management options. Given that stormwater management's main purpose is to reduce adverse impacts on receiving water beneficial uses, it is important in any stormwater runoff study to assess the detrimental effects that runoff is actually having on a receiving water.

Nationally, accumulated data on stormwater quality indicate that concentrations and loads vary widely, but several important factors are involved including land use (Minton, 2002, p.13, 17-18). Minton summarizes the influence of land use factors as:

> "Researchers have differed as to the significance of different land uses. There appears to be a general agreement that loading differs between land uses, whereas there is a lack of agreement as to whether concentration differs. At a minimum, land use can be divided into two broad groups with respect to concentration differences: open space and low-density residential and all other urban land uses. The data from the most comprehensive study ever undertaken suggest no significant difference in event mean concentrations between land use types with the exception of open space. It was concluded that land use type is virtually useless as a predictor of concentration. The data indicate that variation is greater within, rather than between, residential, commercial, industrial, and mixed-use sites."

Given this limited applicability of ***event mean concentrations and land use*** data as well as sparse local continuous flow data for estimating loads, this Whipple Creek study performed only exploratory statistical analyses of ***grab sample water quality*** relationships with ***land cover*** (note not specific ***land use*** types). It is acknowledged that multiple interacting factors determine the quality of stormwater and even more so that of receiving waterbodies where additional in-stream processes occur. The underlying complex interactions of mechanistic factors impacting subwatershed stream water quality (such as the magnitude and timing of individual storm event flows, surface runoff impacts, evapotranspiration, in-stream processes, etc.) are addressed through this watershed planning project's implementation of HSPF continuous flow water quality modeling. Importantly, both this statistical analyses and the HSPF model utilize the same watershed wide land cover data while the model calibration focuses on water quality data from the long running lower-watershed monitoring station (WPL050) also included in this study.

Therefore, only Whipple Creek subwatersheds' portions of general land covers falling within open space or development categories are related to their respective stream's median water quality values using simple linear regression. This study's goals are to see if land cover helps explain variation in grab sample monitored water quality and gain insights on potential general pollution sources and possible anomalies.

Methods

Stream water quality monitoring occurred at nine monitoring stations (Figure 44) located at the mouth of four main channel or main stem (labeled from downstream to upstream as WPL010, WPL050, WPL065, and WPL080) and five tributary drainages (from most downstream to upstream depicted as PCK010 [Packard Creek], WPLT01, WPLT02, WPLT03, and WPLT04). From at least July 2014 through May 2015, Clark County staff followed standard operating procedures in taking stream field measurements and collecting grab samples (Clark County, 2014). All water samples were analyzed at a nearby Washington State Department of Ecology accredited laboratory to help meet analytical hold times.

Water quality is represented by six parameters' median values to assign dependent variable values for relationships based on flow type (Table 7). Medians are used for central tendency because they are more resistant to outliers. Each median is based on at least 11 monitoring events per station (grouped by flow type) except for one tributary station with slightly fewer events (WPLT03). Typically, monitoring events at each station included at least 12 random base flow and 11 storm events for most parameters except for 8 base flow events for WPLT03. Additionally, water quality monitoring was performed monthly during unclassified flow events at the Packard Creek tributary and most main stem stations in water year 2012 with substantially more similar monitoring occurring at WPL050 going back to water year 2002 (yielding between 31 and 165 monthly monitored parameter results as part of a long-term monitoring project).

Land cover is represented by the relative portion of five general land cover types upstream from each monitoring location (based on previously mapped catchments). The catchments and land cover types are the same used for input to the Whipple Creek Watershed Plan's HSPF model. Most land cover data was originally derived using methods developed in the Puget Sound area (Hill and Bidwell, 2003) and applied to 2000 Landsat satellite imagery. Clark County staff then aggregated some closely related land cover classes and updated acreages using a Geographic Information System (ESRI, 2014, ArcGIS 10.2.2 for Desktop) and interpretation of 2014 aerial photographs as well more recent subdivision documentation. Final land cover types included forest, pasture, grass, impervious surfaces, and water. During the update, open areas around development were interpreted as falling within the grassy (urban lawn-like) land cover.

Data management and analyses utilized standardized procedures (Clark County, 2014) and existing software systems operated by Clark County staff. Data management included data review, finalization, and upload into the County's water quality database (WQDB based on Microsoft Access) and data manipulation using spreadsheets (Microsoft Excel). Statistical analyses were performed using MiniTab Statistical Software (Minitab Inc., Version 14, 2003). Analyses focused primarily on a straightforward screening of relationships between individual pairs of variables representing available Whipple Creek subwatershed water quality data (using medians) versus proportion of each subwatershed in a particular general land cover category. Relationships were evaluated via simple linear regression (Helsel and Hirsch, 2000, pp. 221 - 222) where one explanatory or independent variable (land cover) is used in statistical models. More complex multiple explanatory variable / multivariate regression statistical models were not evaluated in this basic screening study.

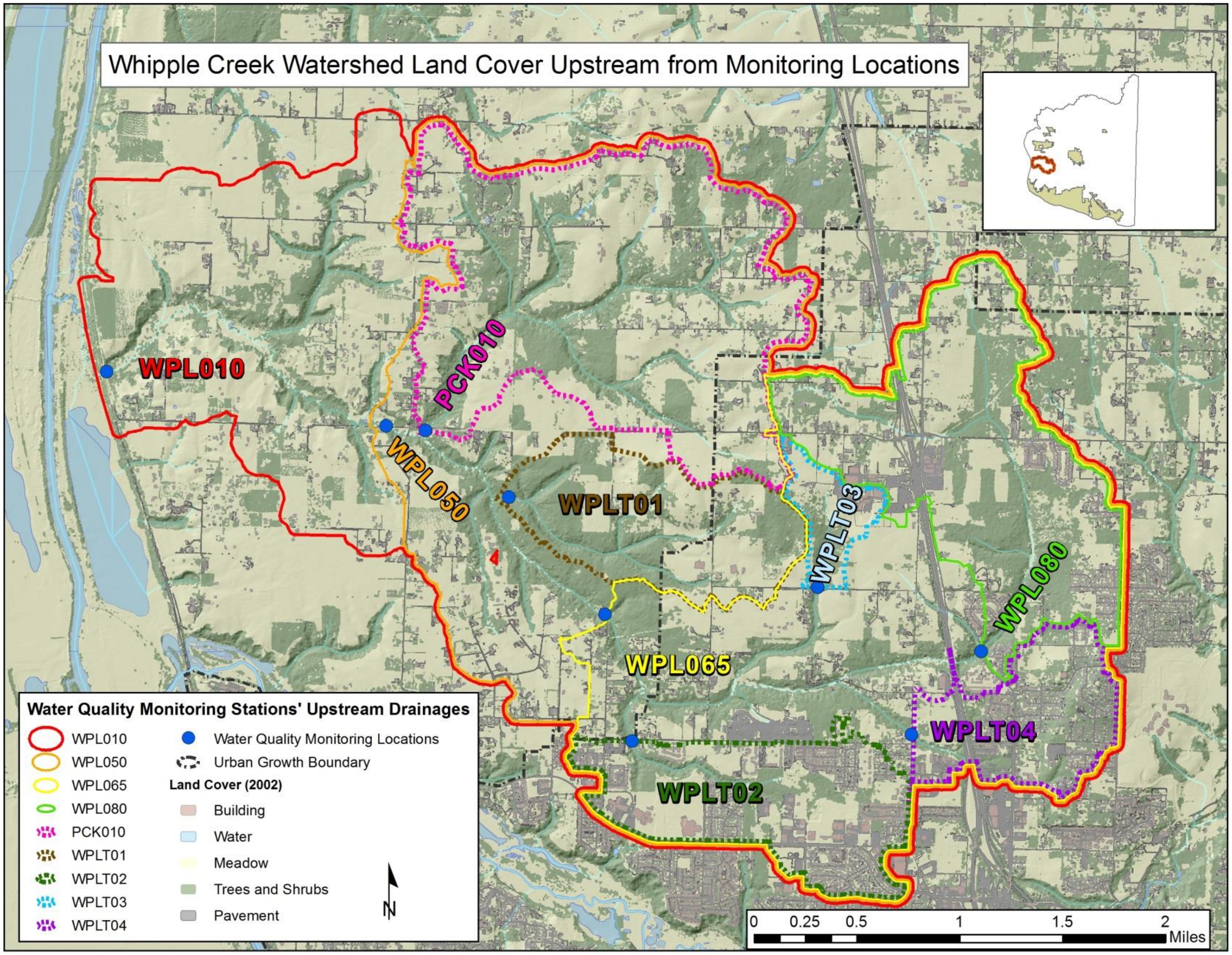

Figure 44 Whipple Creek Subwatersheds Water Quality Monitoring Stations and General Land Covers

Table 7 Whipple Creek main stem and tributary subwatershed median water quality values and sample sizes by flow type

Whipple Creek Main Stem Subwatersheds Water Quality Medians															
Station	WPL010 Medians				WPL050 Medians				WPL065 Medians			WPL080 Medians			
Monitoring Period	WY12 Monthly, July'14-May '15				WY'02-'15 Monthly, July '14 - May '15				July '14 - May '15			WY12 Monthly, July'14-May '15			
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Unclassif.	Overall
Sample Size *	12	12	12	36	12	12	*	*	12	12	24	12	12	12	36
Parameter (units)															
Water Temperature (degrees C)	11	10.9	12.6	11.3	11	10.6	11.2 (164)	11.1 (188)	11.4	10.7	10.7	10.8	11	13.4	11.3
Tubidity (NTU)	8.9	35.3	14.5	13.5	7.6	39.6	8.2 (165)	8.6 (189)	7.6	24.5	11.1	6.2	20.7	6	8.4
pH	7.48	7.37	7.22	7.4	7.89	7.5	7.53 (158)	7.53 (182)	7.52	7.26	7.46	7.54	7.41	7.37	7.38
Dissolved Copper (ug/L)	0.71	1.32	NA	0.87 (24)	0.76	1.28	1.14 (31)	1.13 (55)	0.9	1.86	1.17	0.96	1.82	NA	1.22 (24)
Dissolved Zinc (ug/L)	1.5	0.9	NA	1.0 (24)	1	1	1.1 (34)	1.0 (58)	1.5	2.3	1.8	1.4	3.1	NA	2.3 (24)
Fecal Coliform (CFU/100 mL)	340	800 (11)	335	420 (35)	262	1865 (10)	275 (136)	315 (158)	203	390 (8)	265 (20)	57	280 (11)	76	100 (35)

Whipple Creek Tributary Subwatersheds Water Quality Medians																
Station	PCK010 Medians				WPLT01 Medians			WPLT02 Medians			WPLT03 Medians			WPLT04 Medians		
Monitoring Period	WY12 Monthly, July'14-May '15				July '14 - May '15			July '14 - May '15			July '14 - May '15			July '14 - May '15		
Flow Type	Base	Storm	Unclassif.	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall	Base	Storm	Overall
Sample Size *	12	12	12	36	12	11	23	12	11	23	8	11	19	12	11	23
Parameter (units)																
Water Temperature (degrees C)	10.8	10.5	12.3	11.1	10.5	10.7	10.7	11.1	11.1	11.1	6.1	10.5	9.8	11.5	11.5	11.5
Tubidity (NTU)	9.6	56	13.2	17.3	11.7	50.9	20.8	4.6	32	6.9	9.9	38.6	22.6	9.6	37.9	12.5
pH	7.69	7.6	7.5	7.6	7.89	7.56	7.74	7.65	7.37	7.57	7.46	7.52	7.47	7.2	7.37	7.32
Dissolved Copper (ug/L)	0.82	1.69	NA	1.32 (24)	0.67	1.25	0.8	0.74	1.73	1.25	1.15	1.93	1.85	0.66	2.44	0.88
Dissolved Zinc (ug/L)	0.8	1	NA	1.0 (24)	0.5	0.7	0.6	1.7	6	2.2	2.4	3.3	2.9	2.1	11.2	3.1
Fecal Coliform (CFU/100 mL)	395	3350	276	650	485	1040	760	780	665 (10)	695 (22)	31	660	280	71	740 (9)	250 (21)

* Common sample size across all station parameters unless noted otherwise in parentheses after median value.

Results and Discussion - Water Quality versus Land Cover Relationships

Land Covers

It is assumed that the main stem monitoring stations' water quality reflects that of nested upstream tributary and / or other main stem subwatersheds' land cover (Table 8). Forest, pasture, and grass dominate the main stem subwatersheds' land cover which, combined, total at least 80 %t of each drainage (Figure 45). WPL080 and even more so WPL065 have relatively more grass and impervious surface but less pasture and forest than WPL010 and WPL050. WPL065's higher levels of grass and impervious land covers is impacted by the higher percentages of these same land covers contributed from its nested main stem WPL080 and tributary WPLT02, WPLT03, and WPLT04 subwatersheds (Table 8 and Figure 46).

Table 8 Whipple Creek water quality monitoring stations upstream drainage areas

Whipple Creek Monitored Subwatersheds Nested Hierarchy, Land Cover Acreages and Relative Percentages												
Drainages		Forest		Pasture		Grass		Impervious		Water		Total
Nested Main Stem	Tributaries	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
	WPLT01	228	44	199	38	79	15	16	3	0	0	522
	WPLT02	83	15	61	11	263	47	152	27	3	0	561
	WPLT03	19	16	21	18	41	34	39	32	0	0	119
	WPLT04	64	18	31	9	183	51	83	23	1	0	363
	WPL080*	323	32	223	22	299	30	158	16	0	0	1003
WPL065 Total		743	26	554	19	1031	35	572	20	5	0	2906
	PCK010	535	35	674	44	250	16	59	4	0	0	1517
WPL050 Total		1747	31	1745	31	1459	26	672	12	5	0	5628
WPL010 Total		2136	30	2434	34	1749	25	746	11	7	0	7071

*WPL080 is the main stem headwater tributary

Screening of Overall Flow Type Water Quality versus Land Cover Relationships

A scatterplot matrix allows assessing many pairs of variable relationships at once (MiniTab Release 14 Statistical Software Help). Figure 47 allows a visual assessment of water quality versus land cover variable pairs and the relationship shapes for the overall flow type data. The scatterplots' dashed-red lowess ("LOcally-Weighted Scatterplot Smoother") lines allow exploration of the relationship between two variables without fitting a specific model such as a regression line (MiniTab Release 14 Statistical Software Help). However, the scatterplots are also fitted with linear regressions for comparisons with this basic statistical model. Throughout Figure 47, the overall shape of many of the lowess lines suggests that linear regression often is a reasonable statistical model to use. However, of the six water quality parameters evaluated, dissolved zinc most commonly appears to have relatively little scatter around its linear regression. These simple linear regression plots suggest multiple Whipple Creek subwatershed land covers help predict dissolved zinc levels while impervious surfaces may suggest dissolved copper levels.

Significant Overall Flow Type Water Quality versus Land Cover Relationships

Table 9 summarizes formal statistical tests, using Pearson product moment correlation coefficients (r), of the strength of linear relationships (Ott, 1988, pp. 319-320) or associations between pairs of water quality (response) versus land cover (predictor) variables for overall flow types. The p-values are the likelihood for each null hypothesis of an individual correlation equaling zero versus the two-tailed alternative hypothesis of a correlation not equaling zero (MiniTab Release 14 Statistical Software Help).

The r^2 values give the proportion of the total variability (Ott, 1988, p. 320) in the y-values (individual water quality parameter) that can be accounted for by the independent variable (individual land cover type).

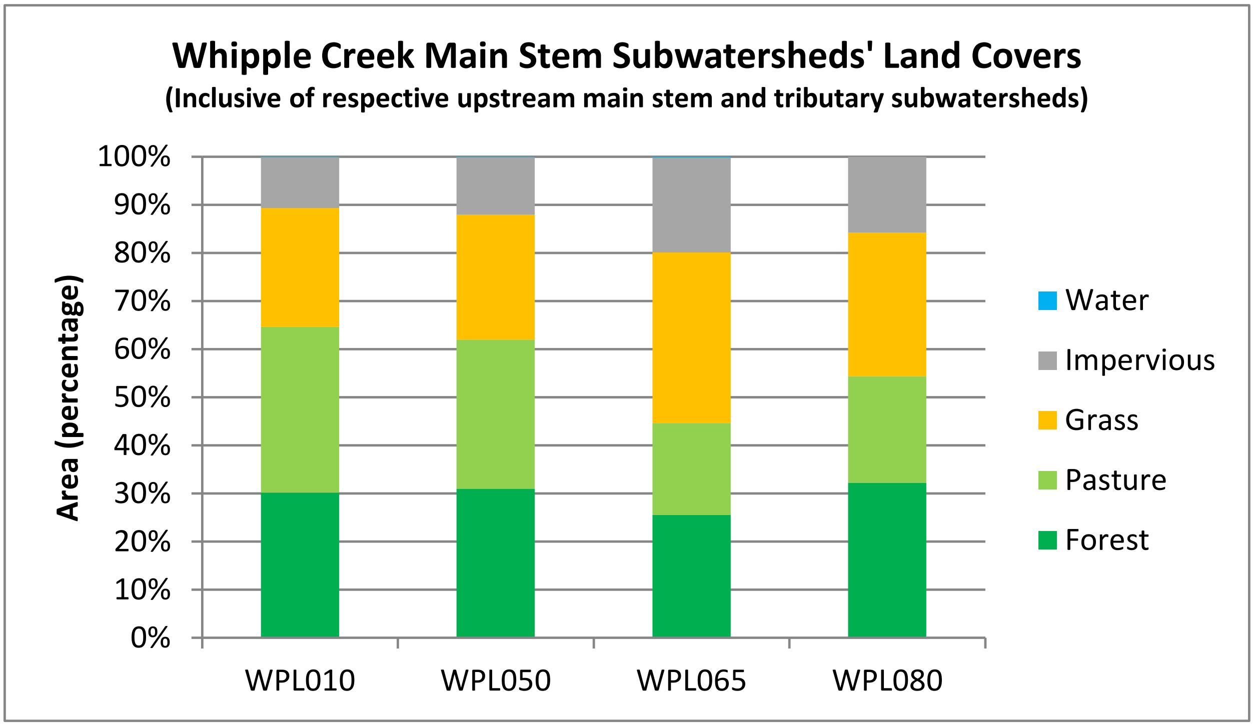

Figure 45 Whipple Creek main stem subwatersheds upstream land cover percentages

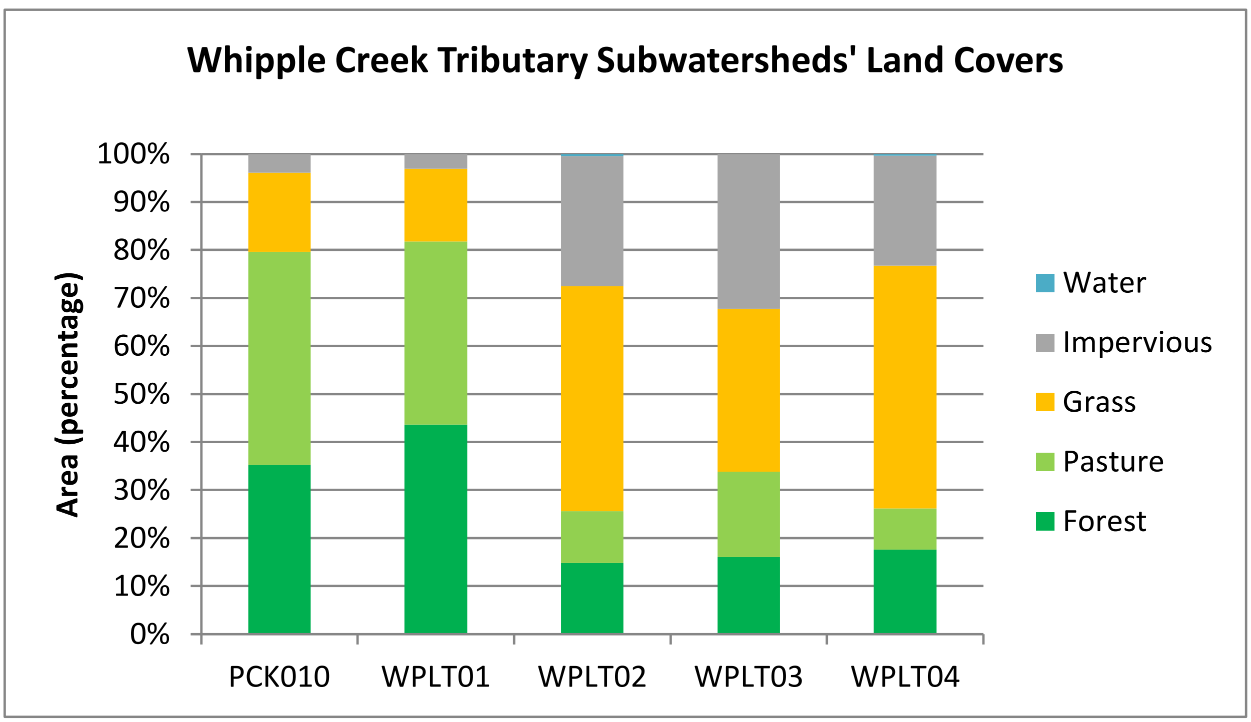

Figure 46 Whipple Creek tributary subwatersheds upstream land cover percentages

Significant linear relationships are high-lighted by two hues of green borders around their respective scatterplots in Figure 47 and two shades of grey cells in Table 9.

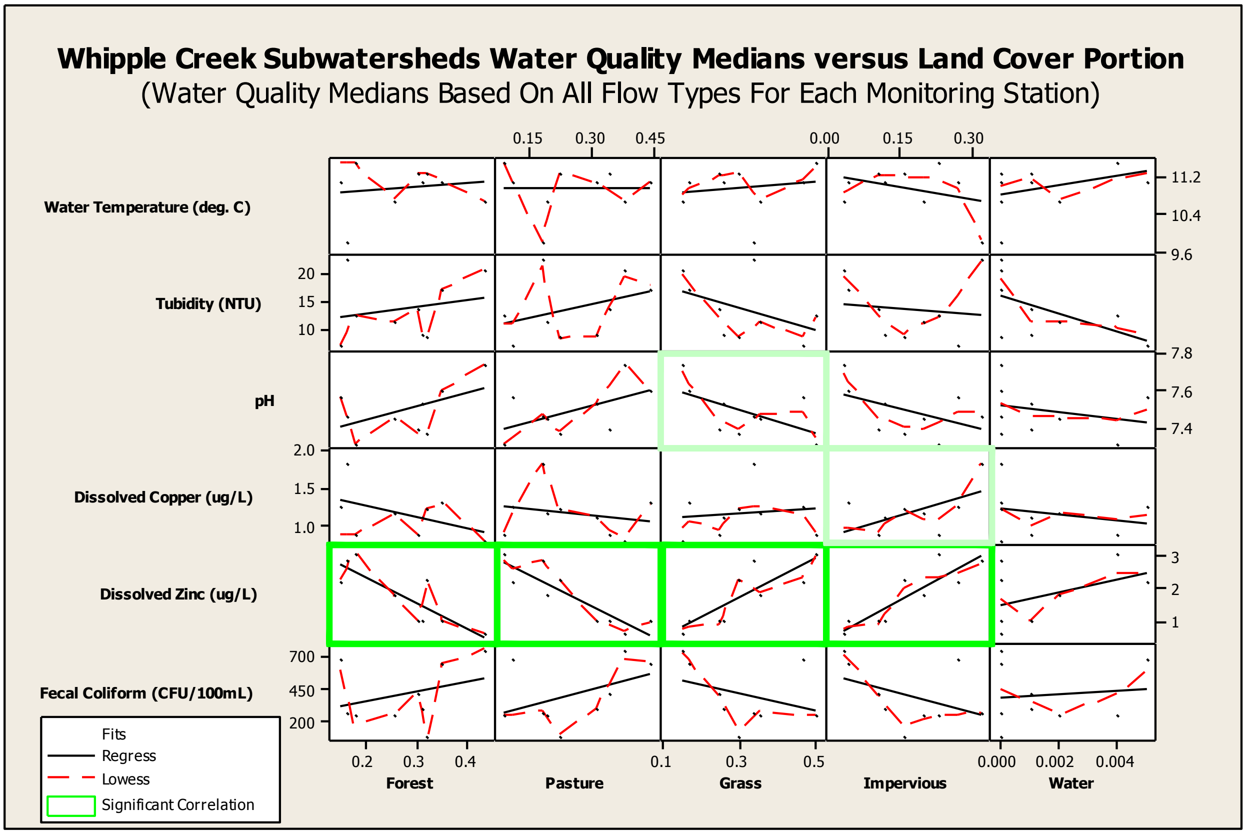

Figure 47 Scatterplot matrix of Whipple Creek subwatersheds' water quality medians versus portion of general land covers fit with linear regression and lowess smoother lines (borders depict significance at 0.05 – bright green and ~ 0.10 - light green)

Table 9 Correlation coefficient matrix for individual Whipple Creek subwatersheds' overall flow type water quality medians versus portion of general land covers relationships

Water Quality Parameter*	Forest			Pasture			Grass			Impervious			Water		
	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Temperature	0.167	0.667	0.03	0.028	0.943	0.00	0.142	0.716	0.02	-0.376	0.319	0.14	0.377	0.317	0.14
Turbidity	0.228	0.555	0.05	0.383	0.309	0.15	-0.454	0.220	0.21	-0.135	0.729	0.02	-0.558	0.118	0.31
pH	0.521	0.150	0.27	0.554	0.122	0.31	-0.582	0.100	0.34	-0.478	0.193	0.23	-0.246	0.523	0.06
Dissolved Copper	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33	-0.218	0.572	0.05
Dissolved Zinc	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77	0.440	0.236	0.19
Fecal Coliform	0.303	0.428	0.09	0.434	0.243	0.19	-0.348	0.358	0.12	-0.409	0.274	0.17	0.099	0.800	0.01

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

At a significance level (α) of 0.05 (highly significant), only overall flow's dissolved zinc medians had any significant linear relationships with or were found to be linearly dependent on (Helsel and Hirsch, 1993, p. 219) any of the land covers (bright green bordered scatterplots in Figure 47 and dark grey shaded p-value cells in Table 9). In fact, dissolved zinc's linear regressions on four of the five land cover types were significant at this level. Water was the only land cover type found to be not significantly associated with dissolved zinc. Water as a land cover is not of practical significance for further subwatershed analyses given its relatively very small total surface area of 7 acres, which represents about 1/1000 of the total Whipple Creek watershed area. The analyses show dissolved zinc has indirect significant relationships (negative r's in Table 9 and scatterplot slopes in Figure 47) with the more open space land cover categories of forest and pasture versus direct relationships (positive r and scatterplot slope) with the more development linked categories of grass and impervious surfaces.

Taking the square of the coefficient of linear correlation (r^2) gives the percent of variance in the response variable that is helped explained by the predictor variable (Helsel and Hirsch, 2000, p. 231). The r^2 for the significant overall flow's dissolved zinc linear relationships, indicates that between 69 and 77 percent of the variance of dissolved zinc medians is explained by the individual effect of four of the five land covers (Table 9). In addition, dissolved copper medians had somewhat of a significant (p-value of 0.105) direct linear relationship with impervious land cover that explained 33 percent of the variation in the median values for this metal. Median pH values also had a moderately significant (p-value of 0.10) indirect linear relationship with grass land cover that explained 34 percent of pH variation. While pH's relationship is statistically significant, most of its values across all monitoring stations fell in an acceptable relatively narrow range (mostly 6.5 to 8.0) as far as possible impacts. Therefore, pH is not discussed further.

Using subwatershed symbols, Figure 48 and Figure 49 depict significant relationships between overall flow's dissolved metal medians versus land cover based on data from all flow types (their overall flow regression equations are in the appendix). In most of the remaining figures, subwatershed symbol colors match those used in the map of Figure 44. The identical vertical and horizontal scales of the individual land cover panels in Figure 49 facilitate comparisons of its fitted regression and lowess lines' slopes and directions. Figure 48 shows dissolved copper's single significant land cover relationship with impervious land cover. Compared to dissolved zinc, dissolved copper medians are lower and its linear relationship's slope appears much smaller suggesting its slower rate of increase with greater amounts of impervious surfaces.

The patterns depicted in Figure 49 reflect the similar and complimentary impacts on dissolved zinc levels from open space versus development related land covers. The direction and slopes of the regression lines are very similar for each of the pairs of open space (forest and pasture) versus development (grass and impervious) relationships. These two groups' regressions also tend to be mirror images of each other. The comparable nature of and apparent parallel regression slopes for each of the open space versus development dominated land cover regressions suggests possible inter-correlations within these pairs of independent land cover variables. This implies that using either regression from each pair may suffice for predicting dissolved zinc. However, multiple regression statistical analysis would be required to evaluate potential inter-correlations of each additional independent variable and their contribution to the prediction of the response variable (Kleinbaum et al. 1988, pp. 106 and 124) of water quality. This level of analysis is beyond the scope of this basic screening study especially given that each linear relationship is based on just nine water quality / land cover pairs of variable values.

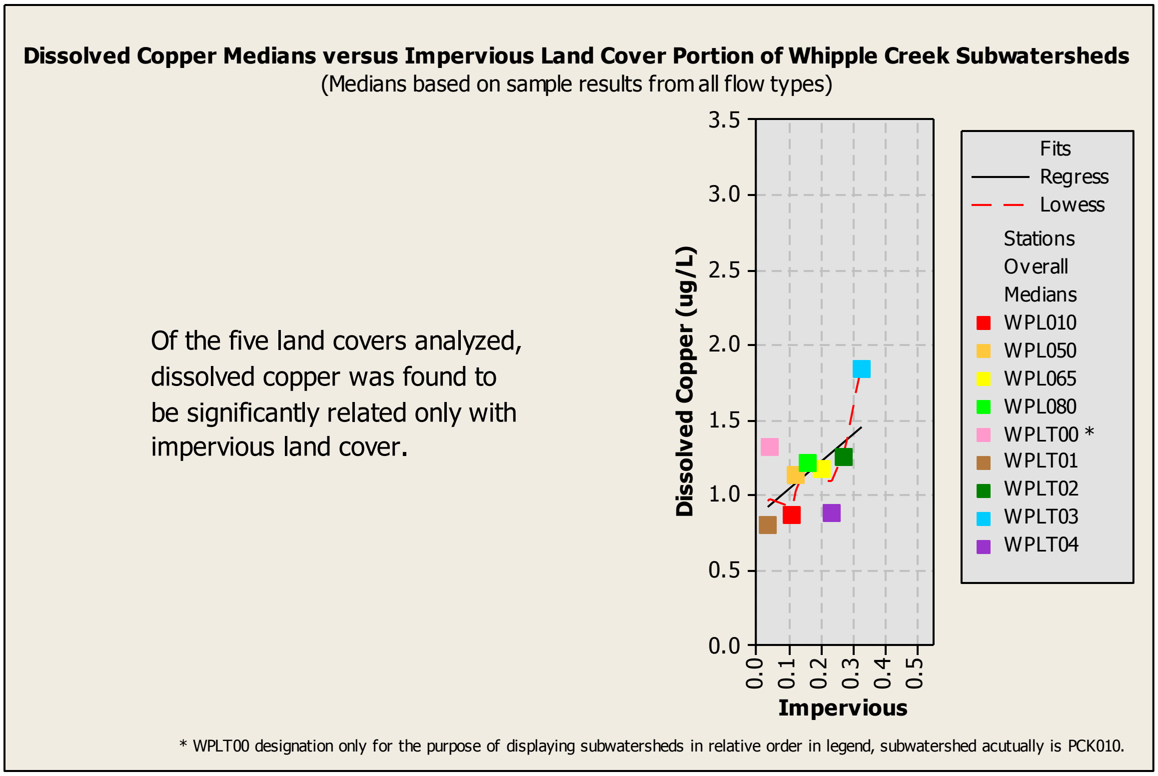

Figure 48 Scatterplot of dissolved copper median concentrations versus impervious surface land cover within subwatersheds

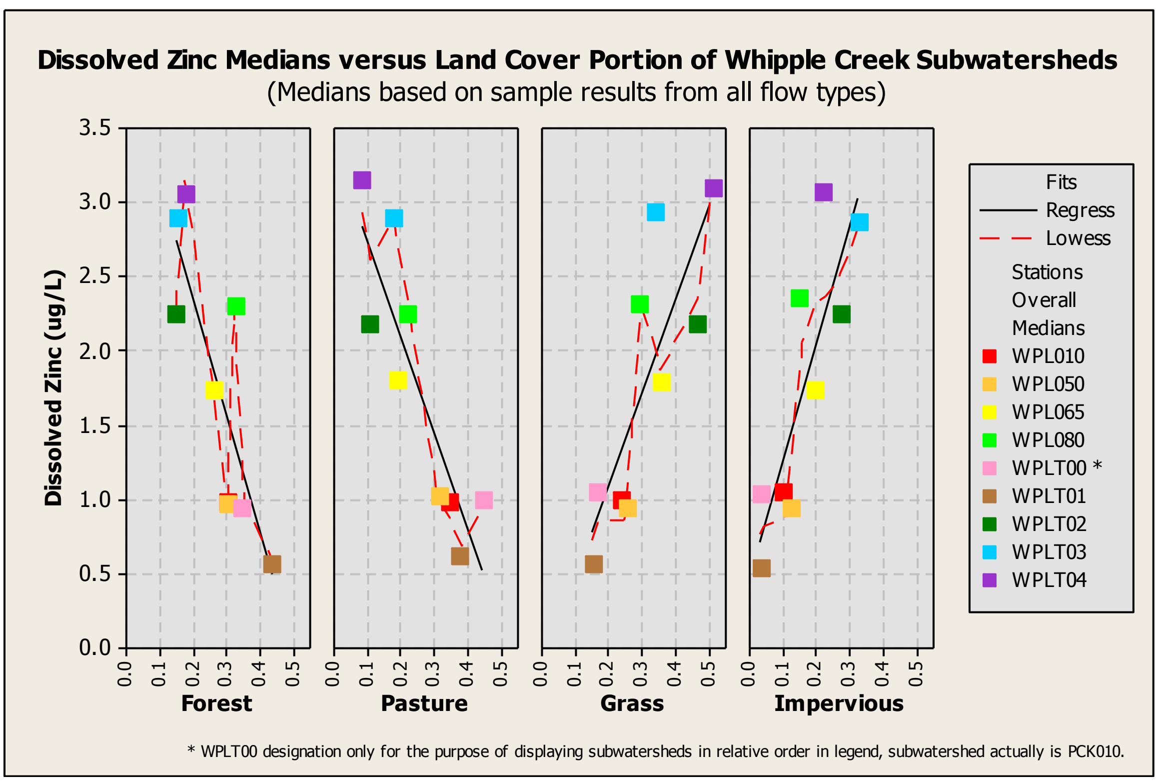

Figure 49 Scatterplot panels of dissolved zinc median concentrations versus general land cover within subwatersheds

Flow Type Dissolved Zinc and Dissolved Copper Distributions

Since dissolved zinc's and to a lesser extent dissolved copper's significant overall flow type linear relationships may have practical watershed management implications, additional exploratory analyses focused primarily on their subwatershed flow-type descriptive statistics and their role in linear regression relationships. Boxplots in Figure 50 and Figure 51 compare these parameters' distribution and central tendencies for each of the monitored Whipple Creek subwatersheds (using color-coding to illustrate flow types for each monitoring station). Each subwatershed boxplot can depict values for its: median (darker color-filled circle), interquartile range or IQR (outer box), 95% confidence intervals around the median (inner boxes), whiskers (values falling within 1.5 times the IQR from the median), and outliers beyond the whiskers (asterisks). These flow type medians represent a more detailed look than the calculated overall medians (based on all of a subwatershed's flow type results) presented so far in the above graphs. Importantly, since all of the base and storm flow boxplots are based on approximately the same sample sizes (except a slightly smaller sample size for WPLT03 base flow, also see Table 7) equivalent weight can be given to their interpretation for flow type boxplots and regressions.

Figure 50 shows the important role storm flow plays in dissolved zinc concentrations for more developed subwatersheds. For the more developed subwatersheds, dissolved zinc median storm flow concentrations (depicted by the blue boxplots' inner boxes illustrating 95% confidence intervals [C.I.] around their medians) are mostly significantly higher than those for their respective subwatershed's base flows (yellow boxplots' inner boxes). The most developed subwatersheds of WPLT02, WPLT03, and WPLT04 have at least 23% impervious and 34% grass land covers (also see Figure 45 and Figure 46). Additionally, WPLT02 and WPLT04 tributary subwatersheds' storm flow dissolved zinc median confidence intervals are much higher than those for all the other subwatersheds' storm and base flows except for WPLT03 (possibly due to fairground's galvanized roofs). Conversely, the two furthest downstream main stem (WPL010 and WPL050) and tributary (PCK010 and WPLT01) stations' storm flow dissolved zinc medians are significantly lower (depicted by their inner blue coded boxes not overlapping with those for WPLT02 – WPLT04) and their respective percentages of grass/impervious surfaces both are relatively low (at most 12% impervious and 26% grass). The relatively inverse pattern of land cover proportions of open space land covers (forest/pasture) for these same subwatersheds reflects their remaining larger undeveloped areas. Importantly, there are no significant differences in the base flow dissolved zinc median concentrations across all of the subwatersheds (all of the inner yellow boxes appear to overlap). The overall contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in dissolved zinc concentrations in the more developed subwatersheds. All of these patterns are consistent with the significant relationships found between the land covers and overall median dissolved zinc values but provide more specific information to support the hypothesis that land cover stormwater runoff contribute to those significant relationships.

Figure 51 shows a few different patterns for dissolved copper medians from those for dissolved zinc. Compared to base flows, higher storm flow median dissolved copper concentrations are more widespread across subwatersheds than for dissolved zinc. Dissolved copper has six while dissolved zinc has four subwatersheds with significantly higher storm flow versus base flow median concentrations. However, as shown by the boxplot median confidence intervals' pattern across subwatersheds as well as their ranges and magnitudes about their medians, dissolved zinc appears to be more sensitive than dissolved copper to development's impact on storm flow water quality. Similar to dissolved zinc, there are no significant differences in the base flow dissolved copper median concentrations across all of the subwatersheds.

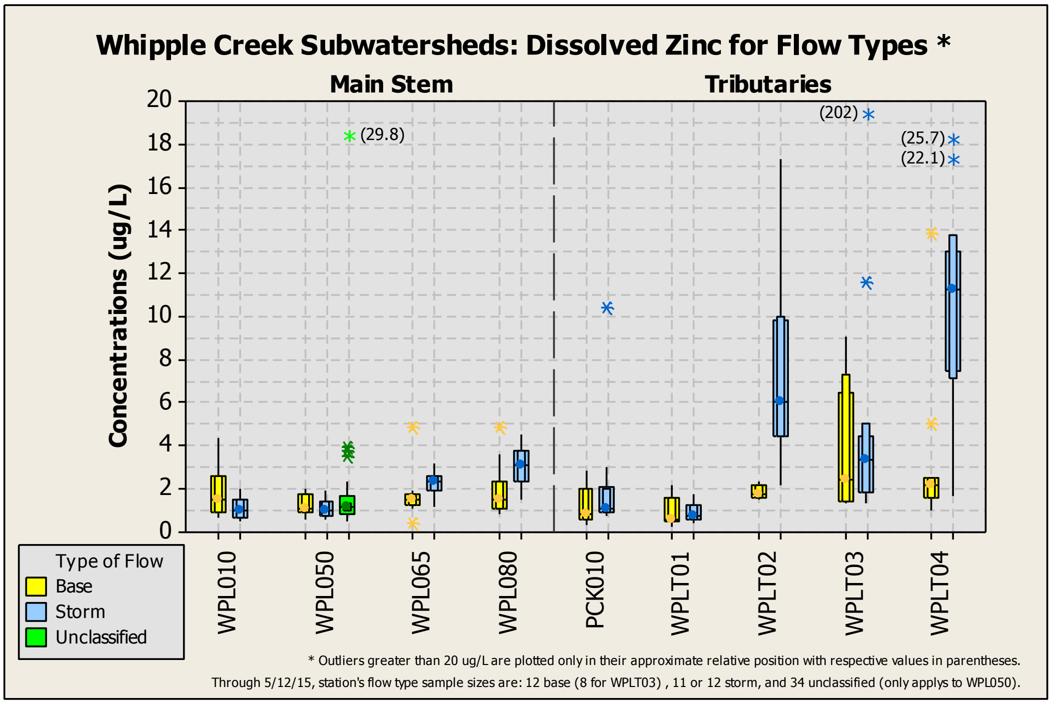

Figure 50 Boxplots of Whipple Creek subwatersheds' dissolved zinc by flow type

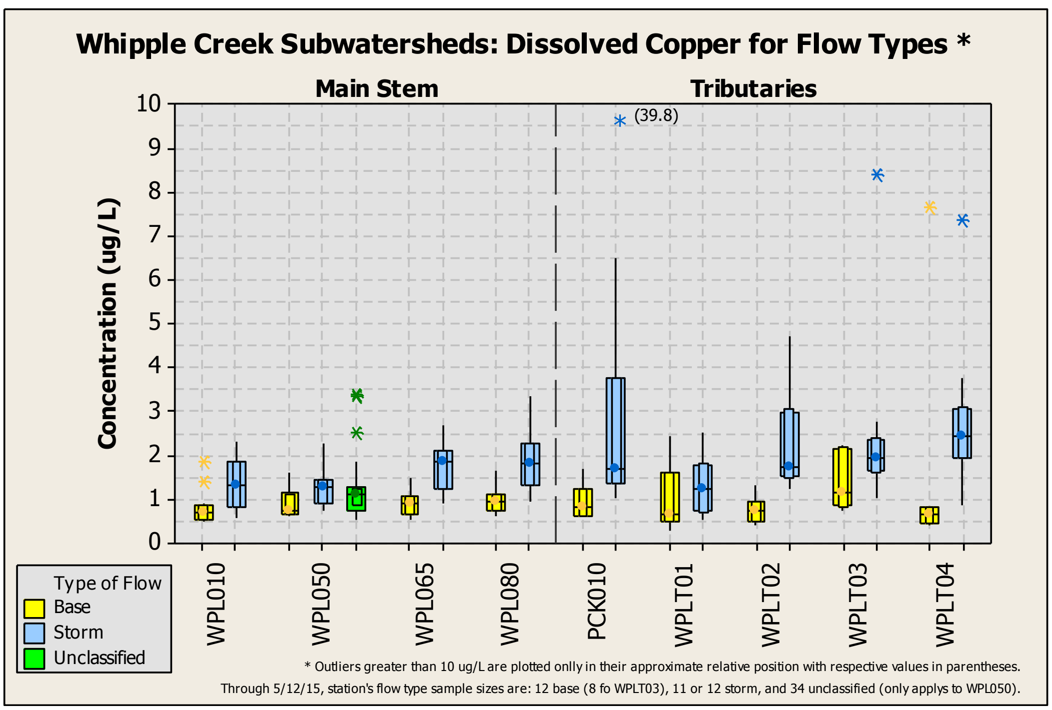

Figure 51 Boxplots of Whipple Creek subwatersheds' dissolved copper by flow type

Flow Type Dissolved Zinc and Dissolved Copper Relationships

Figure 52 through Figure 56 present more detailed analyses of the previously identified overall flow type's significant dissolved metal medians versus land cover linear relationships to help explore base and storm flow's potential impact on the relationships. These figures use the same ranges on their axes to facilitate comparisons. Within each of these figures, each monitoring station's dissolved metals medians are classified into one of the three flow types of base, storm, and overall (symbolized respectively with downward-point triangles, upward-pointing triangles, or squares). Overall is a combined data set consisting of medians calculated from base and storm flow's respective dissolved copper or zinc data values plus unclassified flows' dissolved metals values for just WPL050. The overall regressions are identical to those presented in Figure 48 and Figure 49 but are included for relative comparisons to base and storm flow regressions. In general, based on the lowess lines fitted to these flow type data sets, it appears linear regression is a reasonable model for consistent use across all variable combinations but possibly least applicable for forest and pasture storm flows.

As noted previously, most of the regressions' dissolved metal base and storm flow medians are calculated from very similar sample size data sets. The generally similar sample size exceptions are for WPL050 metals' overall medians which include a much larger sample size that is dominated by unclassified flow type values. However, most of WPL050's unclassified flow dissolved metal values are similar to their respective base and storm flow values. This similarity is shown by WPL050's unclassified data interquartile ranges and whiskers overlapping with those for its base and storm values except for 4 outliers of 34 dissolved zinc values in Figure 50 and 3 outliers of 31 dissolved copper values in Figure 51. Thus, equal weight is assumed in regressions for each base and storm flow dissolved metal median versus land cover data point and WPL050's overall regression is interpreted similarly as all others.

These flow type plots show the substantial and important role that WPLT02 and especially WPLT04 storm flow concentrations have on the slope of their dissolved metals versus land cover linear relationships. The horizontal scatterplot positons for WPLT02's and WPLT04's relatively high storm flow median dissolved zinc concentrations (up-pointing darker green and purple triangle symbols, respectively, in Figure 52 through Figure 55) are consistent with their subwatersheds' relative amounts of potentially pollutant generating land covers. Conversely, all flow types' relatively low dissolved zinc medians for the lower main stem, Packard, and WPLT010 subwatersheds tend to be clustered in the scatterplots' lower right for forest / pasture or lower left for grass / impervious surface. This is also consistent with the expected lower dissolved zinc pollutants levels across all flow types for these mostly open space dominated subwatersheds.

While the dissolved metals versus impervious land cover flow type linear regressions' slopes were not tested statistically for differences, dissolved zinc concentrations across both base and storm flow types appear to respond more than those for dissolved copper to potential impacts from development. This is depicted by the consistent appearance of steeper dissolved zinc versus impervious land cover regression slopes across flow types in Figure 55 compared to those of dissolved copper in equivalently scaled Figure 56. Even though dissolved coppers values are lower overall, this would be a valid comparison in absolute concentration terms since both graphs use the same scales on their axes. Figure 57 shows dissolved copper medians versus impervious land cover using an expanded view of axes scales to better depict differences between dissolved copper flow types across their full range of results.

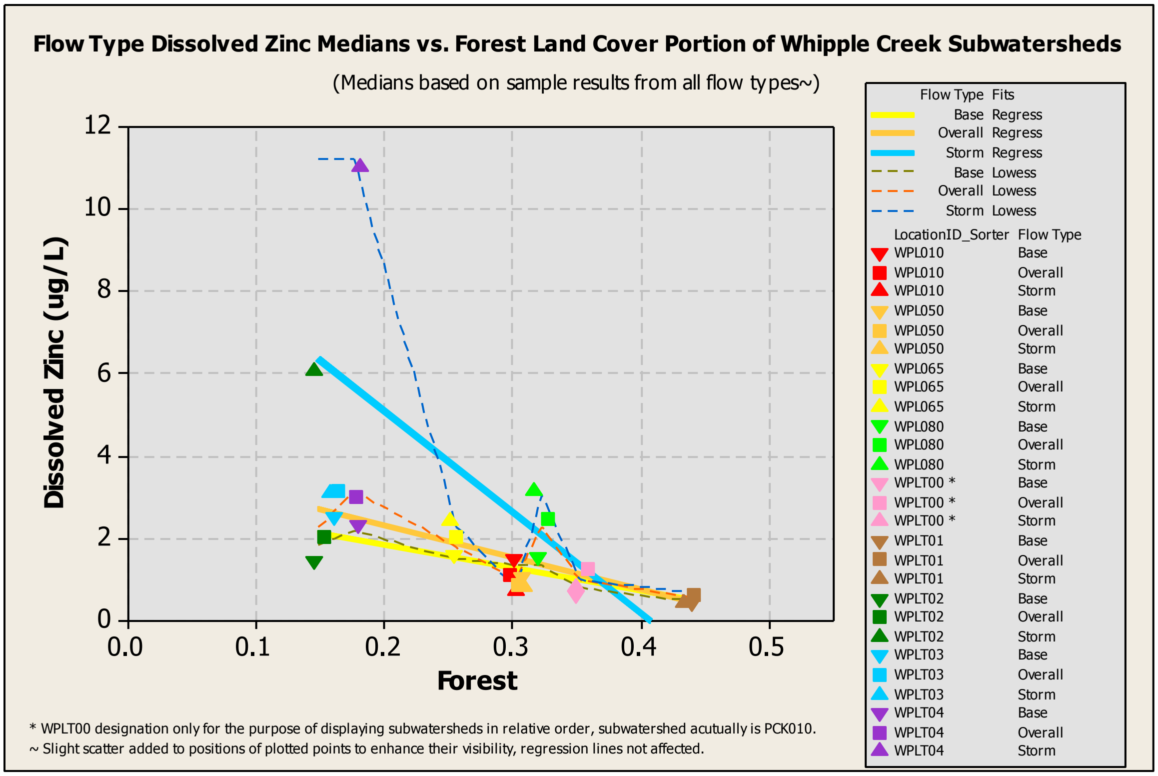

Figure 52 Flow type dissolved zinc medians versus proportion of forest land cover

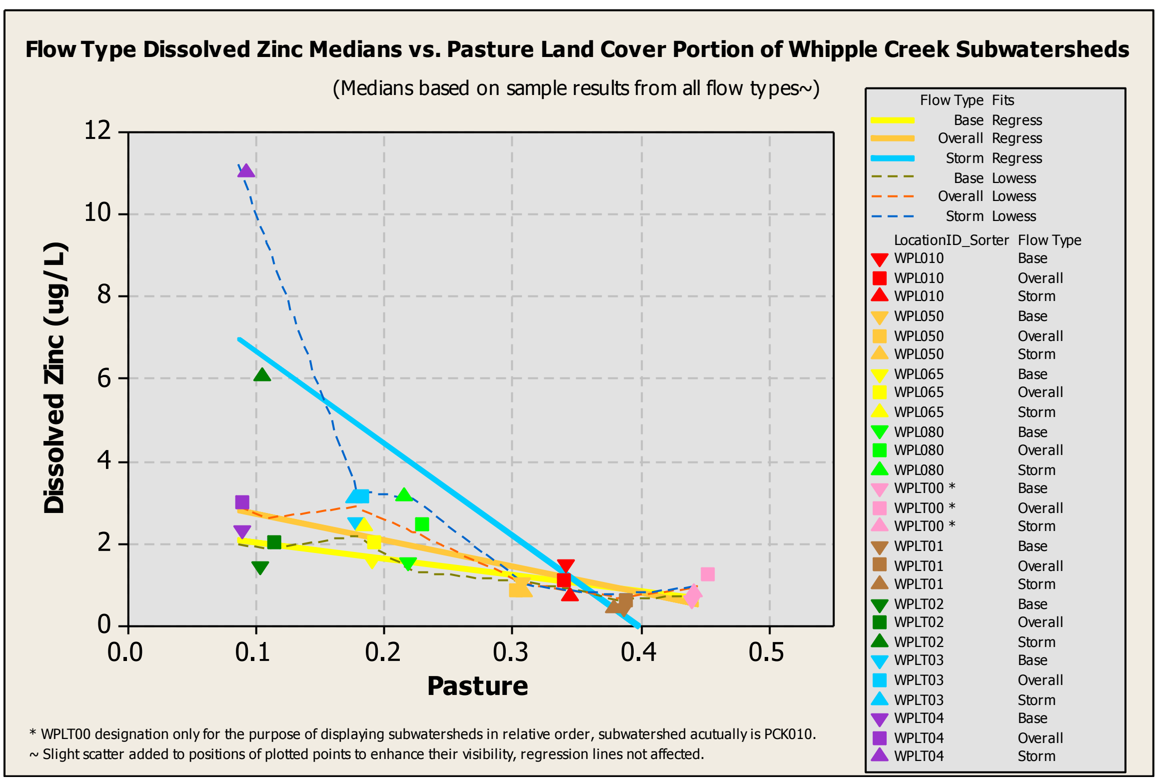

Figure 53 Flow type dissolved zinc medians versus proportion of pasture land cover

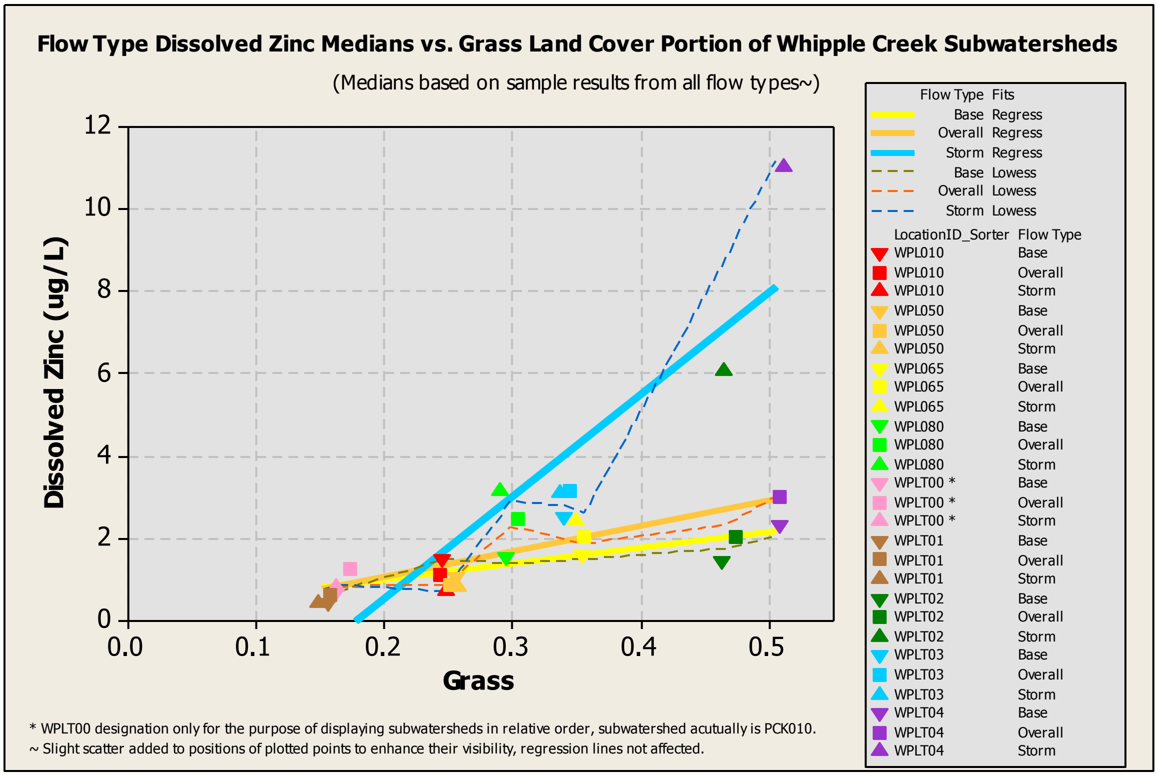

Figure 54 Flow type dissolved zinc medians versus proportion of grass land cover

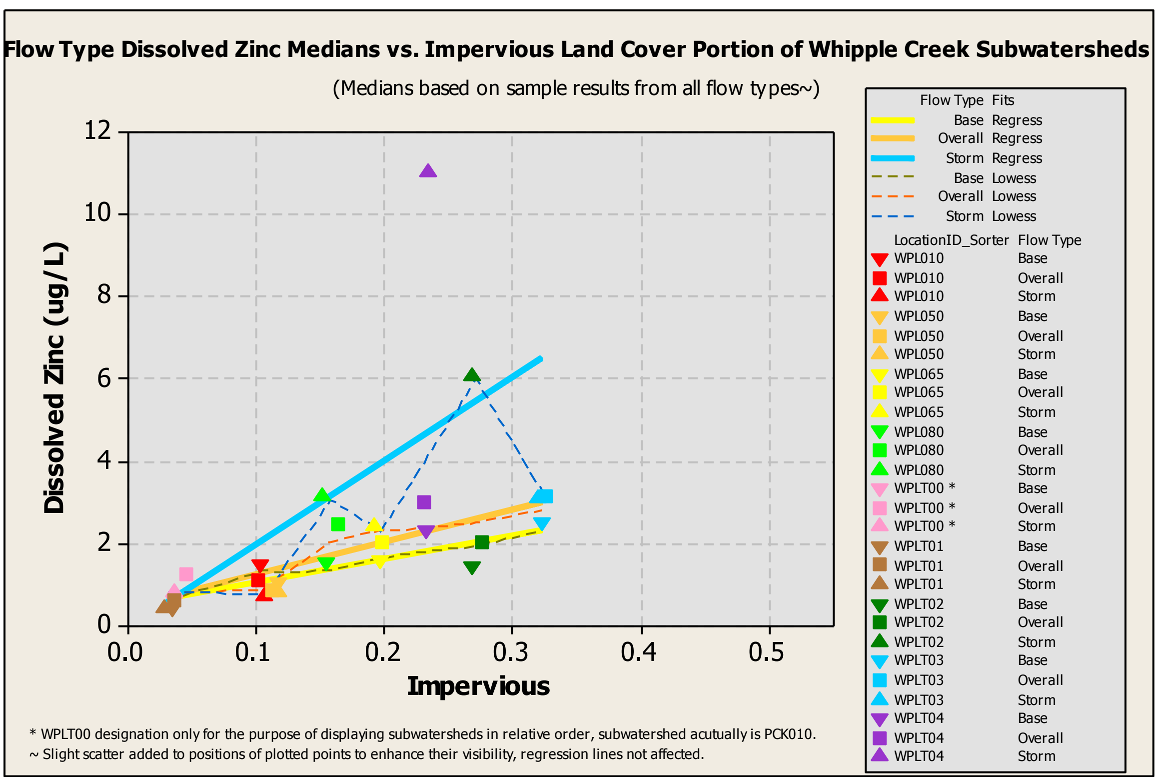

Figure 55 Flow type dissolved zinc medians versus proportion of impervious land cover

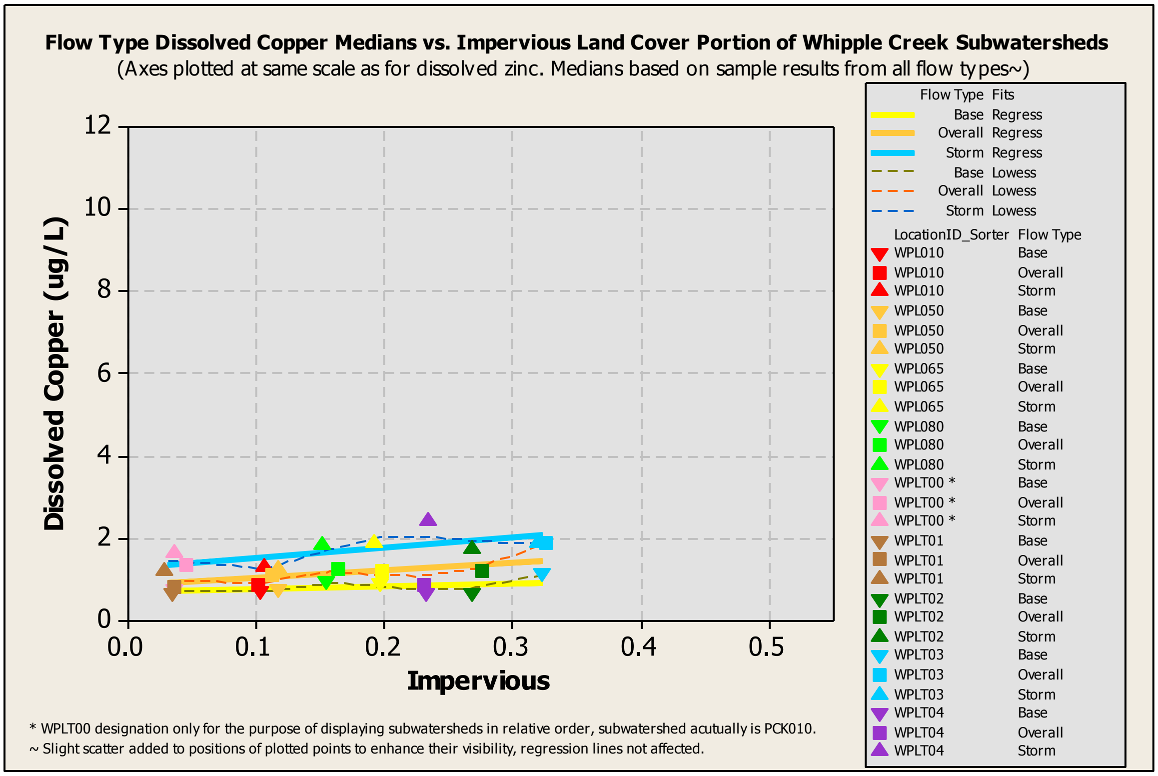

Figure 56 Flow type dissolved copper medians versus proportion of impervious land cover (same scales as dissolved zinc)

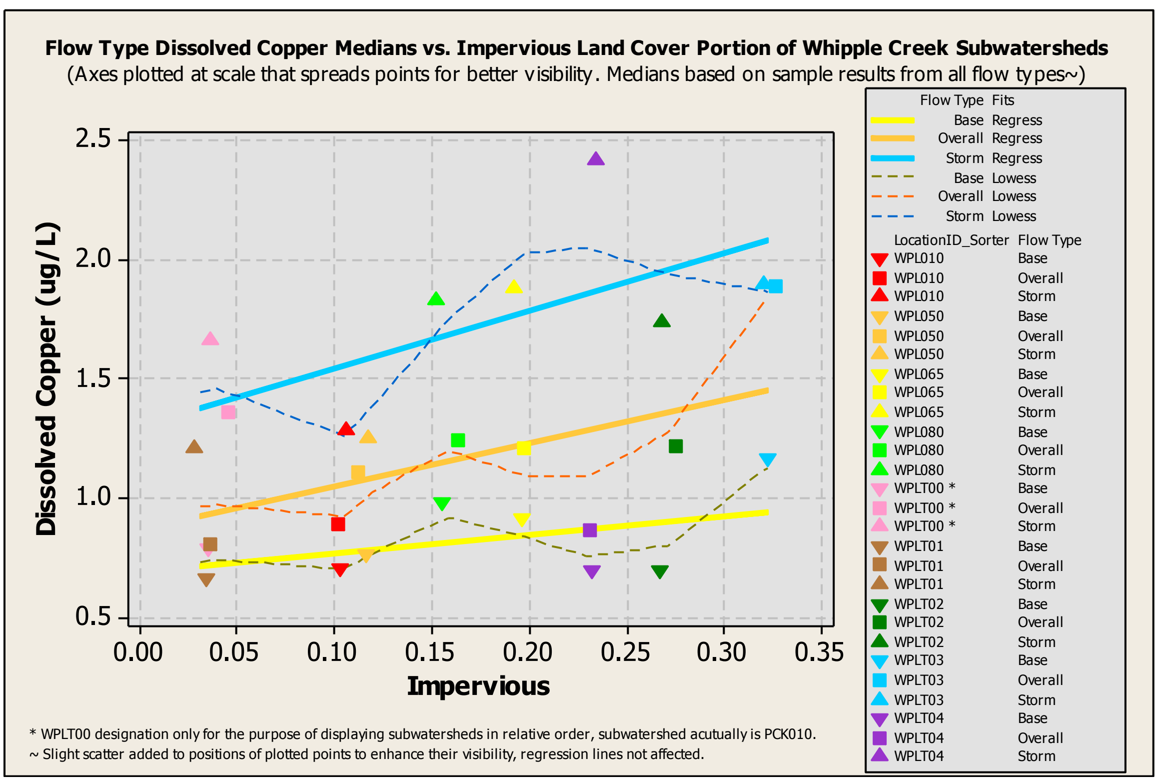

Figure 57 Flow type dissolved copper medians versus proportion of impervious land cover (scales expanded to range of data)

This study's appendix contains the calculated linear regression equations and graphs for Whipple Creek subwatersheds' dissolved zinc medians versus most land covers and dissolved copper medians versus impervious land cover depicted across all flow types. The regressions represent the modeled mean response values (MiniTab Release 14 Statistical Software Help) for a range of predictor values. The potential limited representativeness of this study's small sample size of nine subwatershed monitoring locations was somewhat offset by using water quality medians as dependent variable values for developing the regressions. Each median is based primarily on between 11 and 189 individual parameter results. Importantly, differences in dissolved metals flow type medians versus land cover regressions' slopes were not formally tested statistically given this study's limited screening purpose, the relatively small available sample sizes, and differing correlation significance levels for some base and storm flow type relationships.

Correlation values for base and storm flow dissolved copper versus impervious and dissolved zinc versus four land covers are presented in Table 10 for those relationships found to have significant overall flow type relationships. The overall flow type correlations are identical to those presented in Table 9 but are included here for relative comparisons. Only the correlation for dissolved copper medians' storm flow versus impervious land cover linear relationship was found to be even moderately significant (p-value of 0.066). In contrast, all of the correlations for dissolved zinc medians' base and storm flow types versus the four land covers' linear relationships were highly significant except for storm flow versus impervious which was moderately significant.

Table 10 Correlation coefficient matrix for individual Whipple Creek subwatersheds' with significant overall flow type water quality medians versus portion of general land covers relationships – base and storm flow type correlations

Water Quality Parameter*	Flow Type	Forest			Pasture			Grass			Impervious		
		r	p-value	r^2	r	p-value	r^2	r	p-value	r^2	r	p-value	r^2
Dissolved Copper	Base	NA	NA	NA	NA	NA	NA	NA	NA	NA	.50	0.172	.25
	Storm	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.636	0.066	.40
	Overall	-0.466	0.207	0.22	-0.204	0.599	0.04	0.106	0.786	0.01	0.576	0.105	0.33
Dissolved Zinc	Base	0.908	0.001	0.82	0.807	0.009	0.65	0.783	0.013	0.61	0.919	0.000	0.85
	Storm	0.698	0.037	0.49	0.811	0.008	0.66	0.881	0.002	0.78	0.60	0.088	0.36
	Overall	-0.828	0.006	0.69	-0.880	0.002	0.77	0.832	0.005	0.69	0.875	0.002	0.77

* Shaded cells have correlations (r) that are not equal to zero at attained significance levels (p-values) less than this study's acceptable significance levels (α) of 0.05 (high - dark blue) or approximately 0.10 (moderate - light blue).

However, insights on the potential impacts of flow type on the regressions' modeled average response slope and range are possible from examining their respective confidence interval bands in the detailed regression graphs found in this study's appendix. Overall, potentially significant differences in base versus storm flow regression dissolved zinc values appear more often at the extremes of land cover percentages. This pattern is partially due to storm flow's apparent steeper slope compared to that of base flow. Storm flow's dissolved zinc values appear to become significantly larger over those of base flows when forest or pasture land cover drops below approximately 25% of the subwatershed area (no overlap between their respective storm flows' lower and base flows' upper red dashed confidence interval bands). Conversely, with increasing subwatershed portions of grass land cover over approximately 30%, storm flow dissolved zinc appears to become increasingly larger than that for base flow (increasing gap between their respective lower and upper red-dashed interval bands). Less difference between dissolved zinc's storm and base flow versus impervious land cover relationships is depicted by the slight overlap in their respective lower and upper confidence bands when impervious exceeds 20%. However, this overlap is minimal and probably impacted by dissolved zinc stormflow versus impervious land cover's moderately significant correlation. These preliminary analyses patterns suggest, at or close to the 95% confidence level, that as the portion of Whipple Creek subwatersheds' developed area exceeds 20 to 30 percent there is substantially more average dissolved zinc in storm flows compared to their respective base flows.

Additionally, the location of Clark County Fairgrounds mostly within the smallest monitored subwatershed of WPLT03 could be confounding dissolved metals relationships with land cover. This subwatershed is unique in that its only substantial impervious surface includes the large concentration of Clark County Fairground structures and their adjoining impervious surfaces in the northeast corner of the subwatershed. This group of structures likely represents the largest concentrated galvanized metal surface area (typically a large potential dissolved zinc source) within the entire Whipple Creek watershed. However, this WPLT03 subwatershed has a relatively low storm flow dissolved zinc median value compared to its linear regression model (but still within the regression's 95% confidence interval). Beneficial removal of dissolved zinc could be occurring in the several stormwater treatment facilities treating runoff from the fairgrounds. The low WPLT03 median may also be due to the infrequent seasonal usage of impervious surfaces for vehicle traffic compared to the more constant traffic patterns on impervious surfaces for other more developed subwatersheds. Additionally, the fairground's most intense use is during the month of August which is typically one of the driest months of the year but could conceivably have heavy rainfall events. Nevertheless, there were no such concurrent intense rain events during the annual fair during this monitoring period and any such potential outlier results would be mitigated by using water quality medians. Finally, comparing the respective storm and base flow dissolved zinc medians versus impervious land cover regression lines and their confidence bands after excluding WPLT03 in storm flow results in: increasing the stormflow regression slope by one half, increasing its r^2 to 55% (p-value of 0.035), and decreasing the threshold for significant difference between them to about 17% impervious land cover. This supports the unusual impact that this subwatershed has on the dissolved zinc and likely also the dissolved copper regressions.

Interestingly, while both dissolved copper base and storm flow medians versus impervious land cover regression slopes and values appear substantially less than those for dissolved zinc, there was no overlap in the confidence bands between dissolved copper's base and storm flow regressions. This implies that predicted storm flow dissolved copper values are significantly higher than those of base flow throughout the range of approximately 5% to 30% of impervious land cover.

Based on this limited monitoring data, these storm flow versus base flow dissolved metals concentration differences for various land covers reinforces the need to control stormwater dissolved metals sources especially in more urbanized subwatersheds. This finding has stormwater management implications for the Whipple Creek Plan area.

Statistical Assumption Evaluations

Statistical assumptions were briefly evaluated for the linear regressions of subwatershed median dissolved zinc versus most land covers and dissolved copper versus impervious land cover relationships (primarily by examination of diagnostic plots). The review of linear regression assumptions was limited to just these base, storm, and overall storm flow relationships because they appeared to have the best linear fit of all the parameters monitored (Figure 47). Additionally, the narrow screening purposes of this study and the relatively small subwatershed sample sizes of water quality medians, respectively, reduced the need for and ability to evaluate assumptions.

The five assumptions associated with linear regression (Helsel and Hirsch, 2000, pp. 224 – 225 and 231-238) and their interpretation for this study's limited statistical analyses are summarized below. First, as noted above and depicted by the lowess fitted lines in Figure 47 the linear model appears reasonable for all the significant dissolved metal relationships. Second, the data used to fit the regression model are generally representative of both monitored Whipple Creek subwatershed water quality and land cover. Third, as suggested by the lack of extreme changes in dissolved zinc over time (Figure 58) and displayed more clearly in this study's appendix "Residual Versus the Fitted Values" plots, the variance of the relationships' residuals appears fairly constant (homoscedastic). For each of the land covers evaluated, there appears to be one or two residuals that are slightly larger (usually for the difference between each fitted line and the median of WPLT04 storm flow and less often for WPLT03 base flow) than the remaining others. Fourth, as depicted in the appendix's "Residuals Versus the Order of the Data" plots there may be some correlation between residuals over space (residual are not totally independent) as suggested by consecutive positive or negative residuals clumping together. Given the order of subwatersheds plotted, the net potential effect of this assumption violation suggests that the regression lines somewhat under-predict storm flow dissolved zinc and copper values more often especially for the more developed WPLT04 subwatershed. Alternatively, the linear regression assumption that y-values are statistically independent of one another ((Kleinbaum et al., 1988, p. 45) is supported by the use of median water quality values. Fifth, the appendix's "Normal Probability Plots" and "Histograms of the Residuals" plots and their Anderson-Darling statistics (p-values less than significance level suggest non-normality, MiniTab Release 14 Statistical Software Help) suggest almost all of the residuals are normally distributed at a 0.05 significance level except for dissolved zinc's storm flow versus impervious land cover regression (p-value of 0.02). A lack of normality could slightly reduce the power (Helsel and Hirsch, 2000, p. 236) of this study's storm flow dissolved zinc median versus impervious land cover statistical tests of correlation, thus increasing the chances of falsely declaring the correlations were significant.

However, it is important to not read too much into plots, especially from a couple of odd points or residual variances that seem to both grow and shrink over the range of predicted values (Helsel and Hirsch, 2000, p. 232). For example in small sample sizes ($n<50$), the normal probability plot may display curvature (that increases as sample size decreases) in the tails even if residuals are normally distributed (MiniTab Help "Residual Plot Choices", 2003). Additionally, the likely correlation between residuals over space is not surprising given the nested hierarchy of the monitored subwatersheds where several upper subwatersheds are part of downstream main stem subwatersheds. In addition, potential correlations between residuals over time have been minimized by using medians of water quality values collected over time. Therefore, likely violations of some of the linear regression assumptions are deemed acceptable trade-offs given the overall study's main purpose of limited exploratory screening of potential sources or unusual patterns for stormwater pollution.

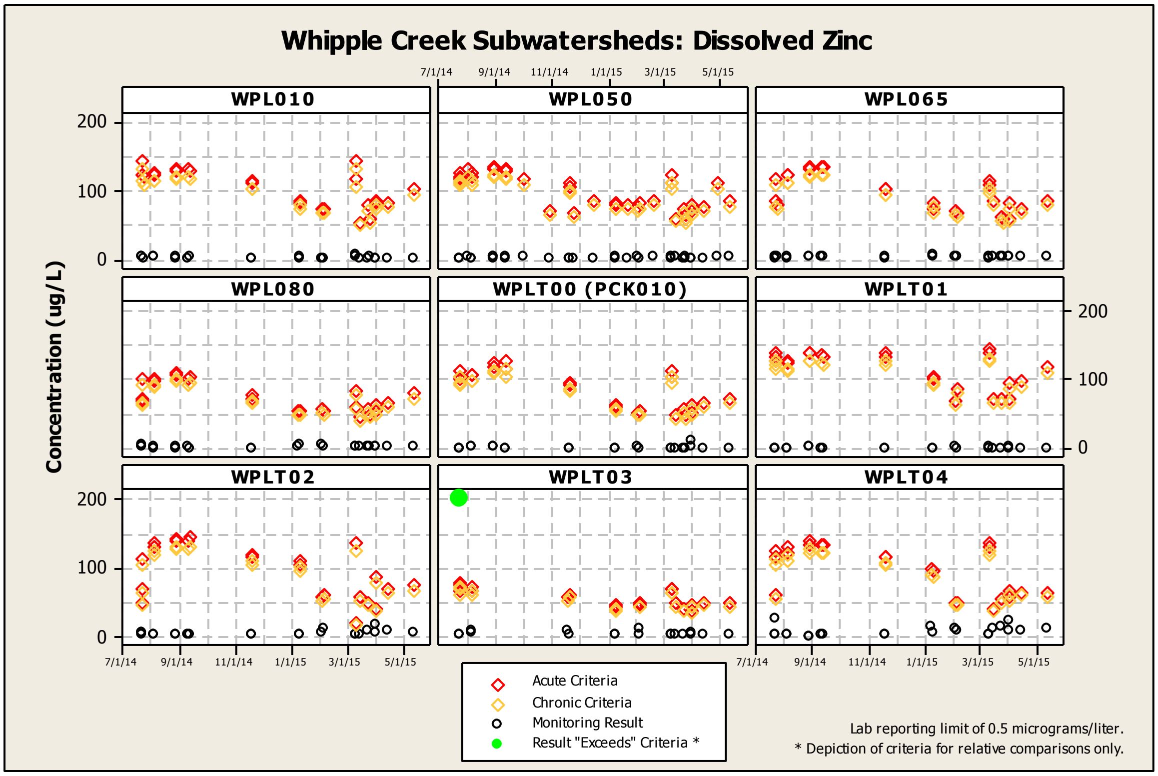

Figure 58 Plot of Whipple Creek subwatersheds' dissolved zinc values over time and applicable state criteria values

Conclusion

In support of Clark County's required stormwater planning for the Whipple Creek watershed, this report summarizes and interprets the relationships between the existing conditions of the watershed's stream water quality and general land covers. The goals of analyzing these relationships focused on screening them for practical insights and potential pollutant anomalies that could affect watershed management approaches as well as providing context for continuous water quality modeling. This report's emphasis on stream water quality versus land cover relationships precludes interpretation of state water quality standards, which is addressed in the Whipple Creek Watershed Plan's "Assessment of Existing Water Quality Conditions" section. The fundamental analyses tools in this report may serve as a template for supporting stormwater planning in other Clark County watersheds.

This Whipple Creek watershed study leveraged limited existing data to evaluate potential general sources of pollution based on broad land cover types that typically reflect relatively low to high stormwater pollutant risk. As watersheds become developed, their proportions of forest and pasture decline while impervious surfaces and residential grass areas increase. This study compared water quality median values from monitoring stations with their upstream relative portions of these general land cover types. An underlying assumption is that subwatershed streams' water quality reflects varying degrees of stormwater impacts typical of broad land cover types. Under this assumption, basic statistical relationships were developed and evaluated based on changes in water quality associated with the proportion of general land covers across nine Whipple Creek subwatersheds. Regression statistical analysis was used to screen the broad land cover types and their impacts as potential stormwater pollutant sources within the Whipple Creek watershed planning area. Specifically, using simple linear regression, the variation in six water quality parameters' medians (response variable) were related to the proportion of each subwatershed in five general land cover types (predictor variable) on a pair-wise basis sequentially for overall, base and storm flow monitored conditions.

This study's important practical findings include:

- No substantial anomalies from what would be typically expected were found in the type and direction of the monitored water quality versus land cover relationships that would otherwise suggest unusual sources of pollution.
- Most of the six monitored water quality parameters were found to be not significantly correlated with land cover under overall flow conditions. However, the uncorrelated parameters of water temperature and pH are often strongly influenced by localized site factors while turbidity and fecal coliform can be impacted by a range of land cover sources.
- Under overall flow conditions, only dissolved zinc had multiple statistically significant (at 95% significance levels) linear relationships with relative amounts of various land covers while dissolved copper had only a single less significant direct relationship with impervious land cover. Subwatershed dissolved zinc median concentrations had four significant linear relationships: inverse relationships (negative correlations) with forest and pasture as well as direct relationships (positive correlations) with impervious and grass land covers. Linear regression correlation (r^2) showed that at least 69% of the variance in dissolved zinc is explained by each of these land covers. Dissolved copper's lone significant linear relationship correlation with impervious land cover was weaker with a p-value of 0.105 and an r^2 indicating 33% of variance explained.
- The direction and slopes of the overall flow type dissolved zinc regression lines are very similar for each of the pairs of open space (forest and pasture) as well as development (grass and

impervious) relationships. The regression lines' mirror image patterns for open space versus development related land covers reflect their likely similar and complimentary impacts.

- Boxplots showed that storm flows from those subwatersheds with more development related land covers usually had significantly and substantially higher median dissolved zinc values than their respective base flows. This, in turn, impacted the slopes of their relationships' regression lines.
- Importantly, boxplots also showed there are no significant differences in the base flow dissolved zinc or dissolved copper median concentrations across all of the subwatersheds.
- Dissolved zinc appears to be more sensitive than dissolved copper to development's impact on stream water quality. While dissolved metals versus impervious land cover regressions' slopes were not tested statistically for differences, dissolved zinc's correlations with land covers were highly significant across both base and storm flows for seven of the eight relationships compared to dissolved copper storm flow versus impervious land cover's one moderate correlation.
- Overall, potentially significant differences in base versus storm flow regression modeled average dissolved metals values become clearer at thresholds of Whipple Creek subwatershed development percentages. These preliminary analyses suggest at or close to the 95% confidence level, when the portion of the subwatersheds' forest or pasture drops below 25 percent or as developed area exceeds 20 to 30 percent there is substantially more and increasing average dissolved zinc in storm flows compared to their respective base flows. Similarly, dissolved copper's threshold appears closer to only 5 percent of a subwatershed classified as the impervious land cover type but its smaller slope indicates that it increases at a slower rate.
- Given the predominant and consistent patterns found across all base, storm, and overall flow conditions between the response variable dissolved zinc and predictor variables of portions of general land cover types, any of the significantly related land covers by themselves could serve as a screening surrogate measure of likely dissolved zinc stormwater impacts on stream water quality. However, known mechanisms and pathways for transport of dissolved zinc from impervious surfaces would make this land cover a logical choice for predictions. Similarly, impervious land cover could serve as a surrogate for dissolved copper's likely impact under both storm and overall flow conditions.

Dissolved zinc and copper have a range of possible sources associated with development's impervious surfaces with many related to vehicle transportation. Among other possible sources, they include: galvanized metal products, building exteriors, public infrastructure and especially vehicle tires, brakes, and bodies (Minton, 2002, pp. 14 - 18). The significant dissolved zinc versus multiple land covers and dissolved copper versus impervious land cover relationships found in this study's analysis of the Whipple Creek watershed are consistent with the amount of development and its typical potential sources of pollution.

Based on this study's limited monitoring data, the potential implications of the overall and especially the apparent storm flow versus base flow dissolved metals relationship differences as subwatersheds become more developed reinforces the need to control stormwater dissolved metals sources. The consistent and substantial contrast between patterns in storm and base flow dissolved zinc median concentrations strongly suggest the important role stormwater plays in the more developed subwatersheds. These results are consistent with the idea that common development land covers such as impervious surfaces and development's typical associated human activities can be significant sources of some stormwater pollutants. As part of the Whipple Creek watershed planning project's existing conditions assessment, this initial and basic statistical analysis of local data is intended to provide context for and compliment more in-depth, sophisticated mechanistic water quality modelling using the continuous HSPF model. This study met its exploratory analyses goals for gaining insights on potential general pollution sources and checking for anomalies in Whipple Creek watershed pollutant versus land cover relationships.

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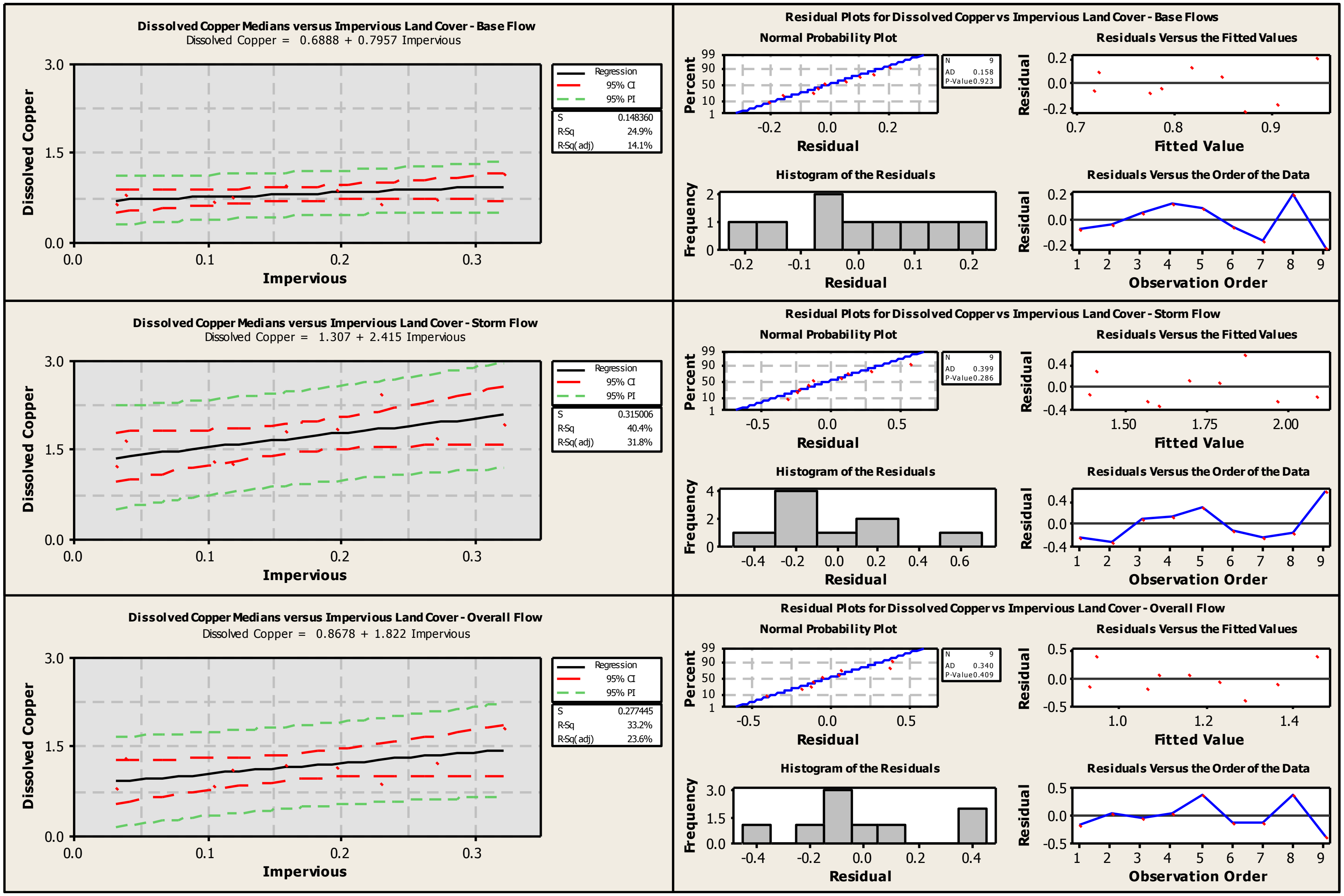
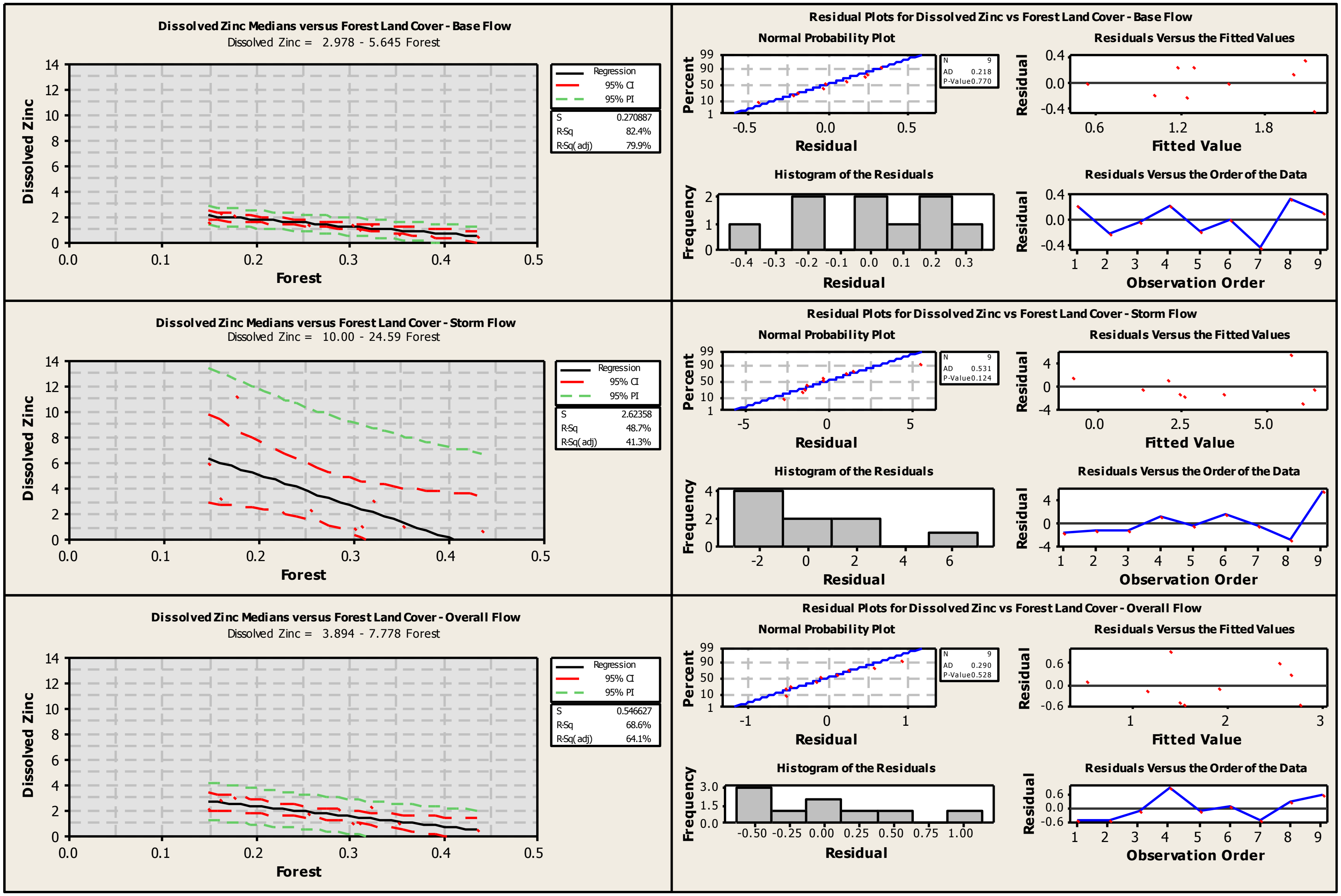
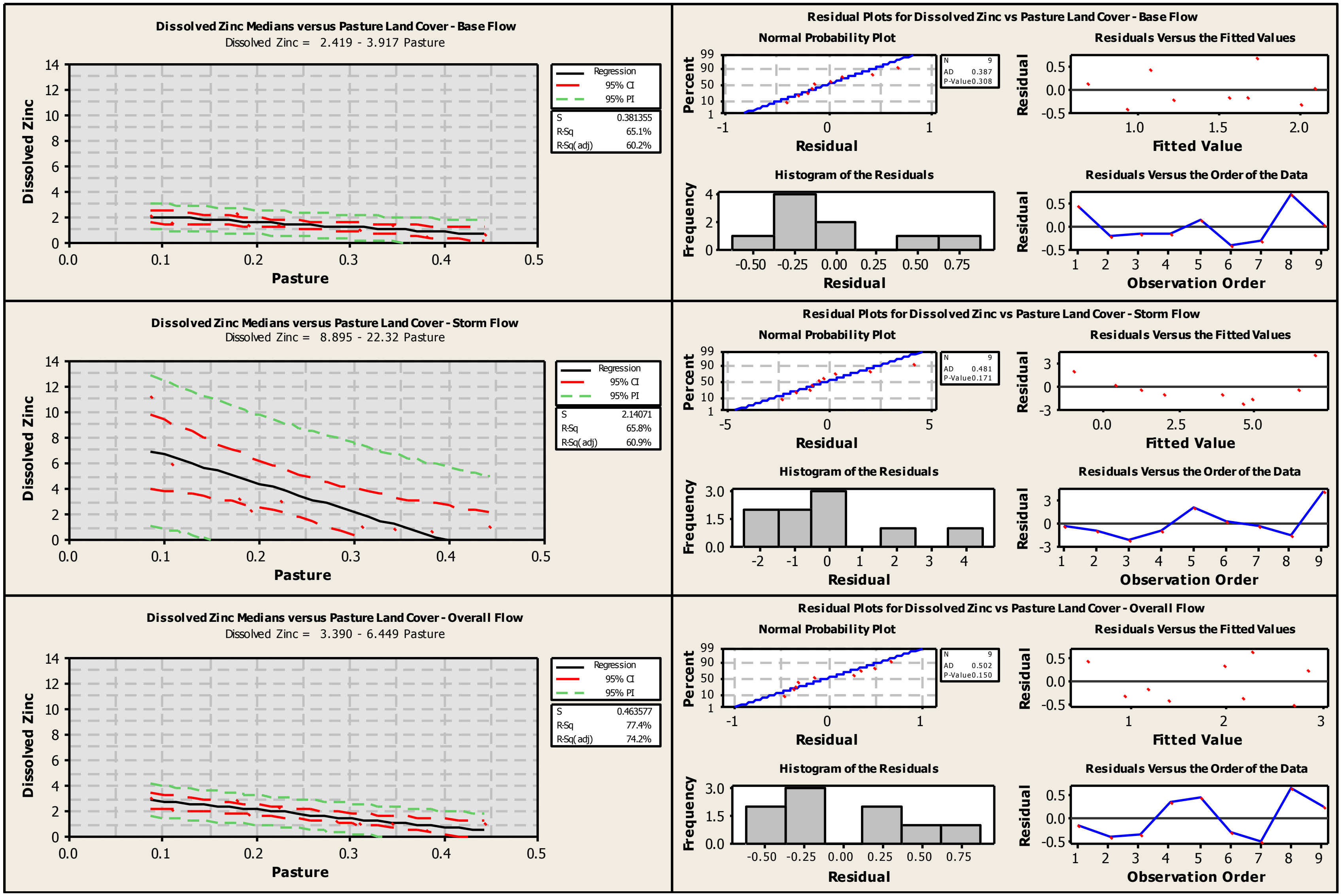
Appendix 3 Detailed graphs summarizing flow-type dissolved metals versus land cover regressions' confidence / prediction intervals and assumption evaluations



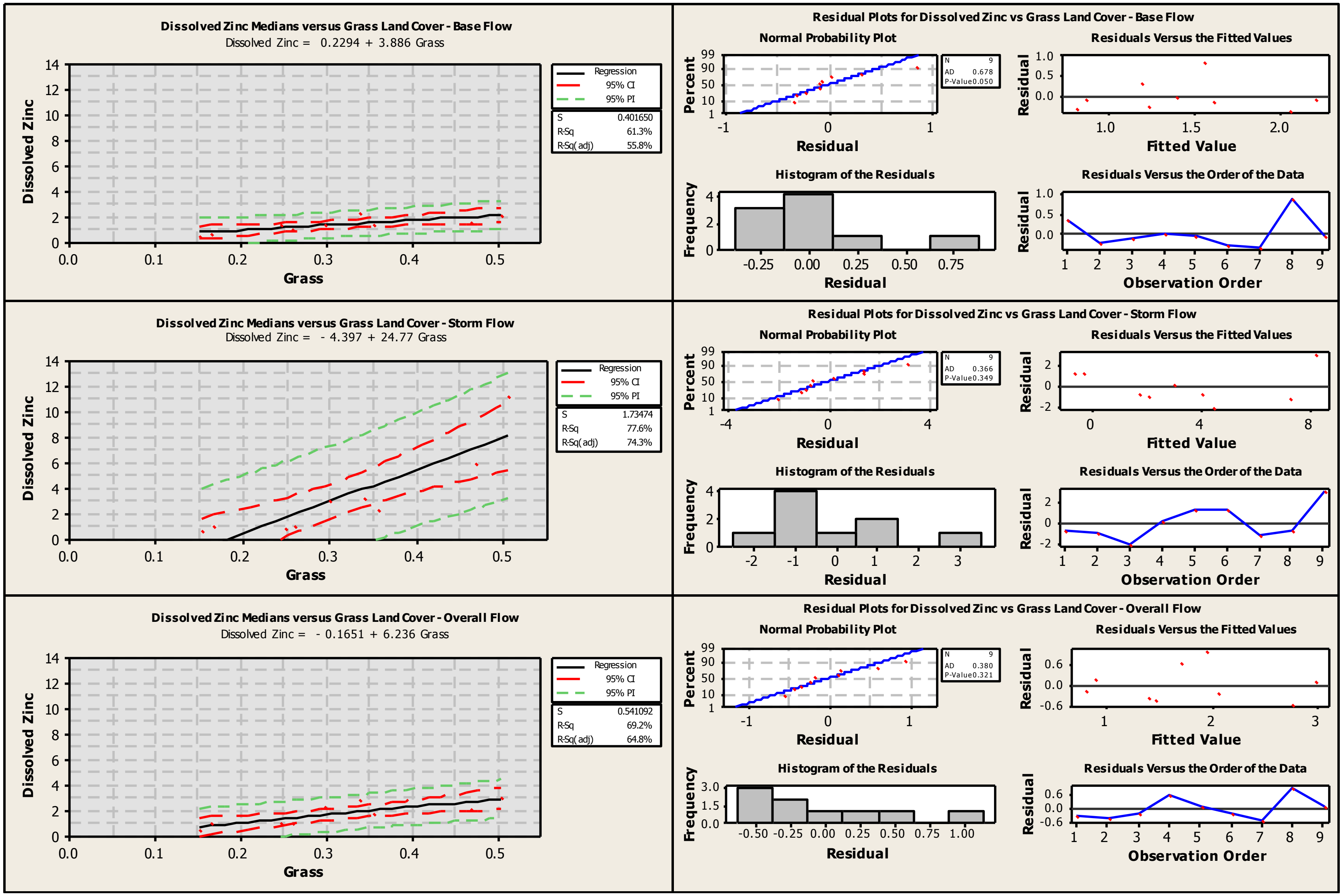
Flow Type Dissolved Copper versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



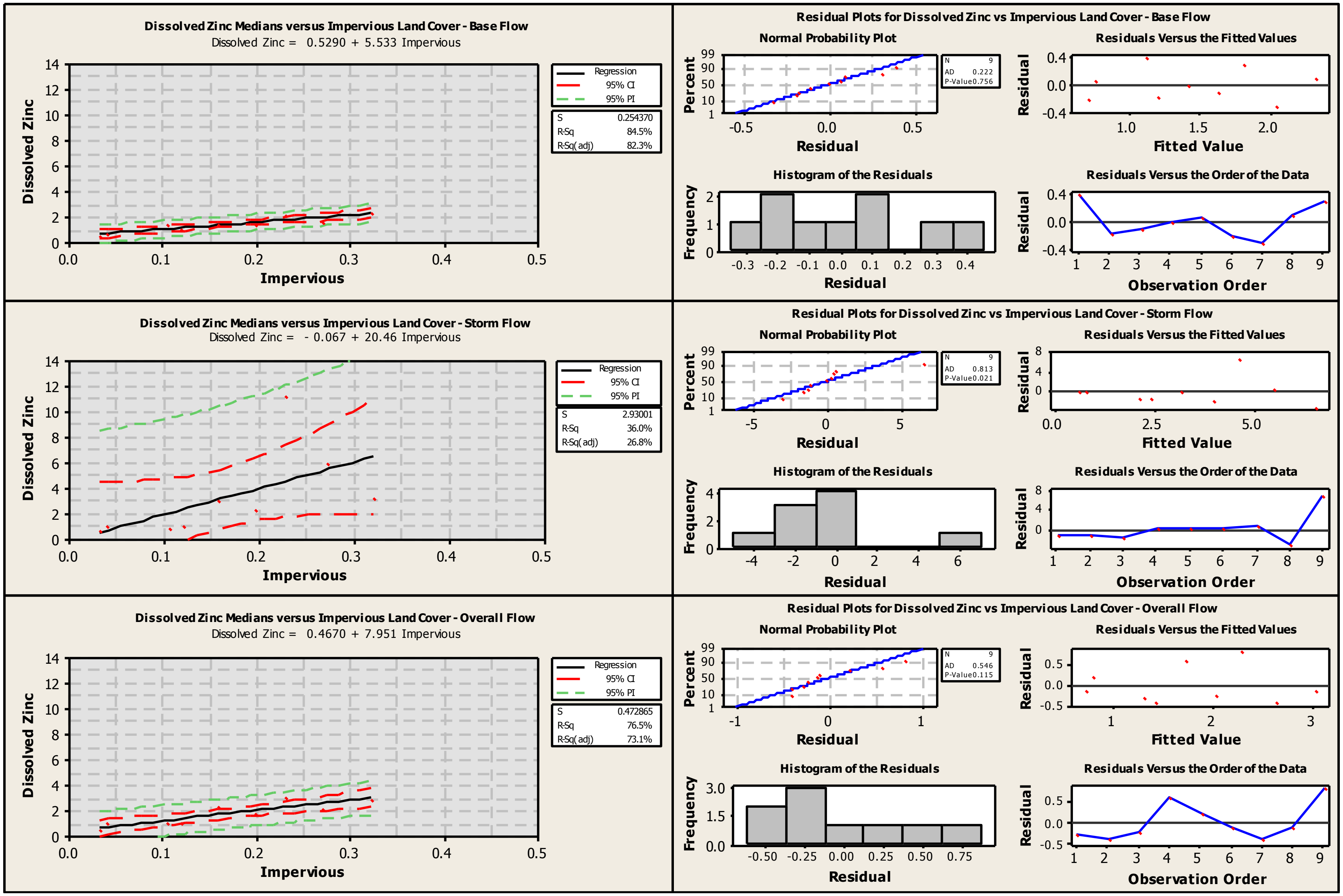
Flow Type Dissolved Zinc versus Forest Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Pasture Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Grass Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations



Flow Type Dissolved Zinc versus Impervious Land Cover Regression Confidence / Prediction Intervals and Assumption Evaluations

Appendix C

Whipple Creek Watershed-Scale Stormwater Plan Report

2015 Benthic Macroinvertebrate Summary

Prepared by

Ian Wigger, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

June 2016

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Figures

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Introduction

The Washington State Department of Ecology issued a 2013-2018 Phase I Municipal Stormwater Permit (Permit) on August 1, 2012 that requires Clark County (County) to select a watershed and perform watershed-scale stormwater planning as outlined in section S5.C.5.c. This summary outlines the results of the 2015 benthic macroinvertebrate field work performed for the Clark County Watershed-Scale Planning of Whipple Creek.

Benthic Macroinvertebrate data, as presented as the Benthic Index of Biological Integrity or BIBI is a widely used stream health indicator in the Pacific Northwest. Macroinvertebrate data will be used to characterize current watershed conditions and compare to modeled flow metrics as described in the Permit. The BIBI is a multimetric index that considers 10 characteristics of the creatures inhabiting gravel riffles in wadeable streams. Stream hydrology impacts on streambed stability have a major influence on the assemblage of creatures livening within the gravel substrate. Benthic macroinvertebrates are good indicators of stream health because of their potentially high numbers, known pollution tolerances, limited mobility, wide range of feeding habits, varied life spans, and dependence on the land environment around the stream. The species and number of macroinvertebrates present in a stream segment are used to calculate a Benthic Invertebrate Index of Biological Integrity (B-IBI) score (Karr, 1998; Karr and Chu, 1999) or other appropriate metrics.

Methods

Sampling Schedule

Most work for benthic macroinvertebrate sampling will take place from July to October. Typically base flow conditions are desired, taking into account low-flow years and the potential for perennial streams to run dry. Benthic macroinvertebrate populations are stable and individuals are large enough to be easily identified at the lab Samples were collected at gravel reaches in the main stem and gravel bedded tributaries during summer base flow (early August 2015).

Representativeness

The Watershed Plan Macroinvertebrate project data are intended to be representative of conditions at each sample station. The Clean Water Division utilizes standard monitoring procedures designed to facilitate the collection of representative samples.

Benthic macroinvertebrate protocols are also designed to facilitate the collection of representative samples. For example, macroinvertebrate sampling is typically conducted moving from downstream to upstream to avoid contamination of downstream samples.

Site Selection

Key of the BIBI metric assumptions limited sites to stream reaches where sample reaches consisted of riffle-habitat with gravel substrate. Whipple Creek geology is predominantly fine-grained Ice Age Cataclysmic Flood deposits with limited amounts of Pliocene Troutdale Formation sand and gravel deposits. Data will be collected at WPL050, WPL080, MCT010, and PCK010. There are over 10 years of macroinvertebrate data at WPL050, and as of 2015, two years at MCT010, PCK010 and WPL080 (Figure1).

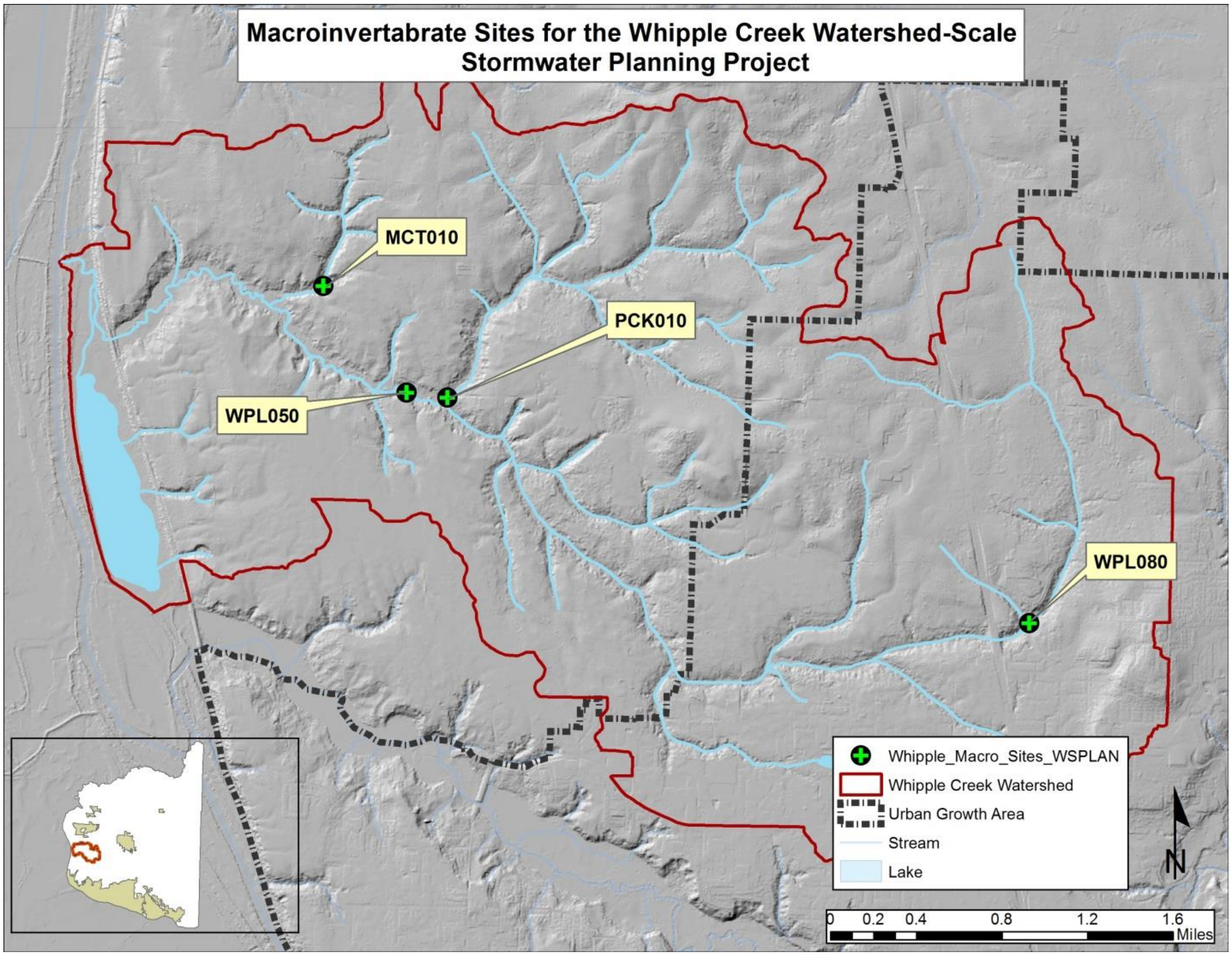

Figure 1 Clark County macroinvertebrate sites

Field Procedures

Benthic macroinvertebrate samples are collected following procedures described in the Washington State Department of Ecology Standard Operating Procedures and Minimum Requirements for the Collection of Freshwater Benthic Macroinvertebrate data in Wadeable Streams and Rivers (Ecology 2010). All sampling, analyses, and data management procedures are conducted according to guidelines established in the Clark County NPDES Whipple Creek Water Quality and Biological Assessment Project (2014), the county's Standard Procedures for Monitoring Activities: Clark County Water Resources Section (2003), and as referenced in the contracts between Clark County and the laboratory facilities.

All field activities are conducted by CWP staff (Figure 2). Benthic macroinvertebrate samples are collected in one liter polyethylene bottles preserved according to laboratory specifications. These samples are kept refrigerated or in coolers until delivery to the contracted benthic macroinvertebrate laboratory for analysis.

Figure 2 B-IBI stream macroinvertebrates field sampling

Results and Discussion

Table 1 provides an assessment of the 2014 B-IBI scores for the Whipple creek subwatershed. Benthic macroinvertebrates are used as an indicator of stream health as they require high water quality for sensitive species to survive in the waterbody. Laboratory-assigned B-IBI ranges biological integrity are:

- Low: 10 - 24
- Medium: 24 – 39
- High: 40 - 50

The higher the presence of sensitive insect species, the more likely fish and other wildlife will thrive at the location. As of 2015, Three out of four stations had low biological health based on the benthic index. PCK010 and WPL050 represented the lowest scores of the sampled reaches. WPL080 had the highest score on the main stem. MCT010 a tributary of Whipple creek had the overall highest score. However, MCT010A, a duplicate sample of MCT010, had a very low score, which may be accounted for in fouling of the substrate but the field crew. Stations with low to moderate biological health reflect impacts from both urban and rural land uses.

Table 1 2015 Clark County BIBI results

Station	Packard Creek		Whipple Creek		Whipple Creek		Whipple tributary		Whipple tributary	
River mile	PCK010		WPL050		WPL080		MCT010		MCT010A-dup	
METRIC	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Total number of taxa	36	3	39	3	43	4	44	4	39	3
Number Ephemeroptera taxa	4	1	4	1	3	1	4	1	4	1
Number Plecoptera taxa	2	1	1	1	5	3	6	3	4	3
Number Trichoptera taxa	5	3	6	3	7	3	6	3	5	3
Number of long-lived taxa	4	3	3	3	4	3	4	3	4	3
Number of intolerant taxa	2	1	1	1	0	1	4	5	2	1
% Tolerant taxa	73.55	1	60.41	1	61.43	1	25.45	3	37.89	3
% Predator	3.5	1	3.7	1	7.3	1	12.5	3	8.4	1
Number of clinger taxa	17	3	19	3	22	5	16	3	19	3
% Dominance (3 taxa)	62.2	3	46.2	5	50.1	3	42.4	5	64	3
TOTAL SCORE		20		22		25		33		24

Error! Reference source not found. provides an assessment of the 2014 B-IBI scores for the Whipple creek subwatershed. All of the scores were poor with the exception of MCT 010 tributary, which is consistent with the 2015 results. MCT010 is a fairly isolated tributary with little urban influences. The site is primarily surrounded by rural private land.

Table 2 2014 Clark County BIBI results

Station	Packard Creek		Whipple Creek		Whipple Creek		Whipple tributary		Packard Creek	
River mile	PCK010		WPL050		WPL080		MCT010		PCK010A-dup	
METRIC	Value	Score	Value	Score	Value	Score	Value	Score	Value	Score
Total number of taxa	31	3	32	3	40	4	44	4	29	3
Number Ephemeroptera taxa	3	1	4	1	2	1	6	1	3	1
Number Plecoptera taxa	2	1	2	1	5	3	7	3	2	1
Number Trichoptera taxa	2	1	5	3	5	3	3	3	2	1
Number of long-lived taxa	4	3	6	5	7	3	7	3	4	3
Number of intolerant taxa	0	1	1	1	1	1	3	5	1	1
% Tolerant taxa	53.96	1	35.25	3	59.50	1	21.58	3	39.93	3
% Predator	1.66	1	0.72	1	5.41	1	2.34	3	1.78	1
Number of clinger taxa	10	1	15	3	14	5	15	3	12	3
% Dominance (3 taxa)	69	3	55	3	54	3	40	5	63	3
TOTAL SCORE		16		24		24		32		20

Maximum score of 50.
Each metric scored:
1=low, 3=moderate, 5=high

Conclusions

The B-IBI scores for the 2015 sampled year are consisted with the urbanized land-use expected. Biological condition has remained about the same over the two-year assessment period.

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Appendix D

Whipple Creek Watershed-Scale Stormwater Plan Report

Status of Aquatic Community with a Focus on Fish Use

Prepared by

Bob Hutton, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

November 2014

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Introduction

This chapter summarizes the aquatic community status for the Whipple Creek Watershed Stormwater Plan to help meet Clark County's 2013-2018 NPDES stormwater permit section S5.C.5.c.ii.(1)d requirements. The complexity of an entire community, a self-sustaining system of interacting physical and biological components, forces a reduced scope of evaluation (Hauer and Lamberti, 2006, p. 490) for aquatic systems often to fishes. Under the permit, salmonids are the primary focus of the biological conditions assessment utilizing several existing sources of plan area data. Data sources and uses were: the Statewide Washington Integrated Fish Distribution (SWIFD) geodatabase (Washington State Department of Fish and Wildlife [WDFW], 2014) for salmonid presence / distribution; SalmonScape web page (WDFW, 2014) for fish passage barriers and Endangered Species Act listings; Whipple Creek Stormwater Needs Assessment Program (SNAP) report (Clark County, 2006) for a detailed stream reach physical habitat assessment; and an associated SNAP technical memo (Inter-Fluve, Inc., 2006) with field observations for multiple Whipple Creek watershed stream segments. ArcMap (ESRI, 2010) was used to summarize the latest Whipple Creek watershed salmonid presence and distribution spatial data.

Presence and Distribution of Salmonid Uses

Figure 1 through Figure 4 map the presence and distributions of salmonid species within the Whipple Creek Watershed based on SWIFD (WDFW, 2014). Each map presents the spatial distribution (and applicable general timing of the species run), basis for distribution definitions, and life cycle history for: coho salmon, fall chinook salmon, winter steelhead trout, and rainbow trout. Table 1summarizes salmonid use information on a stream reach basis for Whipple Creek mainstem, Packard Creek, an unnamed mid-watershed tributary, and the lower watershed's Green Lake and its outlet stream.

Three SWIFD fish distribution types are applicable to the Whipple Creek watershed (WDFW, 2014): *Documented* - "Aquatic stream habitat that is documented to be presently utilized by fish (based on reliable published sources, survey notes, first-hand sightings, etc.). This includes habitat used by any life history stage for any length of time. This designation is applied to all stream sections downstream of a documented sighting to the next documented habitat section, unless otherwise indicated by a formal review group. Synonyms include 'Known' and 'Currently Occupied'."

Presumed – "Aquatic habitat lacking reliable documentation of fish use where, based on the available data and best biological opinion/consensus, fish are presumed to occur. For migratory fish, such habitat will extend upstream to the end of the stream OR to the first known natural barrier (including sustained 12% stream gradient or small stream size). Best biological judgment includes consideration of suitable (species-specific) habitat availability, life history strategies, proximity and connectivity to adjacent documented habitat sections or logical extrapolation of range from similar systems. Synonyms include 'Suitable Habitat'."

Potential – "Aquatic habitat that meets the basic criteria for 'Presumed' but is unused by fish due to artificial (man-made) obstructions, degraded habitat quality, or extirpation of local fish populations. This category is used in cases where habitat could be made available to fish through removal of obstructions, improvement of habitat, or re-introductions of fish. Synonyms include 'Recoverable Habitat'."

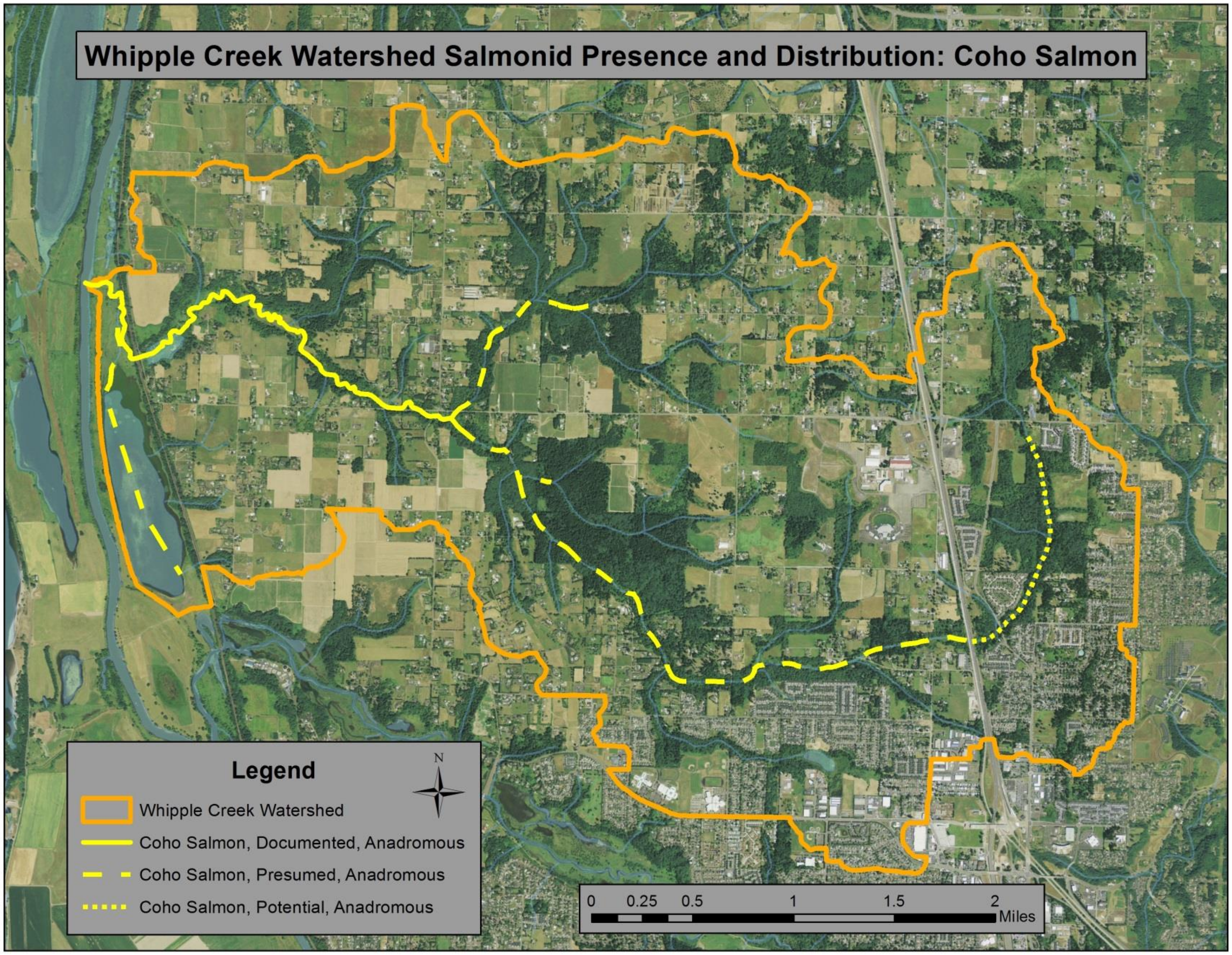

Figure 1 Whipple Creek Watershed Coho Salmon presence and distribution

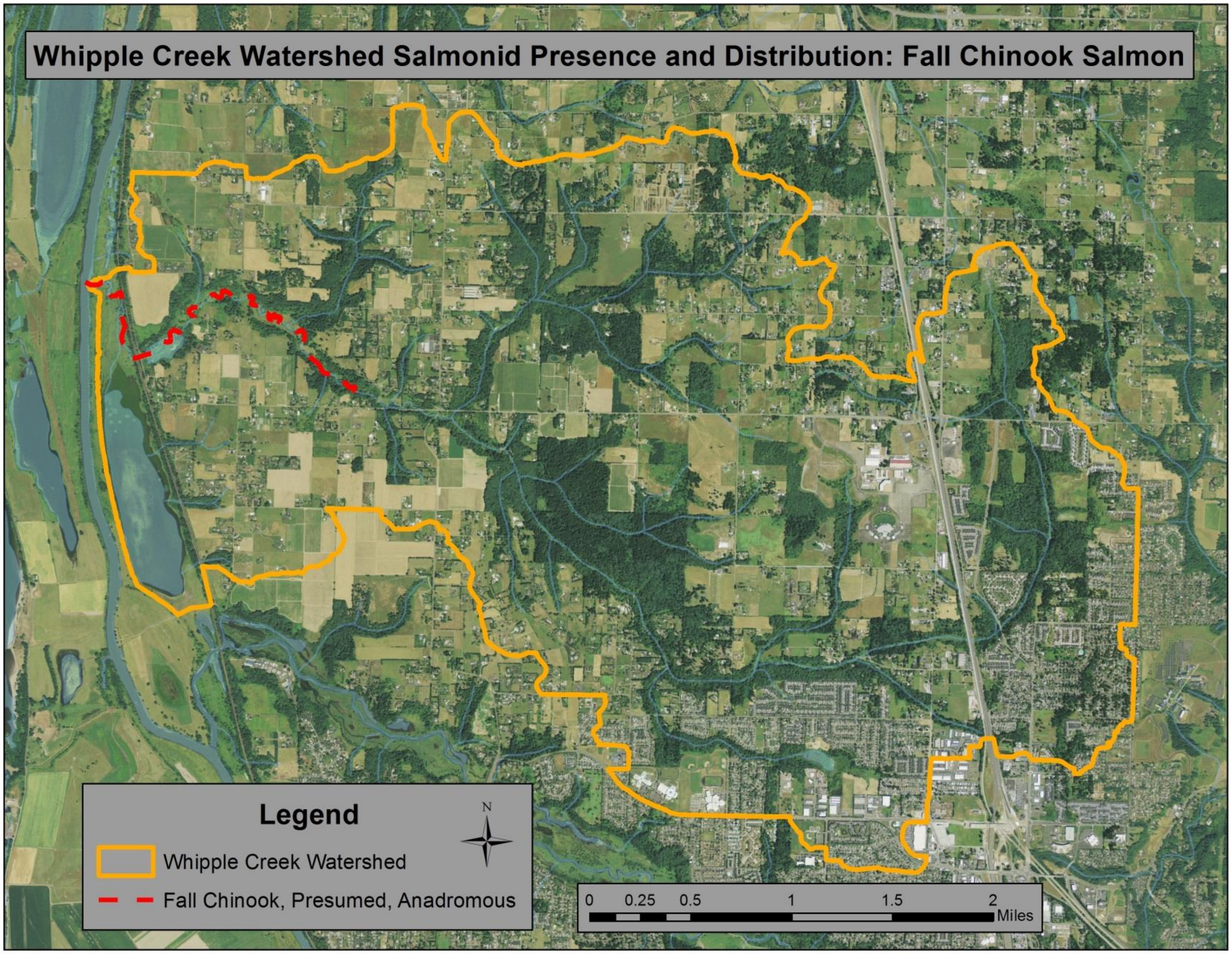

Figure 2 Whipple Creek Watershed Fall Chinook Salmon presence and distribution

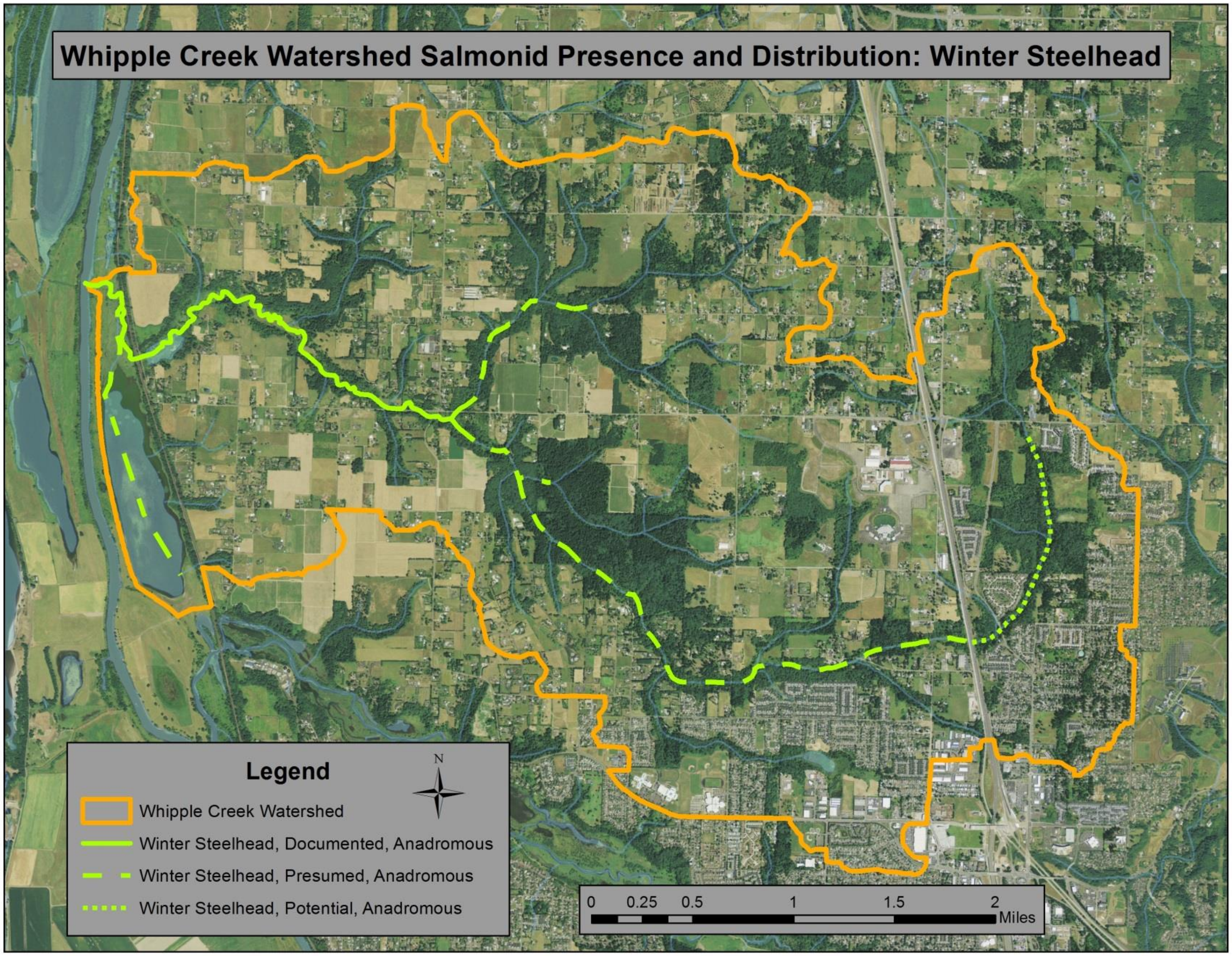

Figure 3 Whipple Creek Watershed Winter Steelhead Trout presence and distribution

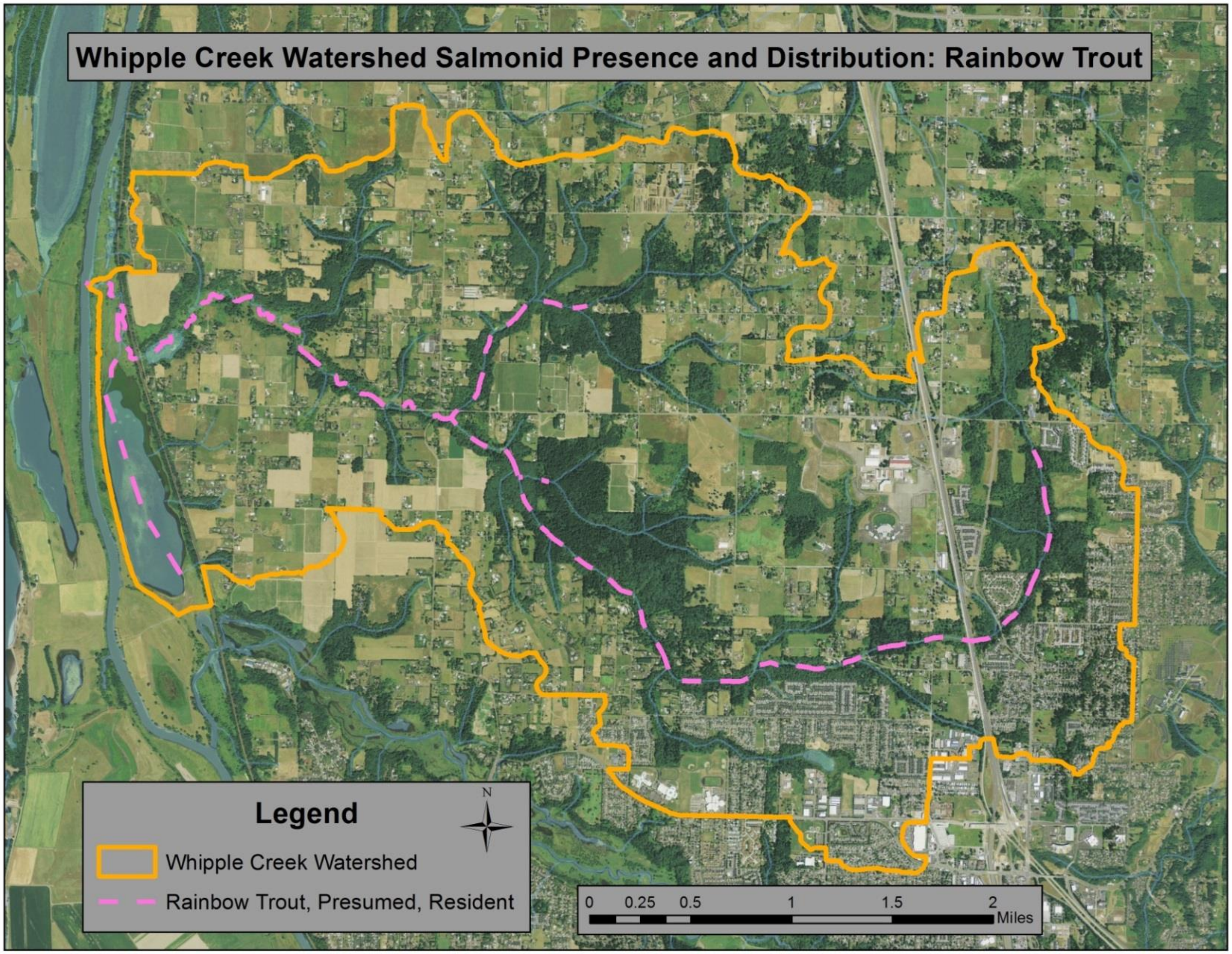

Figure 4 Whipple Creek Watershed Rainbow Trout presence and distribution

Table 1 Summary of presence and distribution of salmonid uses in the Whipple Creek watershed

Salmonid Species / Run	Whipple Creek Watershed Waterbody*	Timing of Species Run	Distribution Type	Use Type Description	Life Cycle History	Stream Reach Length (ft.)	% of Specie's Stream Reaches	Total Reach Length (ft.)	Brief Reach Descriptor (Approximate Distances)
Coho Salmon	Whipple Creek Mainstem	Unknown	Documented	Presence	Anadromous	15,944	40		Whipple Mainstem to Packard Tributary
		Unknown	Presumed	Presence	Anadromous	17,369	44		Whipple Mainstem between Packard & I-5
		Unknown	Potential	Presence	Anadromous	6,460	16	39,772	Whipple Mainstem above Interstate 5 (I-5)
	Packard Creek Tributary	Unknown	Documented	Presence	Anadromous	178	3		Lowest 0.1 mi. of Packard Creek
		Unknown	Presumed	Presence	Anadromous	4,899	89		All Packard Crk. except uppermost 0.1 mi.
		Unknown	Presumed	Presence	Anadromous	410	7	5,486	Uppermost 0.1 mi. Packard Creek
	Unnamed Tributary	Unknown	Presumed	Presence	Anadromous	874	100	874	Unnamed Right Bank Tributary 0.5 mi. upstream of Packard Creek
	Green Lake*	Unknown	Presumed	Presence	Anadromous	7,579	100	7,579	Green Lake and outlet reach
Fall Chinook Salmon	Whipple Creek Mainstem	Fall	Presumed	Presence	Anadromous	12,941	100	12,941	Whipple Mainstem from mouth to 3/4 way up to Packard Creek
Winter Steelhead Trout	Whipple Creek Mainstem	Winter	Documented	Presence	Anadromous	15,941	40		Whipple Mainstem to Packard Tributary
		Winter	Presumed	Presence	Anadromous	17,372	44		Whipple Mainstem between Packard & I-5
		Winter	Potential	Presence	Anadromous	6,460	16	39,772	Whipple Mainstem above I-5
	Packard Creek Tributary	Winter	Documented	Presence	Anadromous	388	7		Lowest 0.1 mi. of Packard Creek
		Winter	Presumed	Presence	Anadromous	4,689	86		Packard Creek except lowest & uppermost 0.1 miles
		Winter	Presumed	Presence	Anadromous	375	7	5,451	Uppermost 0.1 mi. Packard Creek
	Unnamed Tributary	Winter	Presumed	Presence	Anadromous	855	100	855	Unnamed right bank tributary 0.5 mi. upstream of Packard Creek
	Green Lake*	Winter	Presumed	Presence	Anadromous	7,579	100	7,579	Green Lake and outlet reach
Rainbow Trout	Whipple Creek Mainstem	NA	Presumed	Presence	Resident	39,772	100	39,772	All Mainstem Whipple Creek
	Packard Creek Tributary	NA	Presumed	Presence	Resident	5,077	93		All Packard Crk. except Uppermost 0.1 mi.
		NA	Presumed	Presence	Resident	386	7	5,463	Uppermost 0.1 mi. Packard Creek
	Unnamed Tributary	NA	Presumed	Presence	Resident	808	100	808	Unnamed right bank tributary 0.5 mi. upstream of Packard Creek
	Green Lake*	NA	Presumed	Presence	Resident	7,579	100	7,579	Green Lake and outlet reach

* Green Lake waterbody includes its outlet stream reach; Data source: Statewide Washington Integrated Fish Distribution (SWIFD), WDFW, 2014

Fish Passage Barriers

The WDFW SalmonScape interactive computer mapping website was utilized to research Whipple Creek watershed's salmonid fish passage barriers and possible Endangered Species Act (ESA) status. This information can help identify and prioritize potential salmonid protection areas, mitigation activities, and restoration sites that offer the most benefit to fish (WDFW SalmonScape Help webpage "Interacting with SalmonScape", 2014). The website merges into an integrated, accessible system salmonid fish distribution, use and habitat data collected by state, federal, tribal and local biologists from Limiting Factors Analysis and Salmonid Data Information Integration projects. SalmonScape is based on the Washington Integrated Fish Distribution (WIFD) dataset, which combines WDFW and NorthWest Indian Fish Commission (NWIFC) fish distribution information. SalmonScape hydrology utilizes the National Hydrographic Dataset (NHD), the new state and federal standard for depicting waterbodies.

Based on existing Whipple Creek watershed information downloaded from WDFW SalmonScape website, Figure 5 depicts fish passage barriers for all salmonid fish species (same anadromous species as shown in this chapter's previous figures). Table 2 summarizes the SalmonScape salmonid fish passage barriers information (from downstream to upstream, including tributaries) along applicable stream reaches depicted as black stream lines in Figure 5.

ESA Listings

SalmonScape also provides mapped distribution information on Endangered Species Act (ESA) listing units that are current as of January 2013 (WDFW - SalmonScape, 2014, "Interacting with SalmonScape" Help web page). These include National Oceanic and Atmospheric Administration (NOAA) Fisheries Evolutionary Significant Units (ESUs) for salmon and US Fish and Wildlife Service (USFWS) Distinct Population Segments (DPS) for Steelhead trout. Under ESA, a "species" can be listed as *endangered* if it is in danger of extinction throughout all or a significant portion of its range or *threatened* if it is likely to become an endangered species within the foreseeable future (NOAA, 2014).

The 1991 NOAA Technical Memorandum MFS F/NWC-194 (NOAA, 1991) states: 'For the purposes of the ESA, a "species" is defined to include "any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature". For anadromous Pacific salmonids, a distinct population segment is interpreted as 'a population (or group of populations) will be considered "distinct" (and hence a "species") if it represents an evolutionary significant unit (ESU) of the biological species. A population must satisfy two criteria to be considered an ESU: 1. It must be reproductively isolated from other conspecific population units, and 2. It must represent an important component in the evolutionary legacy of the species.' The memo further clarifies: 'Isolation does not have to be absolute, but it must be strong enough to permit evolutionarily important differences to accrue in different population units. The second criteria would be met if the population contributed substantially to the ecological /genetic diversity of the species as a whole.'

SalmonScape maps indicate all of Whipple Creek watershed's respective anadromous salmonid distributions (also shown in Figure 1 through Figure 3) have ESA Listing Units that are "Threatened, Accessible" (portions free of manmade blockage, dams). These Lower Columbia River ESA Listing Units include fall chinook and coho salmon ESUs as well as winter steelhead DPS. "ESU/DPS are the spatial extents of populations, defined under the ESA, as Endangered, Threatened, a Species of Concern, or Not Warranted for listing" (WDFW - SalmonScape, 2014, "Interacting with SalmonScape" Help web page).

Areas of Whipple Creek Watershed with Fish Passage Barriers

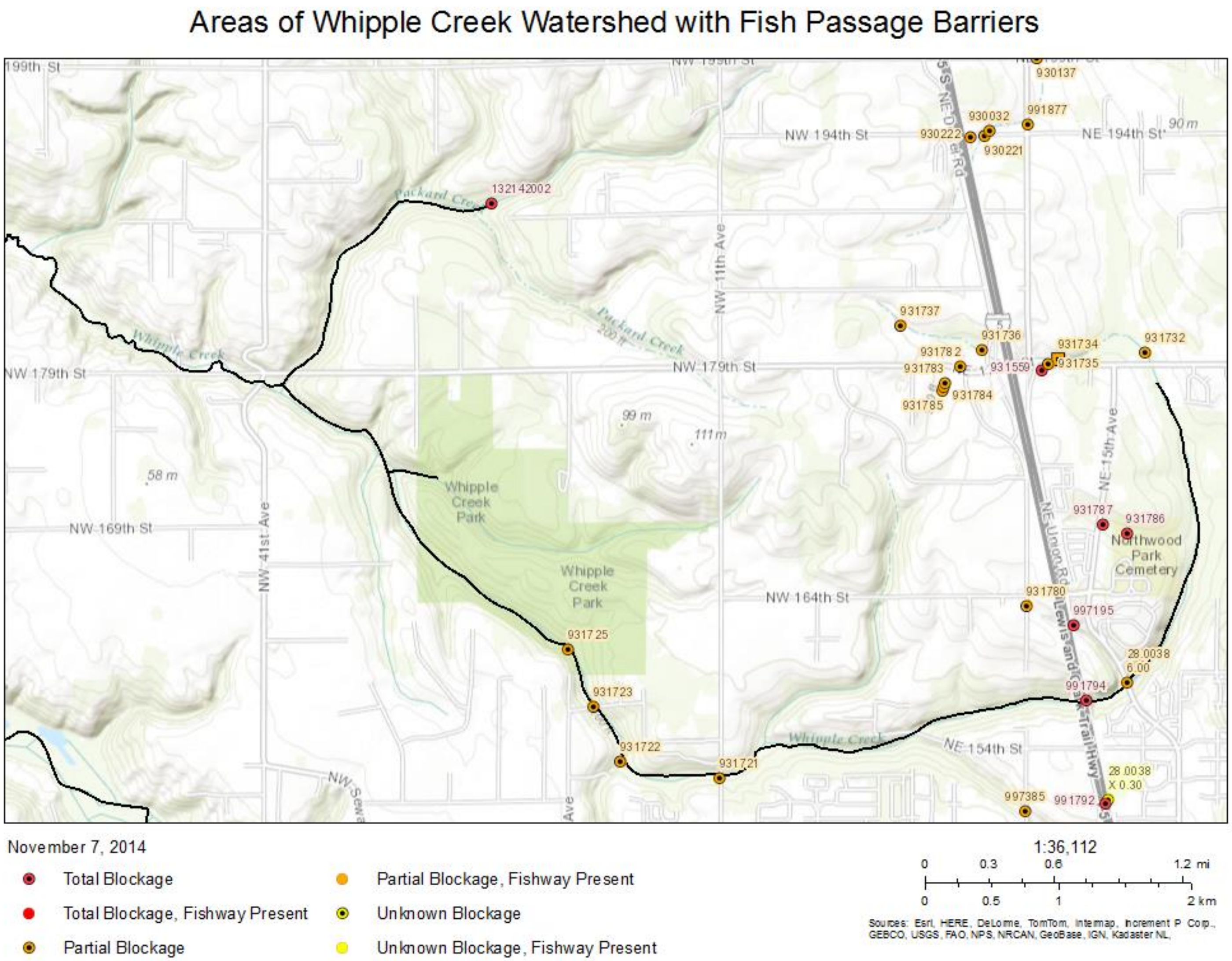

Figure 5 Salmonid fish passage barriers within the Whipple Creek Watershed based on WDFW SalmonScape web page

Table 2 Whipple Creek watershed's stream fish passage barrier details from WDFW SalmonScape

Site Number	Road	Stream	Fish Use	Fish Use Criteria	Feature Type	Barrier Status	Blockage	Fishway	Survey Date	Owner Type
132142002	Prvt; NW 189th St	Fraser Creek (Trib. to Packard Creek)	Yes	Mapped	Culvert	Yes	Total	No	6/27/2014	Private
931725	<Null>	Whipple Creek	Yes	Biological	Culvert	Yes	Partial	No	1/25/2011	County
931723	<Null>	Whipple Creek	Yes	Biological	Culvert	Yes	Partial	No	1/25/2011	Private
931722	<Null>	Whipple Creek	Yes	Biological	Culvert	Yes	Partial	No	1/25/2011	Private
931721	NW 11th Ave	Whipple Creek	Yes	Biological	Culvert	Yes	Partial	No	1/24/2011	County
991794	I-5	Whipple Creek	Yes	Physical	Culvert	Yes	Total	No	2/8/2011	State
28.0038 6.00	NE Union Rd	Whipple Creek	Yes	Biological	Culvert	Yes	Partial	No	2/8/2011	County

Aquatic Community Status Focused on Multiple Stream Segments

In addition to the above statewide salmonid database perspective, this section utilizes more detailed local information to summarize historical impacts to and the present status of the Whipple Creek watershed aquatic community's physical and biological components. Figure 6 and the following four subsections (Aquatic Habitat, Fish Species Presence, Passage Barriers, and Physical Habitat Availability) are primarily excerpts from a consultant's technical memorandum (Inter-Fluve, Inc., May 18, 2006) supplement to the 2006 Whipple Creek SNAP report (Clark County, 2006, p. 102 [Figure 6] and pp. 134-136). The consultant reviewed existing watershed information, made field observations of targeted stream segments, and suggested further evaluations. Figure 6 depicts the stream segments surveyed by Inter-Fluve, Inc. staff on five field trips during the winter –spring of 2005-2006. Unless noted otherwise in the text, location identifiers (e.g., tributary W#.##, R.M #.#) utilize river mile distances upstream from the mouth of Whipple Creek as shown in Figure 6.

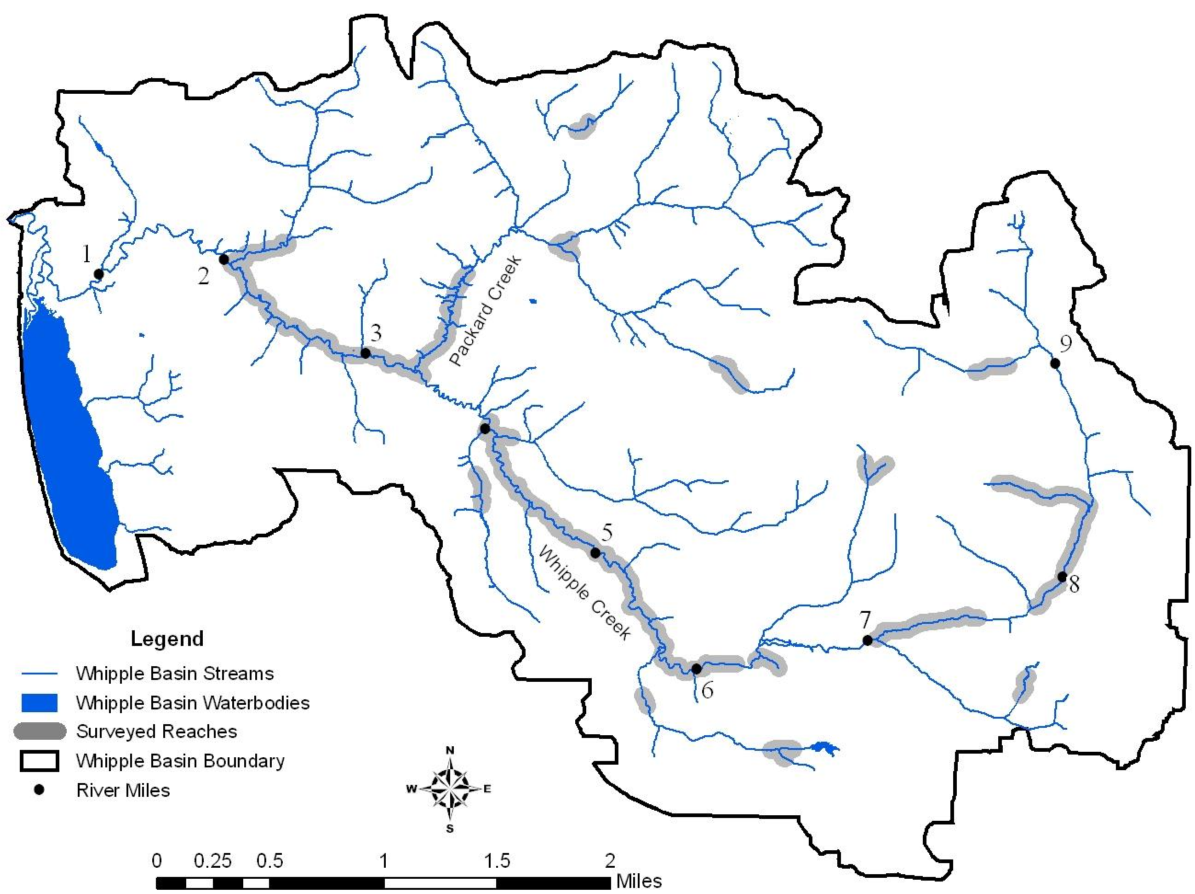

Figure 6 Stream segments surveyed by Inter-Fluve, Inc. (graphic from 2006 Technical Memo)

Aquatic Habitat

Aquatic habitat conditions would historically have been good in Whipple Creek, especially for fish such as coho, steelhead, and cutthroat trout that utilize small streams (Clark County, 2006, p. 134). Habitat has been affected by a century of land use impacts and may have improved considerably since the original phase of timber harvest and land clearing for agriculture (except possibly in currently urbanized areas). Land clearing would have altered flow regimes and increased fine sediment delivery. Riparian timber harvest would have reduced streambank integrity, reduced shading, and reduced large wood recruitment. As with many streams in the region, direct removal of wood from channels would have altered channel morphology and removed important fish habitat including pools and cover.

In the years following initial land clearing, conditions would have improved due to channel adjustment to the new sediment and flow regime and re-growth of riparian forests (Clark County, 2006, p. 134). In the 1970s, however, urbanization in the upper watershed began to alter stream hydrology and increase pollutants that not only impacted the aquatic habitat again but also had the potential for long-lasting effects. Aquatic habitat integrity generally declines with urbanization (Schueler 1994, May et al. 1997). The hydrologic, channel geomorphic, riparian, and floodplain processes resulting from urbanization tend to reduce and simplify the habitats that are available for aquatic organisms. The presence of suitable substrates, pools and riffles, cover, cool temperatures, dissolved oxygen, and access to channel habitats can all become impaired.

Fish Species Presence

According to accounts from local biologists, cutthroat trout have been observed in the mainstem upstream of I-5 and steelhead have been observed in the mainstem near the Packard Creek confluence and in Packard Creek itself (Clark County, 2006, pp. 134-135). A field visit on December 14, 2005 noted a potential coho redd in lower Packard Creek. The mainstem up to I-5, Packard Creek, and the lower quarter mile of tributary W2.04 are accessible to anadromous fish. However, given the lack of quality habitat in the mainstem above Packard Creek, anadromous use probably does not extend much beyond this point.

The species most likely to be present in the watershed are coho, steelhead, and cutthroat trout (Clark County, 2006, p. 135). The watershed’s streams are too small for any significant use by chinook salmon. Although chum salmon may have historically been present in low numbers in the lower mainstem, their poor status in the region suggests they are currently absent from the system. The numbers of all species are likely to be low because of lack of quality habitat.

Passage Barriers

The I-5 and Union Road crossings likely obstruct fish passage on the mainstem. Passage through this area needs further evaluation. There are also barriers on several mainstem tributaries (Clark County, 2006, p. 135). One of the most significant is a perched culvert at an abandoned stream crossing about a quarter mile up tributary W2.04. This stream contains good gravels and the basin is relatively intact, suggesting that opening up this barrier could provide access to quality habitat. Additional investigation into the extent of upstream habitat should be conducted. A damaged culvert at tributary W4.09 may also be blocking access to suitable habitats on this tributary stream. The extent and quality of habitat above this blockage also warrants further investigation.

There are many large, channel-spanning beaver dams on the mainstem and Packard Creek that could potentially limit fish passage (Clark County, 2006, p. 135). Some large beaver dams that remain in place year after year may warrant investigation for fish passage. The potential benefits of removing beaver dams to increase passage should be weighed against the potential impacts on channel and floodplain function.

Physical Habitat Availability

Field observations suggest spawning habitat is the greatest limiting factor for salmonids in the basin. Habitat is naturally limited due to stream sizes, topography, and substrate conditions. Human alterations have further limited available habitat through changes to the sediment and flow regimes, fish passage conditions, and increased channel degradation (Clark County, 2006, p. 135).

Rearing habitat in the form of beaver ponds is abundant (Clark County, 2006, p. 135). These areas provide important winter refuge for young coho salmon. Studies on the Oregon coast have shown that winter rearing habitat is typically limiting for coho (Nickelson, 1998). Whipple Creek, in contrast, contains scarce spawning habitat but abundant beaver pond habitat, suggesting that spawning is limiting factor. Compared to coho, steelhead rearing habitat is less abundant. Steelhead prefer to rear in higher gradient channels, where they can seek flow refuge behind structures (wood, substrate) while having quick access to adjacent high flow areas for drift feeding. Age-0 steelhead are likely to rear in their natal stream. Age-1 steelhead, due to their larger size and feeding requirements, are more likely to rear in the mainstem.

A quick gage of available habitat can be conducted by looking at stream gradient and channel type (Clark County, 2006, pp. 134-135). Suitable spawning habitat for anadromous salmonids is typically located in pool-riffle or plane-bed channels with gradients less than 3% (Montgomery et al. 1999). In the Whipple Basin, channels below approximately 0.5% slope contain sand and silt substrate that is unsuitable for spawning. This leaves a few isolated areas where conditions are suitable. These include the mainstem between river mile 2.4 and 3.2, lower Packard Creek, and the lower end of tributary W2.04. Other potentially suitable areas, such as tributary W4.09 and the mainstem above I-5, are isolated by passage barriers but may contain suitable habitat for resident cutthroat.

The best habitat is located on the mainstem between river mile 2.4 and 3.2 (Clark County, 2006, p. 136). This is a pool-riffle and plane-bed reach with suitable gradient and spawning gravels. Wood accumulations create pools, cover, and habitat complexity. Moderate-to-high shading is provided by relatively intact riparian canopies and by topography in some areas. The pasture reach downstream of RM 2.2 may have provided suitable habitat historically, but incision has lowered the gradient and simplified the channel.

The lower portion of Packard Creek also contains suitable habitat, although gravels are less abundant than in the mainstem (Clark County, 2006, p. 136). Pool-riffle sequences are interspersed with segments of lesser quality, where channel incision has degraded habitat complexity.

Tributary 2.04, while small, contains abundant gravels that would be suitable for coho, steelhead and resident trout spawning. The lower few hundred feet, which courses through the low gradient floodplain of mainstem Whipple Creek, is deeply entrenched and would have to be evaluated for fish passage (Clark County, 2006, p. 136).

Detailed Physical Habitat Assessment for Lower Watershed Stream Segment

During 2002, Clark County staff collected detailed quantitative habitat measurements for a 500-foot mainstem stream reach just upstream from the mouth of Packard Creek in the lower portion of the Whipple Creek watershed (Clark County, 2006, pp. 96-98, 191). This analyzed reach is mostly just upstream from the upper extent of the mainstem reach identified by Inter-Fluve, Inc. as the best suitable spawning habitat in the Whipple Creek watershed. The USEPA Environmental Monitoring and Assessment Program (EMAP) Western Pilot Study: Field Operations Manual for Wadeable Streams (Peck et al., eds. 2001) methods guided this reach work.

The EMAP protocols are designed for robust, quantitative descriptions of reach-scale habitat that could be used for site classification, trend interpretation, and analysis of possible causes of biotic impairment (Peck et al., 2001). The protocols allow calculation of numeric results for several habitat categories metrics such as channel morphology, substrate composition, fish cover, and canopy density, as well as overall habitat quality (e.g., Habitat Quality Index: HQI).

The calculated HQI, reflecting the overall habitat quality for the monitored Whipple Creek reach, indicated a highly disturbed system with marginally functional stream conditions (Clark County, 2006, pp.96-98). Site-specific overall riparian quality rated good based on relatively abundant fish cover and moderate riparian shading but these do not necessarily integrate or reflect watershed-wide conditions. For most other metrics, including those that integrate impacts from the upstream watershed, Whipple Creek fell short of desired conditions including being the most “flashy” of ten streams evaluated during 2002. The monitored reach channel morphology was dominated by glide habitat, with far fewer pools and riffles than recommended. The stream reach’s substrate was also dominated by sand, silt, and fine gravels, with a high level of embeddedness reflecting a relatively unstable streambed. Total Large Woody Debris (LWD) density was relatively high in the assessed reach but most pieces were not large enough to qualify as high quality wood. Invasive plants, especially Himalayan blackberry and Reed Canary grass, dominated the monitored riparian vegetation.

While the results from the EMAP evaluation of the single 500-foot reach may not be indicative of the entire stream system, the cumulative upstream land use impacts have resulted in a highly disrupted and unstable stream at the assessment site (Clark County, 2006, p. 98). The assessment metrics indicate that Whipple Creek is subject to high flows and carries a significant amount of silt and sediment. The SNAP report’s Physical Habitat Assessment section concludes “stormwater projects and watershed activities that help stabilize flow regime and control channel erosion could lead to localized improvements in stream habitat. However, due to the complexity and extent of influences on hydrologic condition, it is difficult to predict whether stormwater projects alone can have a substantial impact on watershed-wide habitat quality.”

Conclusions

From the stormwater permit focused perspective of salmonid uses, the overall status of the Whipple Creek watershed planning area's aquatic community appears seriously degraded. Good quality salmonid habitat is very limited due to small stream sizes, substrate conditions, and human alterations to the watershed.

While resident rainbow and cutthroat trout are presumed to utilize much of the watershed's streams, anadromous salmonids' use is much more limited by small stream size, fish passage barriers, and habitat quality (WDFW SWIFD, 2014 and SalmonScape, 2014). Based on state salmonid presence and distribution information for Endangered Species Act salmonids listed as threatened, there is documented presence of listed coho salmon and winter steelhead on the mainstem below its confluence with the Packard Creek tributary and the lowermost several hundred feet of this tributary. Additionally, there is a presumed presence of threatened fall chinook in the approximately 13,000 lowermost feet of the mainstem. Whipple Creek's main stem up to I-5, much of the lower half of the Packard Creek tributary, and the lower quarter mile of an unnamed tributary at river mile 2.04 have no known total blockages for fish passage. However, there are four partial blockage culvert barriers on the mainstem midway between the Packard Creek confluence and the total blockage culvert under I-5. Given the lack of quality habitat in the mainstem above Packard Creek, anadromous use probably does not extend much beyond this point.

Based on existing information and field observations across multiple stream reaches within the Whipple Creek watershed, land use activities over time have negatively impacted the aquatic community's physical and biological components. Prior to timber harvest and land clearing for agriculture, watershed aquatic habitat conditions were likely good for fish utilizing small streams (Inter-Fluve, Inc. 2006 / Clark County 2006, p. 134). Timber harvest and land clearing would have altered flow regimes, increased fine sediment delivery to streams, reduced streambank integrity and shading, and reduced large wood recruitment. These would have resulted in altered channel morphology and removal of important pools and cover habitat for fish. In the years following initial land clearing, conditions likely improved due to channel adjustment to the new sediment and flow regime and regrowth of riparian forests. However, starting in the 1970's impacts from urbanization in the upper watershed again altered stream hydrology and contributed pollutants, both with the potential for long lasting effects.

"Field observations suggest spawning habitat is the greatest limiting factor for salmonids in the basin. Habitat is naturally limited due to stream sizes, topography, and substrate conditions. Human alterations have further limited available habitat through impacts to the sediment and flow regime, fish passage conditions, and channel degradation (Inter-Fluve, Inc. 2006 / Clark County 2006, pp. 135-136)". The best habitat is located on the mainstem between river mile 2.4 and 3.2 where there is a pool-riffle / plane-bed reach with suitable gradient, spawning gravels, habitat complexity, and riparian shading.

While not necessarily indicative of the entire Whipple Creek watershed, cumulative upstream land use impacts have resulted in a highly disrupted and unstable 500-foot stream reach near the mouth of Packard Creek based on a habitat evaluation using EPA protocols (Clark County, 2006, p. 98). The SNAP report's Physical Habitat Assessment section concludes "stormwater projects and watershed activities that help stabilize flow regime and control channel erosion could lead to localized improvements in stream habitat. However, due to the complexity and extent of influences on hydrologic condition, it is difficult to predict whether stormwater projects alone can have a substantial impact on watershed-wide habitat quality."

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Appendix E

Whipple Creek Watershed-Scale Stormwater Plan Report

Watershed Areas Appropriate for Special Attention in Regard to Hydrologic and Water Quality Impacts

Prepared by

Chad Hoxeng, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

December 2016

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Introduction

Whipple Creek watershed is located in southwest Clark County, draining west from low hills to the Columbia River flood plain (**Error! Reference source not found.**). The watershed's land use was once dominated by rural and agricultural land uses. Currently the watershed is moderately developed with a mix of rural lands, as well as urban and urbanizing areas at the northern edge of the unincorporated Vancouver Urban Growth Area (UGA). The 8.8 square mile upper sub-watershed (including Packard Creek) has approximately 4.4 square miles inside the UGA while the 3.3 square mile lower subwatershed is entirely outside the UGA. Historic land clearing and development impacts have degraded stream habitat and caused areas of severe channel instability and erosion. Impacts on channel stability, water quality, and overall ecological function from urbanization within the watershed are consistent with those documented elsewhere around Washington State.

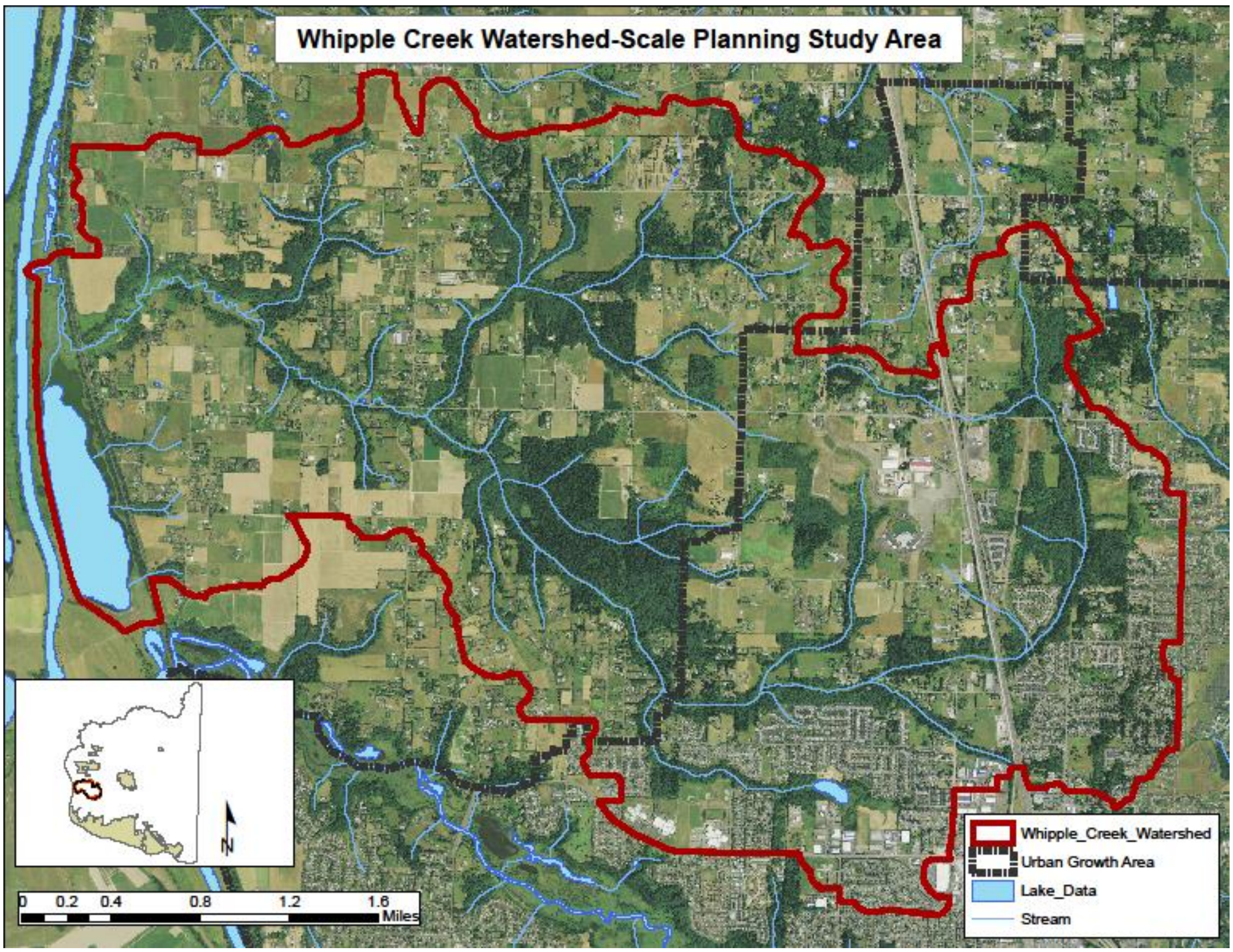

Figure 1 Whipple Creek watershed area map

The Whipple Creek stream system's designated beneficial uses are for: 1) aquatic life use of salmonid spawning, rearing, and migration; and, 2) human use of primary contact recreation and swimming (WAC 173-201A-020). However, it is degraded due to historical clearing and development. Additionally, the Whipple Creek watershed is predicted to become increasingly developed under future conditions, especially within the UGA and along the Interstate 5 corridor.

This chapter presents a review of Whipple Creek watershed historic field observations, existing reports, and geographic information system (GIS) data analyses to identify areas appropriate for special attention in regard to hydrologic and water quality impacts for watershed planning.

This analysis is designed to help address Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (Permit) section S5.C.5.c.ii.2 watershed-scale stormwater planning requirements (WA Dept. of Ecology, 2012). Specifically, areas appropriate for special attention in regard to hydrologic and water quality impacts are identified and mapped. Such areas include riparian buffers, wetlands, hydric soils, floodplains, steep slopes, forests, valuable habitat zones, and other sensitive resource areas. Human caused disturbances and impacts in and around these areas of special attention should be avoided. If disturbance or impacts are unavoidable, they should be minimized through stormwater best management practices to reduce further impacts on channel stability, water quality, and overall ecological function.

Methods

Review of reports of data for stream reconnaissance was conducted by Clark County Clean Water Division from December 2004 through May 2005. County staff assessed about 25 miles of Whipple creek and its tributaries. Stream reaches were assessed for stormwater impacts and stream enhancement opportunities. The assessment of stream reaches utilized the Unified Stream Assessment (USA) protocol designed by the Center for Watershed Protection (March 2004) for EPA's Office of Water Management. The USA is part of a larger set of protocols developed by the Center as an integrated framework for improving and rehabilitating small urban watersheds. Assessments focused first on the more heavily developed upper watershed stream reaches, followed by the more rural Packard Creek tributary. Stream reconnaissance data were recorded and mapped in the field, then transferred digitally to a shapefile using ESRI ArcMap software.

The current Whipple Creek watershed planning GIS analysis included utilizing existing shapefile data and creating new shapefiles to identify and map areas appropriate for special attention in regard to hydrologic and water quality impacts within the Whipple Creek watershed. Shapefiles were then extracted and a new feature class created as new shapefiles that are within the watershed using the Clip Feature function in ArcMap.

Review of existing county reports fulfills requirements under section S5.C.5.c.ii.1 of the county's Permit which includes Assessments of Existing Conditions (Clark County 2014), Clark County Stream B-IBI Versus Hydrologic Metrics Relationships (Clark County 2015), Status of Whipple Creek Watershed Aquatic Community (Clark County 2015), Water Quality and Land Cover (Clark County 2015). Additionally, the Whipple Creek Hydrology and Hydraulic Modeling (Clark County 2005), Whipple Creek Stormwater Needs Assessment (Clark County 2006) and the Whipple Creek Technical Memo (Inter-Fluve 2006).

Results

The following figures and associated text identify areas appropriate for special attention in regard to hydrologic and water quality impacts.

Regulated Critical Areas (Title 40)

Title 40 of the Clark County Code includes limitations on development in critical areas associated with certain natural features. Title 40 includes chapters 40.420 Flood Hazard Areas, 40.430 Geologic Hazard Areas, and 40.440 Habitat Conservation, 40.450 Wetland Protection. Since critical areas are already protected by county code (Figure 2), these areas were not the main focus in the analysis of areas of special attention for Whipple Creek watershed stormwater planning. Instead, areas of special attention were derived from a combination of documented field observations during stream reconnaissance, GIS exploration, and analysis of existing water quality data.

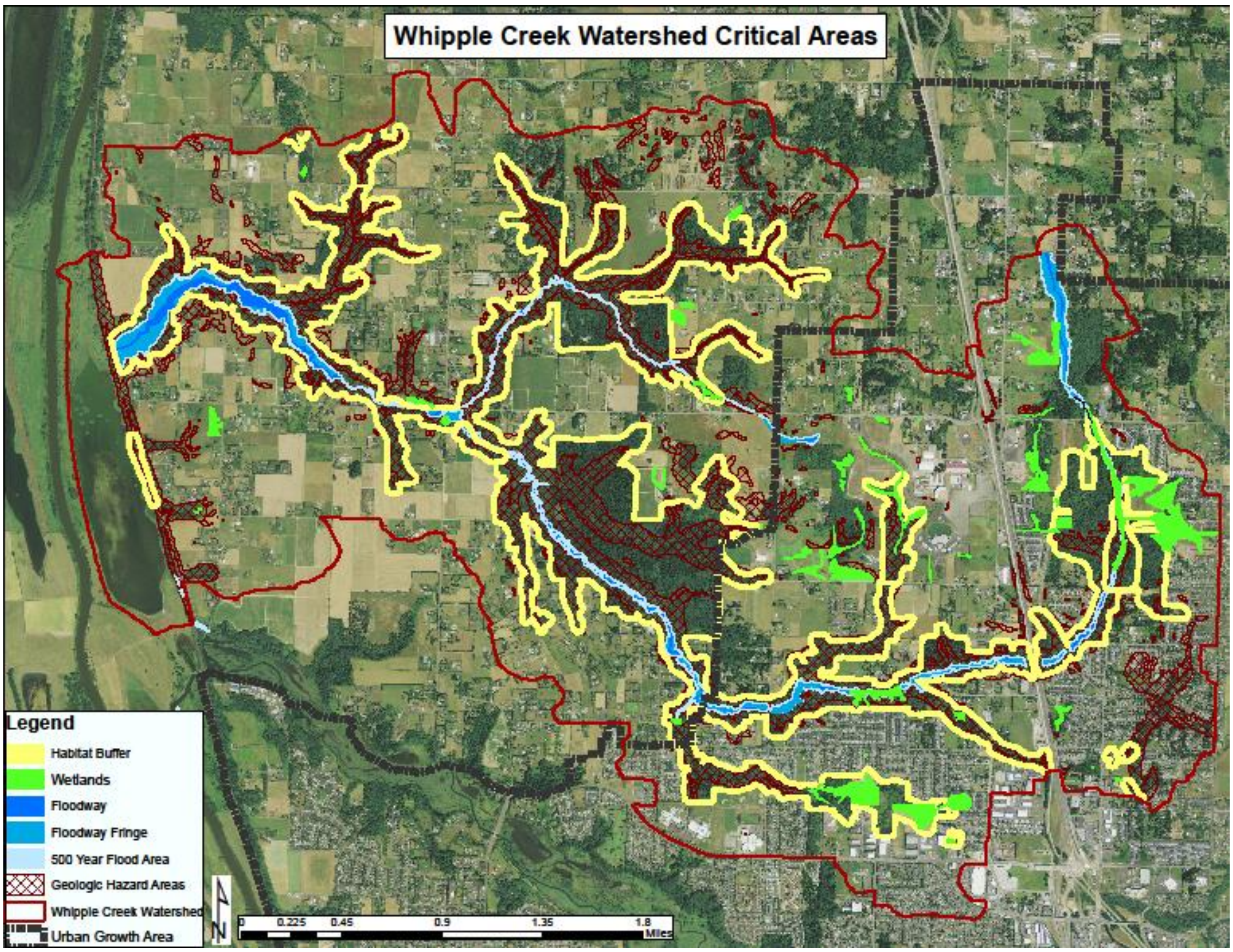

Figure 2 Whipple Creek critical areas as defined by Clark County Code 40.420 through 40.450.

Stream Channel Erosion and Floodplain Disconnection

Within the stream reconnaissance assessed reaches, degraded areas far exceeded those that remained intact. In many assessed reaches, it was evident that increased runoff from historical clearing and development led to substantial stream channel incision, streambank scour, and floodplain disconnection (Clark County, 2006). Observed stream channel erosion reaches mapped during stream reconnaissance efforts are considered one important category for areas of special attention (Figure 3). These areas should be revisited and further assessed for channel enhancement or restoration opportunities.

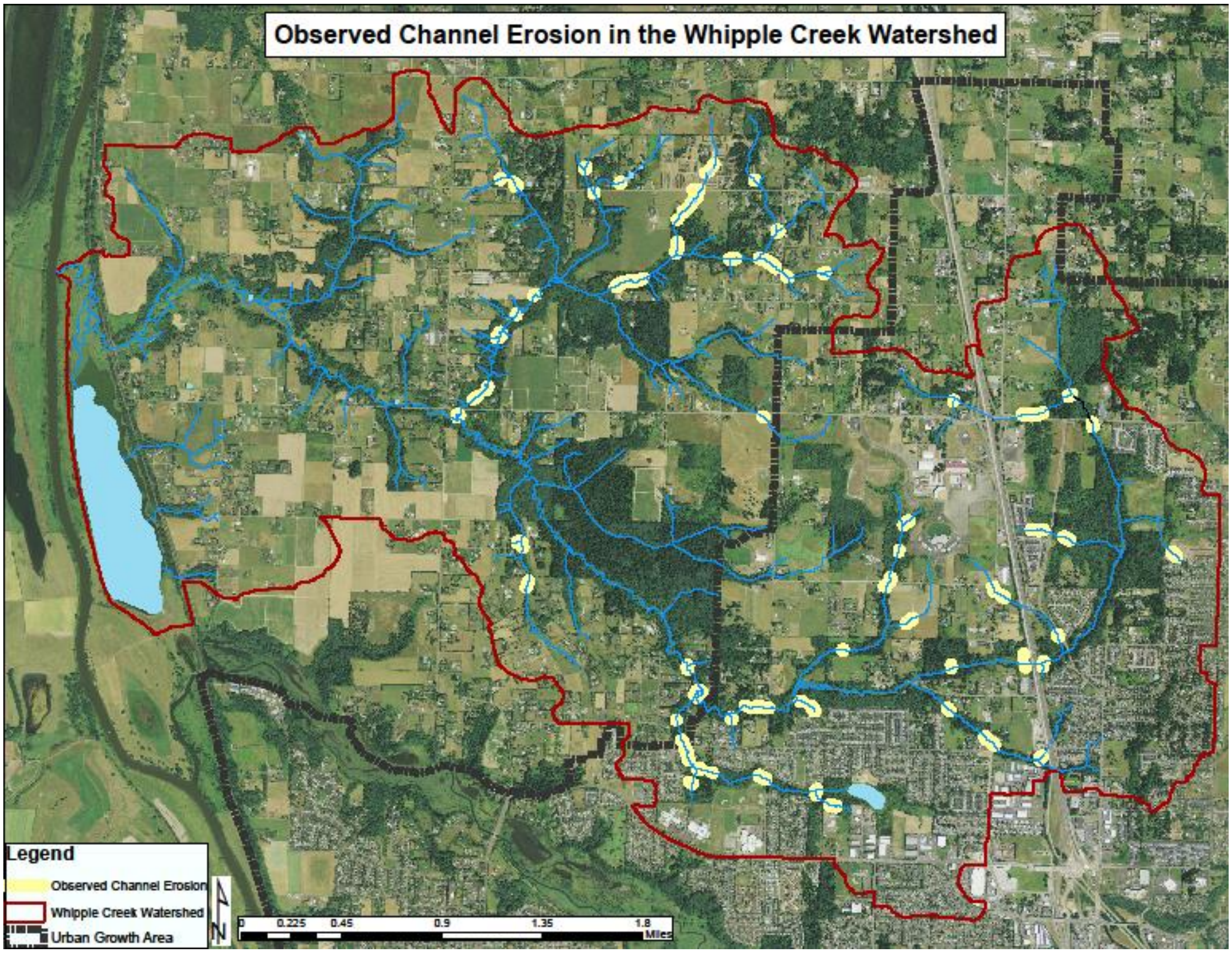

Figure 3 Areas of observed stream channel erosion within the Whipple Creek watershed

Developed Catchments with No Stormwater Detention

Streambank erosion is a natural process. However, human activities can induce acceleration of this natural process which can cause excessive channel erosion leading to disproportionate sediment supply, stream channel instability, habitat loss, channel incision and other degraded conditions. The effects of excessive channel erosion are pervasive throughout Whipple Creek and most of its tributaries. Poor water quality and impaired biological communities are due, in large part, to the erosion and subsequent habitat degradation caused by urbanization and altered hydrology. Fine sediment from eroded soil and channels gets suspended in the water column which subsequently can degrade habitat by impeding oxygenated flow through salmonid spawning substrate and covering riffle habitat for invertebrates that are an important source of food for many fish.

Channel incision also greatly reduces instream habitat. Since incised channels are straighter, steeper and often wider, larger flows are contained within the channel (as opposed to spilling over into the floodplain) leading to flashier flows and reduced hydraulic retention. As channel incision occurs, stream flood plain interaction is eliminated or greatly reduced, and floodplain wetlands are often dewatered, cleared, filled or destroyed by channel erosion (Shields et. al, 2009). Within Whipple Creek, channel incision has reduced overbank flooding, ultimately disconnecting floodplains in multiple stream reaches and has reduced channel migration (Inter-Flueve, 2006).

Developed catchments within the Urban Growth Area having no stormwater detention best management practices were identified as areas of special attention (Figure 4). These areas of special attention should be evaluated for stormwater flow control retrofit and low impact development (LID) opportunities; especially in areas upstream of observed channel erosion areas.

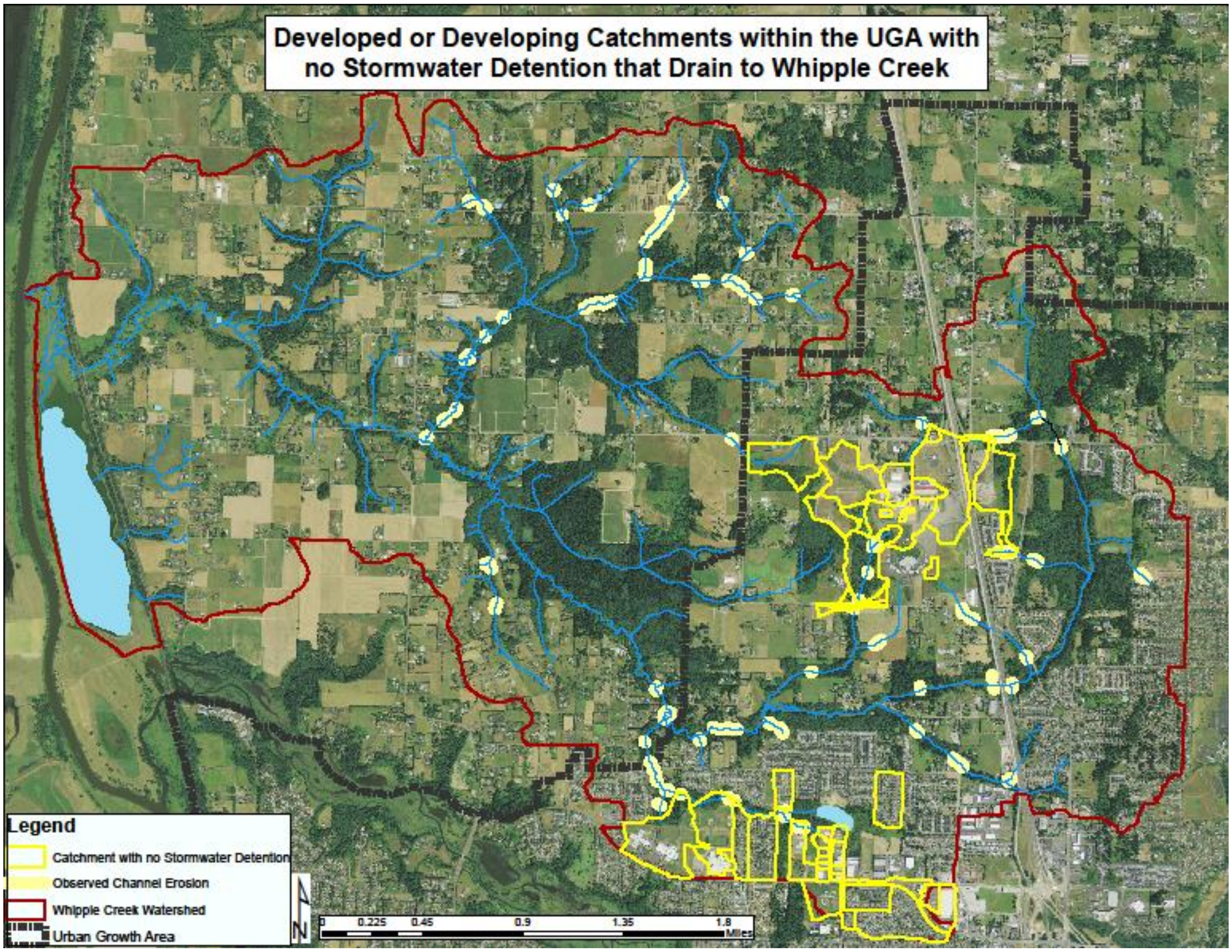

Figure 4 Catchments with no stormwater runoff detention best management practices within the UGA of the Whipple Creek watershed

Suitable Salmon Spawning Habitat and Wetlands of Concern

Within the Whipple Creek watershed, field observations suggest spawning habitat is the greatest limiting factor for salmonids. Importantly, salmonid spawning habitat is already substantially limited due to occurring stream size, topography, and substrate (Inter-Fluve, 2006). Within the basin, channels below 0.5% gradient contain sand and silt substrate that is unsuitable for spawning which leaves only a few isolated areas where conditions are potentially suitable. Protecting observed suitable spawning habitat within the Whipple Creek watershed from the effects of channel erosion will need to be a high priority.

Stream channel incision has already put several wetlands at risk of being drained from migrating headcuts that can deepen and widen the stream channel leading to transporting stored sediment downstream and covering suitable spawning habitat (Inter-Fluve, 2006). Protecting existing wetlands is important because wetlands can slow the velocity of water down which allows for floodplain sediments to settle out of the water column. Suitable spawning habitat for salmonids, wetlands, and wetlands at risk are considered areas of special attention (Figure 5).

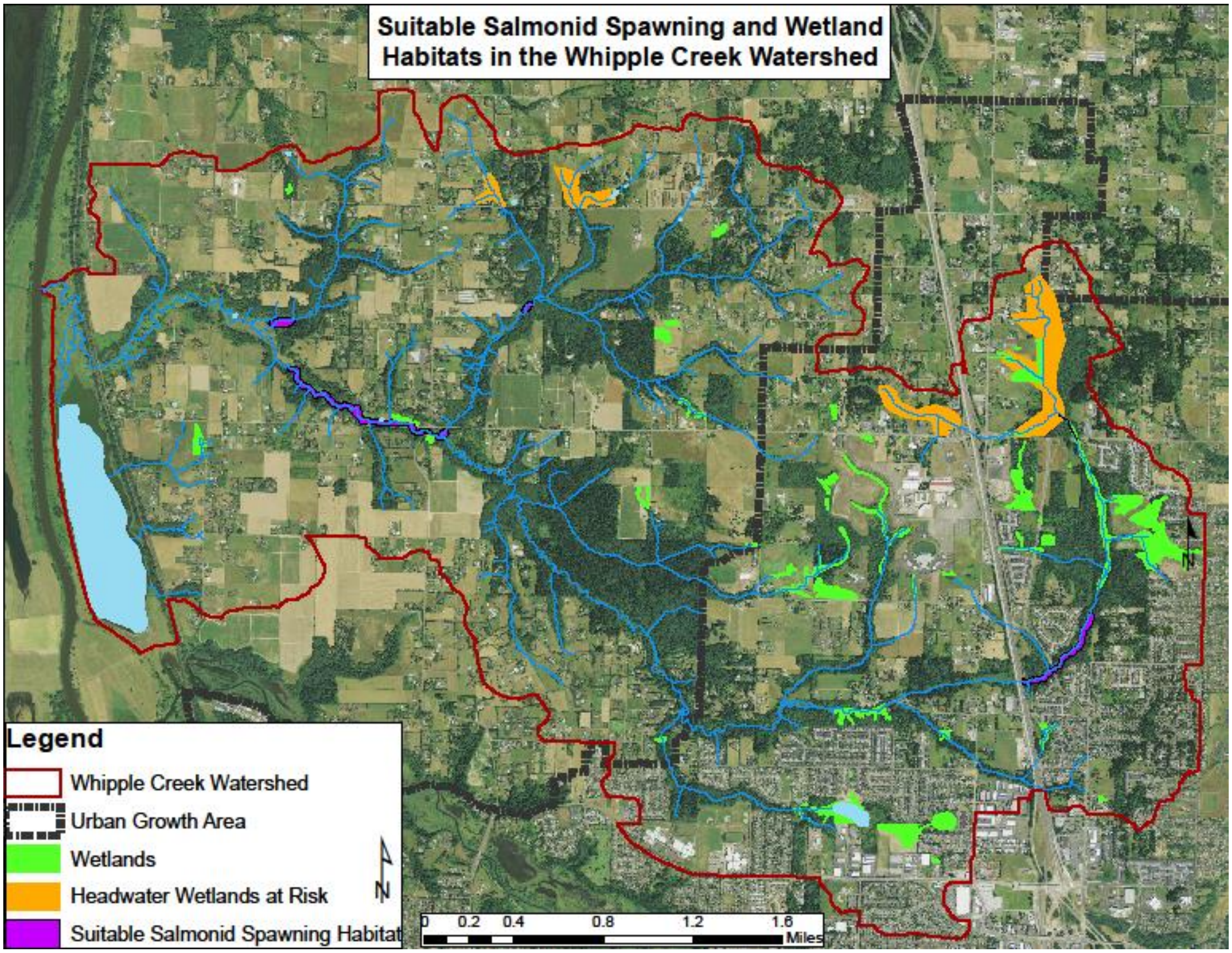

Figure 5 Field observations of wetlands, headwater wetlands at risk due to channel erosion, and suitable salmonid spawning habitat in the Whipple Creek watershed

Whipple Creek Stream Temperatures and Possible Sources of Thermal Refugia

Stream temperature is one of the most important environmental influences on salmon biology. Under the state water quality stream standards, Whipple Creek is designated Salmonid Spawning, Rearing, and Migration and has the Aquatic Life Temperature Criteria Highest 7DADMax temperature of 17.5°C (63.5°F). Continuous summer stream temperature data collected approximately at river mile 3.1 of Whipple Creek (WPL050) show that the 17.5°C criterion is often exceeded; especially in the hotter months of July and August (Figure 6).

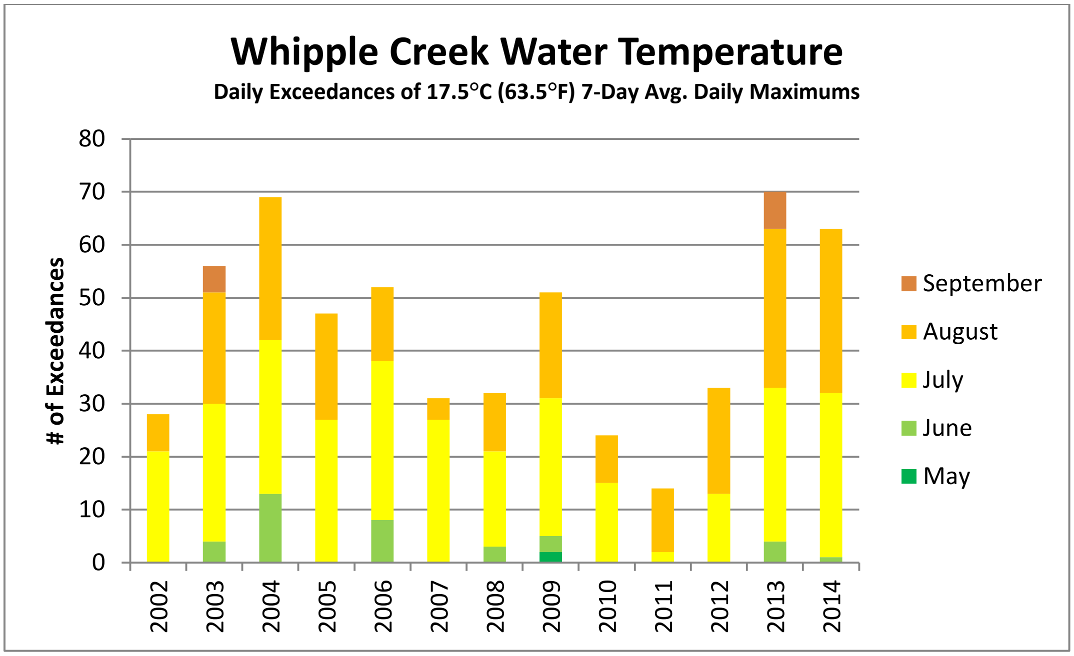

Figure 6 Whipple Creek station WPL050 water temperature exceedances 2002 through 2014

Continuous summer stream temperature data collected from May 2014 through June 22, 2015 at four unnamed tributary stations (WPLT01, WPLT02, WPLT03, and WPLT04), Packard Creek (PCK010), and four Whipple Creek mainstem stations (WPL080, WPL065, WPL050, and WPL010) show that Packard Creek and all mainstem sites exceeded the 17.5°C criterion (Figure 7). Additionally, based on logged daily minimum water temperatures, monitoring stations WPL065 had 26 days where continuous temperature loggers show that the stream temperature never got below the *maximum* 63.5°F: PCK010 - 10 days, WPL050 - 7 days: and WPL010 had 2 days.

When stream temperatures exceed the 17.5°C criterion, thermal refugia can provide important habitat conditions for salmonids survival. Salmonids that are exposed to stressful or lethal temperatures for part of the day can effectively block migration, stress fish, affect reproduction, inhibit smoltification, create disease problems, and alter competitive dominance (Carter, 2005). Tributaries of Whipple Creek may provide thermal refugia for salmonids during the hotter months of summer. Tributaries WPLT01, WPLT02 and WPLT03 did not exceed the 17.5°C criterion during the monitoring timeframe (May 2014 through June 22,). These same tributaries also have relatively intact forested riparian areas. It is possible that other unnamed tributaries not monitored for continuous stream temperature also provide thermal refugia during the hotter months. Stream temperatures and summer base flows from unmonitored tributaries should be further evaluated for areas of special attention that help provide thermal refugia for salmonids.

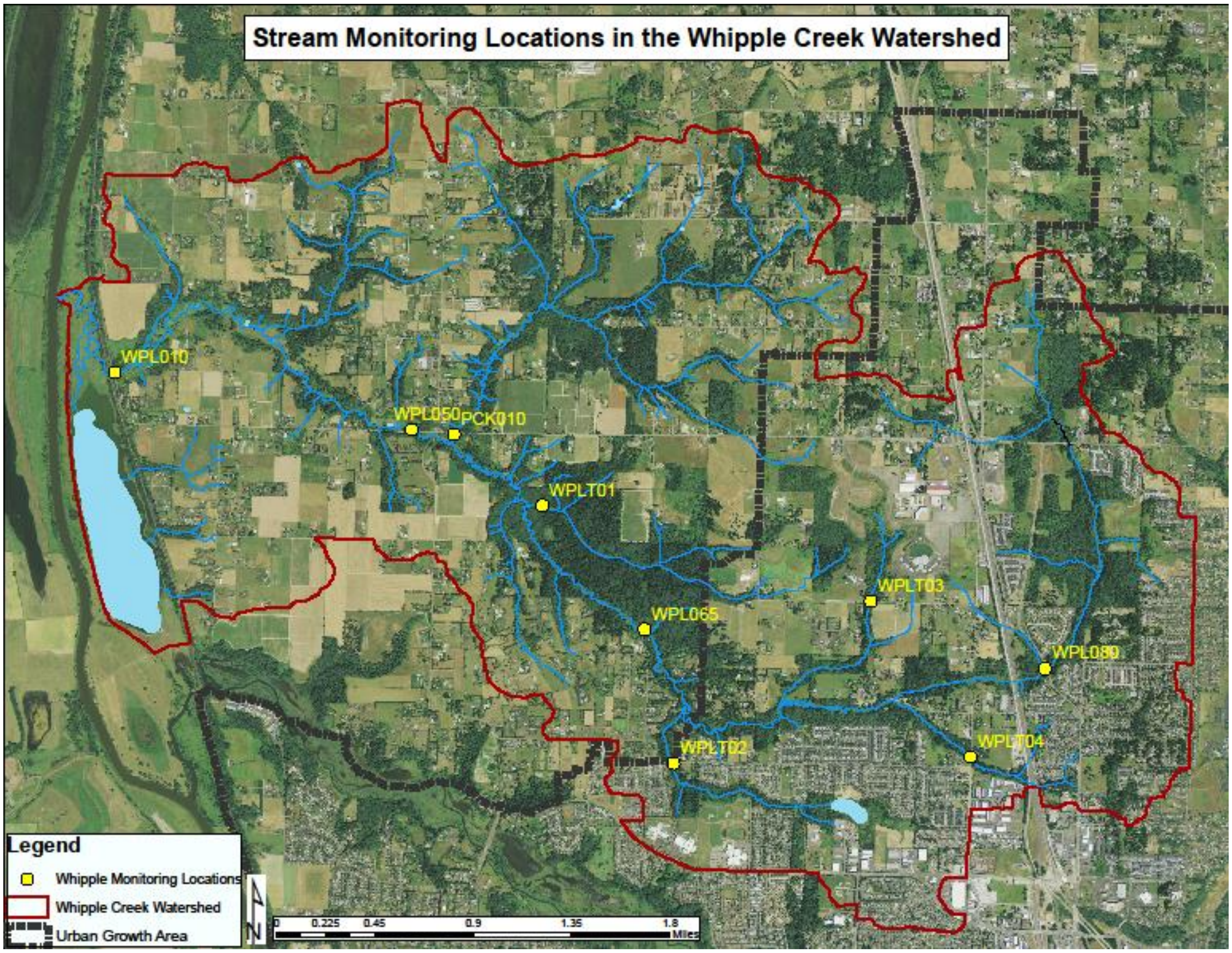

Figure 7 Stream monitoring location within the Whipple Creek Watershed

County Owned Properties with Stream/Riparian Enhancement Opportunities

County owned properties should be evaluated as areas of special attention that may provide opportunities for riparian and stream channel restoration and enhancement opportunities. Parcels that the county or other regional partners own are considered areas of special attention because they alter beneficial opportunities for implementing stormwater planning (Figure 8). Solar radiation is the primary driver of water temperature. Increasing riparian tree coverage within the Whipple Creek watershed would enhance shading and help reduce sunlight impacted stream temperature. In many areas of the Whipple Creek watershed, invasive species are preventing the natural succession to shade producing coniferous riparian forest (Inter-Flueve, 2006). Riparian restoration activities should include removal of invasive species, planting of native shrubs and trees, fencing where appropriate to prevent livestock access to the creek, and protecting plantings from beaver activity. Channel and habitat enhancement should include large woody debris structures for grade control, recreating historical channel morphologies, reconnection of channels to floodplains, and gravel supplementation where appropriate.

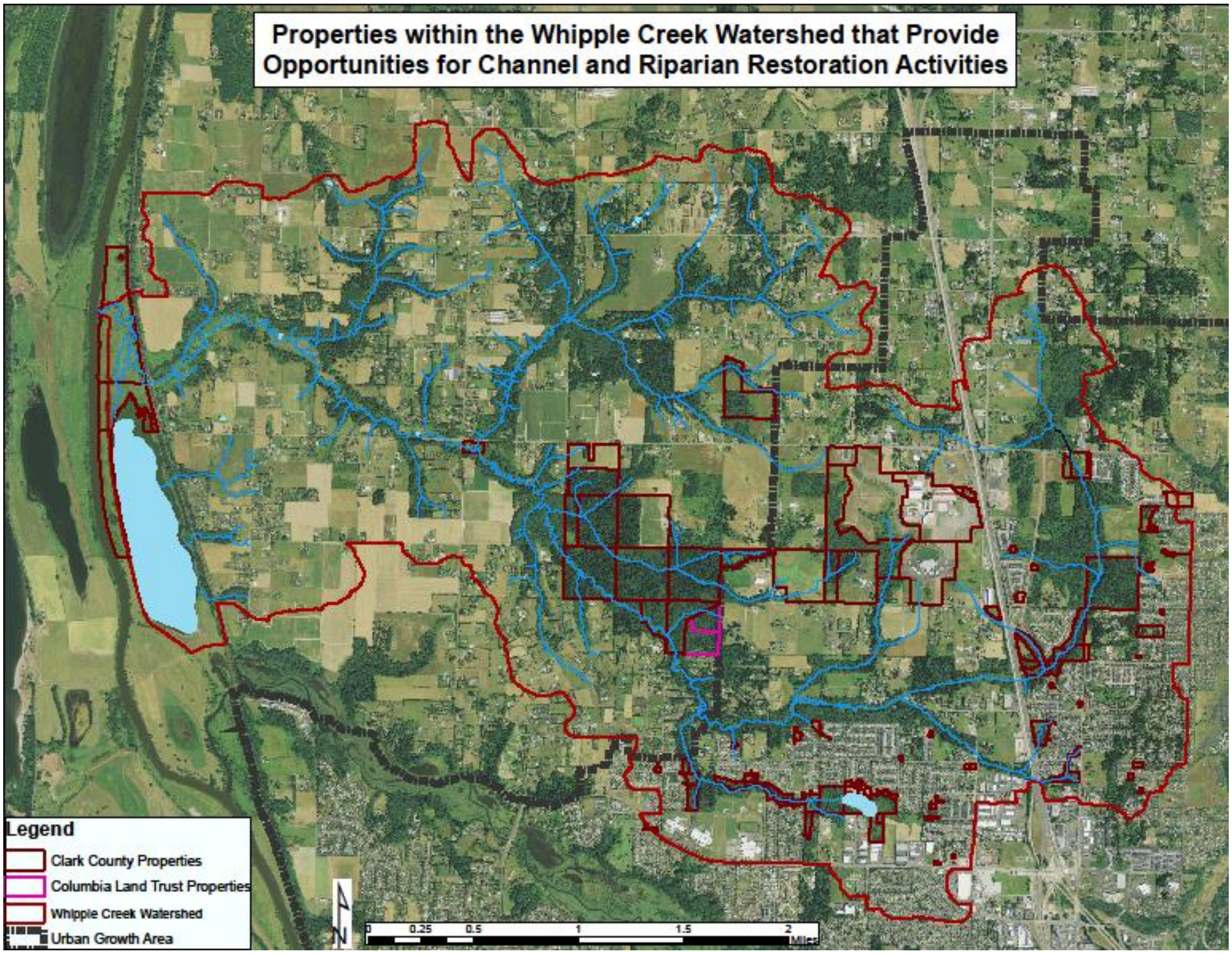

Figure 8 Whipple Creek monitoring locations and associated drainage catchments

Urban Catchments Lacking Stormwater Treatment

Monthly water quality data collected from a Whipple Creek monitoring site (WPL050) since 2003 indicate that water quality in Whipple Creek is often poor as summarized by the Oregon Water Quality Index (Clark County, 2010, Clark County, 2014). The Oregon Water Quality Index (OWQI) was developed as a way to improve the understanding of water quality issues by integrating multiple characteristics and calculating a score that describes water quality status (Cude, 2001). The OWQI integrates eight water quality variables: temperature; dissolved oxygen; biochemical oxygen demand; pH; ammonia + nitrate nitrogen; total phosphorus; total solids; and fecal coliform. For each sampling event, individual subindex scores and an overall index score are calculated. Index scores are aggregated into low flow (June – September) and high flow (October – May) seasons and seasonal mean values are then calculated with the lower of the two scores utilized as the overall water year OWQI score.

Of the four water year 2012 overall OWQI results for multiple stations in Whipple Creek, three were classified as poor and one as very poor. The order from highest to lowest water year 2012 overall seasonal OWQI scores were: WPL080 (74.6, poor), WPL010 (61.3, poor), WPL050 (60.8, poor), and PCK010 (45.0, very poor). Except for WPL080's excellent fecal coliform (91.8) and fair ammonia and nitrate nitrogen (82.5) subindex scores, all of the water year 2012 overall OWQI scores were pulled down by very poor total solids and nutrients and poor to very poor fecal coliform subindex scores (Clark County, 2014).

In addition to monthly stream data collection, base and storm flow water quality was monitored from July 2014 to October 2015 and compared to land cover data for each catchment (Table 1). These parameters included water temperature, turbidity, pH, fecal coliform, and dissolved zinc and dissolved copper. In general, water temperature and pH median values were similar for both base and storm flow. As expected, turbidity median values were higher during storm flow compared to base flow. This was also true for median fecal coliform values with the exception of WPLT02. The median base flow fecal coliform values for WPLT02 were 780 (CFU/100mL) compared to a storm flow median value of 665 (CFU/100mL).

Table 1 Whipple Creek mainstem and tributary station water quality data from base and storm flows

Whipple Creek Mainstem Catchment Water Quality Medians																
Station	WPL010 Medians				WPL050 Medians				WPL065 Medians				WPL080 Medians			
Land Use	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass
Percentage	11	30	34	25	12	31	31	26	20	26	19	35	16	32	22	30
Flow Type	Base		Storm		Base		Storm		Base		Storm		Base		Storm	
Sample Size *	12		18		12		18		12		18		12		18	
Parameter (units)																
Water Temperature (degrees C)	11		13.1		11		13.2		11.4		13.4		10.8		13.3	
Tubidity (NTU)	8.9		26.8		7.6		30.2		7.6		16.6		6.2		15.3	
pH	7.48		7.4		7.89		7.53		7.52		7.46		7.54		7.33	
Total Suspended Solides (mg/L)	5		28		5		29.25		5		22.25		5		13.5	
Dissolved Copper (ug/L)	0.71		1.23		0.76		1.23		0.9		1.55		0.96		1.48	
Dissolved Zinc (ug/L)	1.5		0.82		1		1		1.5		2.14		1.4		2.76	
Fecal Coliform (CFU/100 mL)	340		720		262		1865		203		445		57		440 (17)	

Whipple Creek Tributary Catchment Water Quality Medians																				
Station	PCK010 Medians				WPLT01 Medians				WPLT02 Medians				WPLT03 Medians				WPLT04 Medians			
Monitoring Period	WY12 Monthly, July'14-May '15				July '14 - May '15				July '14 - May '15				July '14 - May '15				July '14 - May '15			
Land Use	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass	Impervious	Forest	Pasture	Grass
Flow Type	Base		Storm		Base		Storm		Base		Storm		Base		Storm		Base		Storm	
Sample Size *	12		18		12		18		12		18		8		18		12		18	
Parameter (units)																				
Water Temperature (degrees C)	10.8		13		10.5		12.7		11.1		12.9		6.1		12.2		11.5		13.65	
Tubidity (NTU)	9.6		46.2		11.7		25.8		4.6		25.7		9.9		30.4		9.6		32.4	
pH	7.69		7.6		7.89		7.65		7.65		7.44		7.46		7.52		7.2		7.37	
Total Suspended Solides (mg/L)	5		45.25		5		16		5		21.85		5		31		5		29.9	
Dissolved Copper (ug/L)	0.82		1.49		0.67		0.79		0.74		1.93		1.15		1.85		0.66		2.39	
Dissolved Zinc (ug/L)	0.8		1		0.5		0.49		1.7		6.1		2.4		2.9		2.1		8	
Fecal Coliform (CFU/100 mL)	395		3100 (17)		485		1170		780		880 (16)		31		660		71		870	

* Common sample size across all parameters unless noted otherwise in parentheses after median value

The high base flow fecal coliform values at WPLT02 suggests that there may be some ongoing issues within the WPTLT02 catchment that are elevating fecal coliform levels. Such issues may include leaking sewage/septic leaks to the stream or direct wildlife or livestock access to the stream. This catchment should be identified as an area of special attention regarding water quality. Efforts should be made to conduct stream reconnaissance within this catchment to detect potential sources of fecal coliform discharging to the stream.

Median dissolved copper and dissolved zinc values were generally higher for storm flow. Also, analysis of these data via linear regression specifically showed that as developed areas (land cover impervious/grass) approach 25% of the subwatershed's total area, storm flow dissolved zinc median values were significantly higher than those for base flow. Based on the significance of these findings, developed areas within the UGA lacking stormwater treatment are considered areas of special attention, for adding stormwater treatment Best Management Practices (BMP's) to reduce potential impacts from untreated stormwater discharging to Whipple Creek (Figure 9).

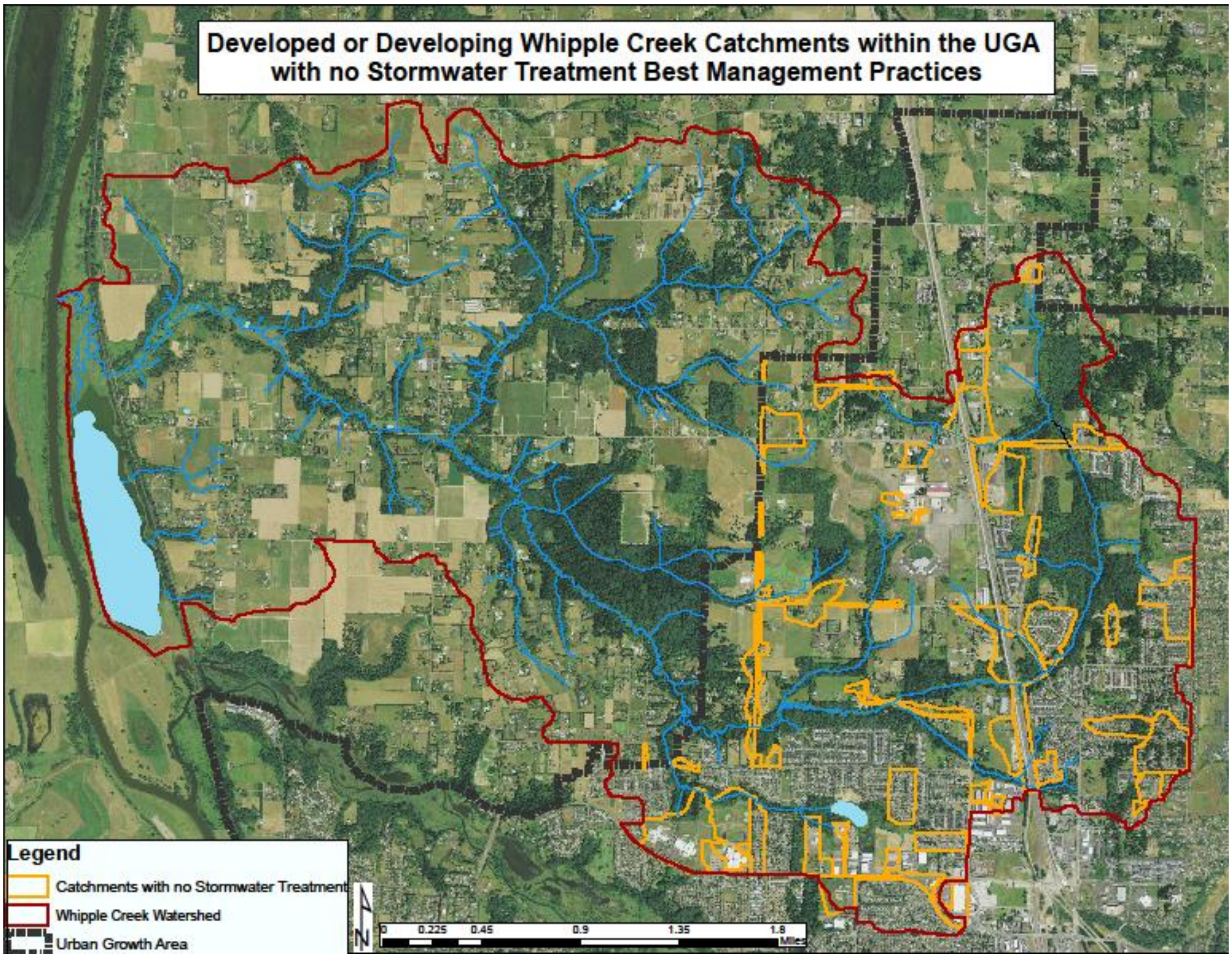

Figure 9 Urbanized catchments with no stormwater runoff treatment best management practices within the UGA of the Whipple Creek watershed

Discussion

This report addresses Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (Permit) section S5.C.5.c.ii.2 watershed-scale stormwater planning requirements to map areas within the Whipple Creek watershed appropriate for special attention in regard to hydrologic and water quality impacts.

Stream hydrology and water quality have been altered dramatically in the Whipple Creek watershed as a result of development that occurred over many decades without stormwater BMPs or with stormwater BMPs that were not designed to today's standards. As a result, the Whipple Creek stream system often does not support its state designated beneficial uses for 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use for primary contact recreation and swimming (WAC 173-201A-020).

The Whipple Creek watershed is predicted to become increasingly developed in the future, especially within the UGA and along the Interstate 5 corridor. Even to just maintain current degraded conditions within Whipple Creek, new development must meet current county stormwater discharge treatment and hydrologic standards. However, the objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that will result in hydrologic and water quality conditions that fully support for 1) aquatic life use of salmonid spawning, rearing, and migration and 2) human use of primary contact recreation and swimming. To obtain this more stringent objective, watershed restoration strategies will need to be developed, prioritized and implemented that address stormwater flow control, water quality, stream temperature, and degraded stream habitat issues.

Clark County has identified and mapped specific areas within the Whipple Creek watershed appropriate for special attention in regard to hydrologic and water quality impacts where watershed restoration strategies can be implemented, these areas include:

- Observed stream reaches with channel erosion and floodplain disconnection
- Developed catchments with no stormwater detention
- Suitable salmon spawning habitat and wetlands of concern
- Possible sources of thermal refugia for salmonids
- County owned properties with stream/riparian enhancement opportunities
- Urban catchments lacking stormwater treatment

The purpose of restoration strategies within the Whipple Creek watershed is to provide a framework for prioritization, decision making and implementation of stormwater and restoration strategies that help address each area of special attention identified in this document to support the objective of watershed-scale stormwater planning.

Recommendations

Priority strategies should first focus on restoring hydrologic conditions in the Whipple Creek watershed, especially in areas of special attention identified as “developed catchments with no stormwater detention” and “observed stream reaches with channel erosion and floodplain disconnection”. Stormwater strategies needed to address stormwater for catchments with no detention facilities include Low Impact Development (LID), stormwater retrofits to adhere to current standards, and the building of new stormwater hydrologic BMPs and/or regional stormwater facilities. Restoration strategies for observed stream reaches with channel erosion and floodplain disconnection should include channel grade control, stream bank stabilization, installation of large woody debris (LWD), riparian plantings, wetland restoration, and floodplain reconnection. Additional site-specific investigations and tools are needed to identify appropriate restoration activities in these areas of special attention.

The secondary priority should be improving water quality in the Whipple Creek system. Urban catchments lacking stormwater treatment were identified as areas of special attention regarding water quality and should be further screened for stormwater treatment BMP feasibility. Stormwater strategies that will need to be implemented to treat stormwater include Low Impact Development (LID), stormwater retrofits to adhere to current standards, and the building of new stormwater facilities and/or regional stormwater facilities. Additionally, stream reconnaissance and IDDE efforts should be conducted in stream site catchments that had high fecal coliform values to determine potential sources of fecal coliform pollution.

The third priority should be preserving suitable salmonid spawning habitat and enhance stream, riparian and wetland habitats. Additional investigations and tools are needed to specifically identify appropriate restoration activities, but generally should focus on enhancement/restoration projects in the identified areas of special attention that include county owned properties with stream/riparian enhancement opportunities and suitable salmon spawning habitat and/or wetlands of concern. Further efforts include conducting additional stream temperature studies on unmonitored tributaries to Whipple Creek to assess specific sources and flow volumes for thermal loads of thermal refugia for salmonids.

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Appendix F

Whipple Creek Watershed-Scale Stormwater Plan Report

Hydrology Model Calibration Report

Prepared by

Fereidoon Safdari

Clark County Department of Public Works

Clean Water Division

and

Doug Beyerlein

Otak, Inc.

August 2017

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1.

1. Introduction

The Washington State Department of Ecology (Ecology) issued a 2013-2018 Phase I Municipal Stormwater Permit (Permit) on August 1, 2012, that requires all Phase 1 Permittees, including Clark County (County), to select a watershed and perform watershed-scale stormwater planning as outlined in section S5.C.5.c. This section states that “the objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support ’existing uses‘ and ‘designated uses’, as those terms are defined in WAC 173-201A-020, throughout the stream system.”

In 2014 the County proposed to conduct a watershed planning study of Whipple Creek (See Figure 1). Clark County’s proposed scope of work included eight (8) tasks including the development and calibration of hydrology and water quality models. As the base for the modeling effort, an uncalibrated HSPF model for Whipple Creek developed in 2007 was used. This model has sufficient detail to simulate scenarios required by the permit. The hydrologic model was calibrated using five years of flow data collected at stream gage WPL050 (downstream of Packard Creek) and County rain gages. The 2007 model has also been updated to reflect 2014 land use conditions. This model has been used to simulate stream flow and water quality for the calibration period (water years 2004-2008). The model parameters were adjusted to calibrate the model to match the observed streamflow and water quality values for the calibration period.

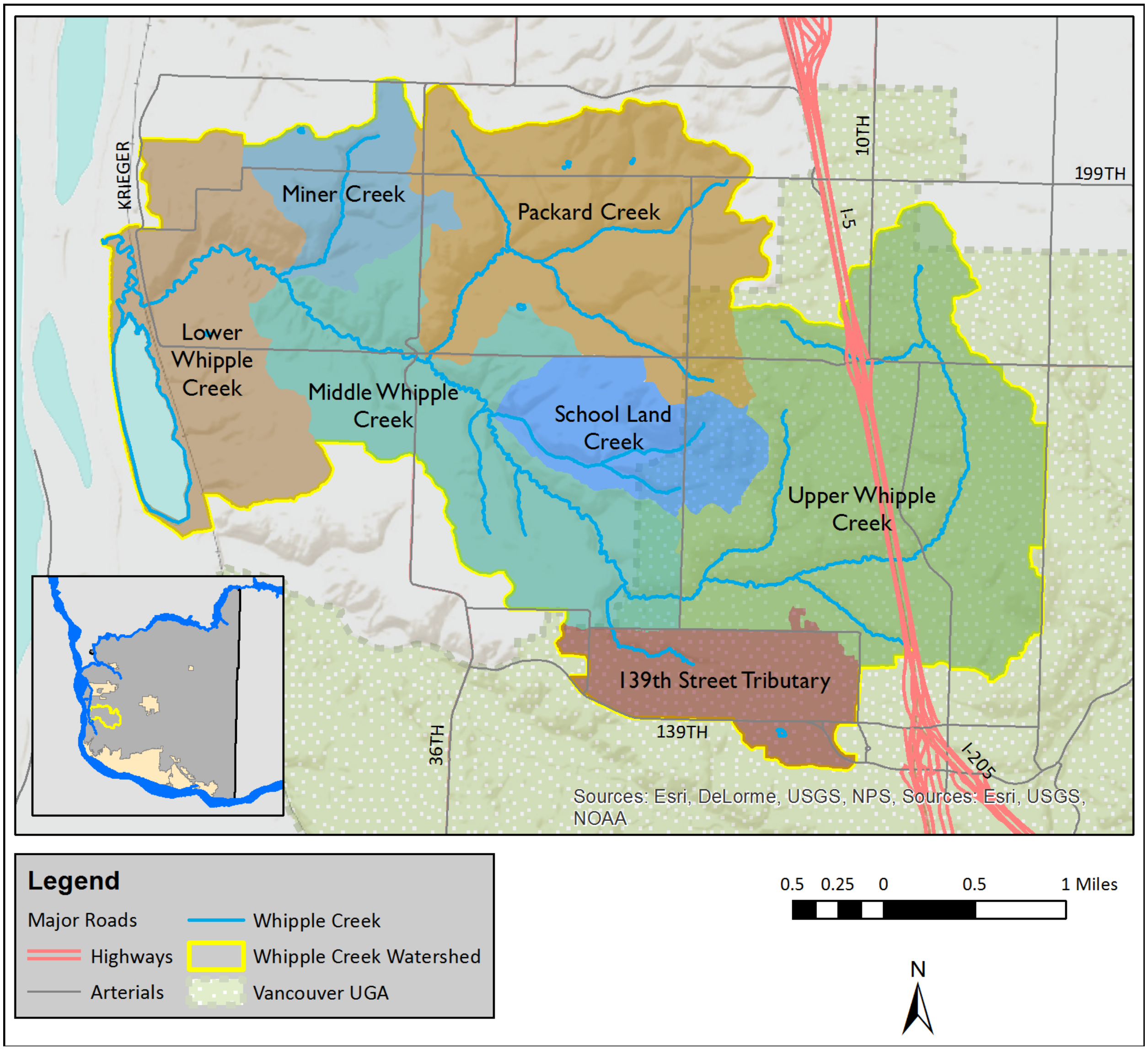

Figure 1: Whipple Creek Watershed

Model performance and calibration accuracy are described by presenting qualitative and quantitative measures, including both graphical comparisons and statistical analysis. Calibration accuracy metrics will focus on observed flow at stream gage WPL050. Statistics characterizing model accuracy may include root-mean-square error and relative percent difference. Other metrics for comparison include mean daily stream flow volumes, mean annual flow volumes, and storm peak discharge rates. Calibration results also include graphical comparisons including hydrographs for simulated flows to observed flows, duration curves, and scatter plots.

1.1 Background and Objective

During a five-year effort from 2006-2010, the Clean Water Division Stormwater Needs Assessment Program (SNAP) focused on describing stream and storm drainage conditions in Clark County watersheds. The program assessed watershed resources, identified stormwater-related problems and opportunities, and recommended specific projects or actions to help protect water quality. As part of the Stormwater Capital Improvement Plan, the CWD staff also began to study several watersheds county-wide to identify capital improvement projects. Staff selected Whipple Creek as the first watershed of which to conduct a detailed study titled "The Whipple Creek (Upper) / Whipple (Lower) Watershed Needs Assessment Report."

Clark County staff completed Part 1 of the Whipple Creek watershed study which included development of hydrologic and hydraulic models to represent the stream flow conditions. The County developed an event-based model using HEC-HMS computer program to estimate peak flow rates throughout the watershed. The county also developed a hydraulic model using HEC-RAS computer program to calculate hydraulic characteristics of Whipple Creek and help predict potential stream channel erosion problems. The second part of the Whipple Creek study involved modeling additional land use scenarios including future land use (2035) alternatives by developing a continuous flow hydrologic model.

1.2 This Report

The objective of this report is to document long-term simulation and calibration of the HSPF model for the Whipple Creek watershed to establish hydrologic parameters for selected soil, topographic, and land use conditions. The report includes a parameter definition, units, and methods for determining input value (e.g. initialize with reported values, estimate, measure, and/or calibrate). The report also includes summary tables that provide 'typical' and 'possible' ranges for the parameters, based on parameter guidance, experience with HSPF over the past four decades on watersheds across the U.S., and world-wide.

2. Hydrologic Modeling

Hydrologic simulation combines physical characteristics of a watershed and observed meteorological data to produce a simulated hydrologic response. HSPF simulates flow to the stream network from four components: surface runoff from hydraulically connected impervious areas, surface runoff from pervious areas, interflow from pervious areas, and shallow groundwater flow from pervious areas. Because historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

In 2007, Otak developed a hydrologic model of Whipple Creek using HSPF. This model was not calibrated due to lack of adequate flow data. The calibration of Whipple Creek hydrologic model utilized the 2007 model, updated the land use within the basin to 2014 conditions, and completed calibration using flow data at Sara Gage for water years 2004 through 2008.

2.1 Modeling Background

HSPF is a mathematically-based computer code developed under U.S. Environmental Protection Agency (EPA) sponsorship to simulate water quantity and quality processes on a continuous basis in natural and man-made water systems. HSPF uses input meteorological forcing data and parameters that reflect system geometry, land use patterns, soil characteristics, and land use activities (e.g., agricultural practices) to simulate the water quantity and quality processes that occur within a catchment.

An HSPF model simulates the full flow regime, including low flows, high flows, dry periods, and back-to-back storm events. This is a useful tool in the Whipple Creek watershed where existing flow levels have already caused extensive erosion in several locations. A continuous flow model can be used to identify whether the future development will significantly increase the time a channel experiences erosive flows on an annual or seasonal basis. HSPF requires input precipitation and potential evapotranspiration (PET), which effectively 'drive' the hydrology of the watershed; actual evapotranspiration is calculated by the model from the input potential and ambient soil moisture conditions. Thus, both inputs must be accurate and representative of the watershed conditions; it is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions in the watershed.

2.2 HSPF Modeling Protocols

The HSPF modeling protocols are the assumptions and guidelines used in developing the model. The modeling framework has very few built-in assumptions and can be configured to simulate natural systems in a number of different ways. HSPF protocol decisions center on the following topics: precipitation, evaporation, subbasins, land use, soils, slope, calibration parameters, and flow routing.

For Whipple Creek, the modeling protocols are generally based on those developed for the Salmon Creek Watershed as documented in Barker, 2003. Otak reviewed the modeling assumptions documented in that report and found them to be fairly consistent with a number of HSPF guidance documents and modeling protocols for other HSPF projects in Western Washington.

2.3 HSPF Modeling Scenarios

The 2007 Whipple Creek Watershed study developed an HSPF model under existing (year-2002 land use) and future (projected 2016 land use) conditions, stream channel conditions based on the FEMA HEC-RAS hydraulic model (developed by West Consultants), and field observations during the County's stream assessment work. Future land use conditions were based on build-out of the urban growth boundary as defined in the County's comprehensive plan at the time of study; channel conditions remained the same as existing model.

3. Input Data and Watershed Segmentation

The calibration model used the same watershed segmentation as the original Otak hydrologic model. However, this study updated the land use to current conditions.

3.1 Data Sources

3.1.1 Precipitation Time Series

As part of the Salmon Creek HSPF modeling project, MGS Engineering developed five rainfall series to simulate the distribution of rainfall across the watershed. In the lower watershed, MGS used multiple scaling factors to adjust the Portland Airport rainfall record to match gage data in Clark County with a mean annual precipitation of 43 inches. The rainfall data set used for the lower Salmon Creek Watershed includes 61 years (1939-2000) of hourly rainfall data. The Salmon Creek modeling report indicated that the rainfall time series could also be used in the hydrologic analyses of other watersheds in Clark County located on the windward slopes of the Cascades with similar mean annual precipitation. As such, Otak used the rainfall dataset from the lower Salmon Creek Watershed for the development of the HSPF model for Whipple Creek Watershed.

The updated Whipple Creek hydrologic model uses extended precipitation data set from Airport Way, Portland, from 1939 to 2012 to conduct a long term simulation of the watershed. However, for the calibration model precipitation data from Salmon Creek Treatment Plant (water years 2004 through 2008) were used.

Figure 2 shows Clark County's streamflow sites and precipitation gage locations.

Stream flow sites

1. Brezee Creek
2. Gee Creek at Abrams Park
3. Whipple Creek
4. Cougar Creek
5. Mill Creek
6. Curtin Creek at NE 139th Street
7. Lacamas Creek at NE 217th Avenue
8. Lacamas Creek at Goodwin Road
9. Jones Creek
10. Little Washougal River at Blair Road

Precipitation stations

1. Ridgefield
2. Salmon Creek Wastewater Treatement Plant
3. Salmon Creek at NE 156th Street
4. Venersborg
5. Yacolt
6. Orchards
7. Lacamas

Figure 2: Clark County Streamflow Sites and Precipitation Stations

3.1.2 Evaporation Time Series

The 2007 Otak study used evaporation time series developed by MGS for the lower Salmon Creek. For the calibration model of Whipple Creek, evaporation data from Aurora Station in Oregon was used.

3.1.3 Flow Time Series

Model calibration used flow data collected at one location on the Whipple Creek main stem, stream gage WPL050. Data was collected between 2002 through 2012. An analysis of the recorded streamflow data for Whipple Creek found the data to be reliable for the five years of the ten-year period of record (water years 2004 through 2008).

The streamflow gage for Whipple Creek watershed at WPL050 was used for the calibration period, as per the scope of work. Table 1 lists information about the streamflow gage.

Table 1: Streamflow Gage Station

Watershed	Gage Location	Drainage Area (Sq. mi.)	Period of Record
Whipple Creek	Downstream of NW 179th Street	8.8	10/1/2003 - 9/30/2008

3.2 Watershed Segmentation

Segmentation procedures and data needs for the original hydrologic model are described in detail in the Whipple Creek Watershed Plan (Otak 2007). Watershed segmentation remained unchanged in the calibrated model.

The Whipple Creek watershed was divided into 102 catchments during the Stream Assessment work performed by County staff. Those catchments were the basis for both the stream assessment and the HEC-HMS modeling previously completed. The Whipple Creek HSPF model grouped these catchments into 27 subbasins. The same subbasin boundaries were used for both existing and future development scenarios.

The subbasin boundaries are shown in Figure 3.

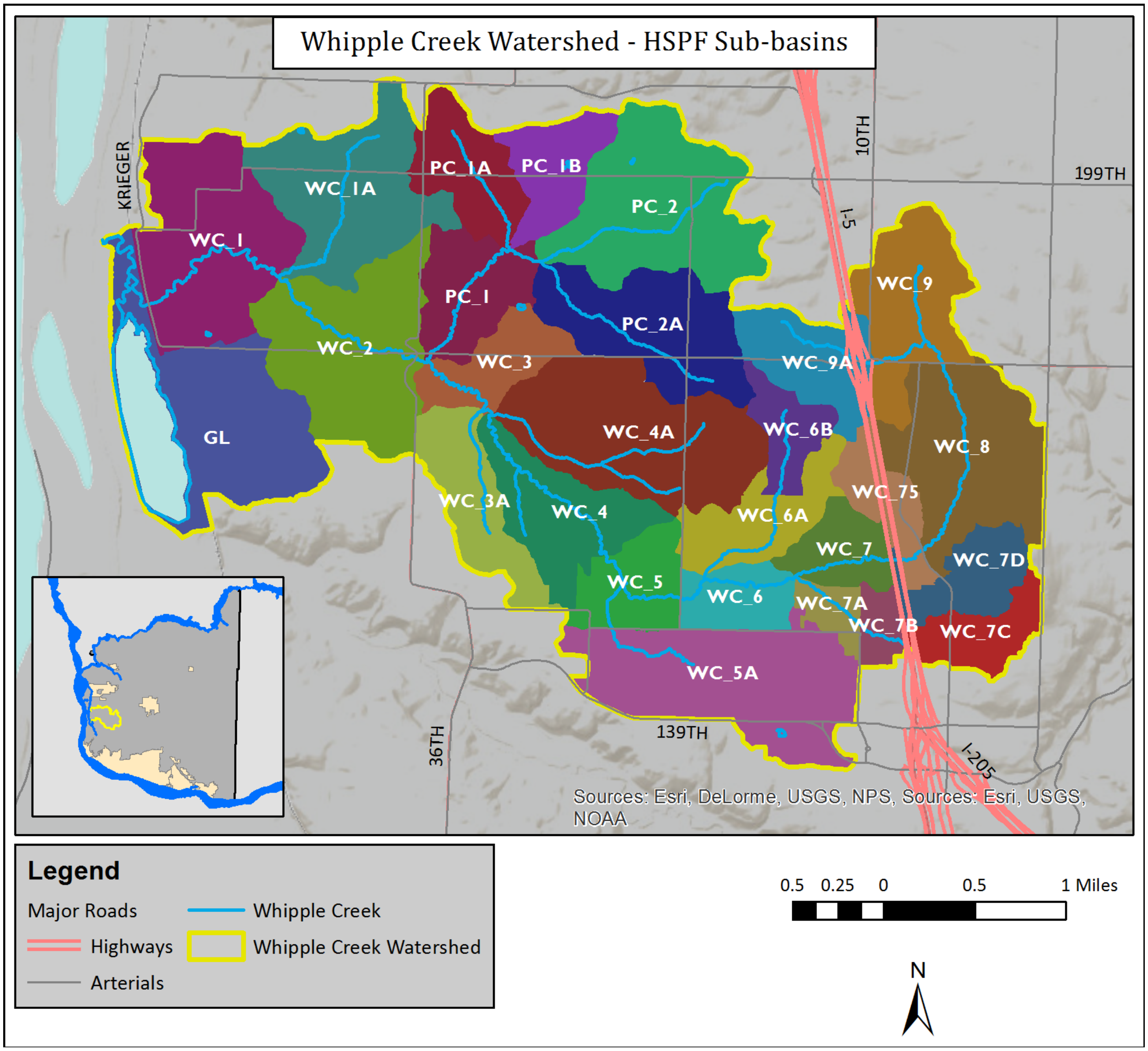

Figure 3: Whipple Creek Sub-basin Boundaries

3.2.1 Land Use

Whipple Creek watershed was once dominated by rural and agricultural land uses. It is currently moderately developed with a mix of rural, urban and urbanizing areas at the northern edge of the Vancouver Urban Growth Area.

The 2007 Otak model land use was based on raster 30-meter data assembled by the University of Washington. The model used land use from Year 2000 as the base and assigned areas to various categories. These categories included bare soil, forest, grass, paved urban, and water. For the Whipple Creek watershed planning study HSPF hydrologic model these land use has been updated using the County's 2014 aerial photos and field verifications to reflect current conditions.

3.2.2 Soils

The Washington State Department of Natural Resources surficial geology data was used to classify the soils hydrologic setting throughout the Whipple Creek Watershed. Nearly all the geology in the Whipple Creek Watershed is identified as either “outburst flood deposits, sand and silt, late Wisconsin” with the geologic unit abbreviation Qfs, or “continental sedimentary deposits or rocks” with the geologic unit abbreviation PLMc (t). Similar to land use, the geology data must be converted into generalized soil categories. The initial HSPF soil categories for Whipple Creek were Bedrock, Outwash, and Saturated. The majority of the Whipple Creek watershed was modeled as Bedrock soil, with all wetland areas modeled as saturated soil.

The NRCS soil types identified within Whipple Creek were later grouped into five categories based on drainage characteristics and knowledge of Clark County soils. From a hydrologic calibration perspective, the most important soil characteristic is infiltration capacity. Therefore, infiltration rates and soil moisture storage capability played the major role in the selection of the soils for each of the five groups. For the final HSPF calibration model PERLND soil categories were converted to SG3, SG4, and SG5 soil types to reflect county soil groups.

The five soil groups in Clark County are:
1. SG1: Excessively Drained soils (hydrologic soil groups A & B)
2. SG2: Well Drained Soils (hydrologic soil group B)
3. SG3: Moderately Drained soils (hydrologic soil groups B & C)
4. SG4: Poorly Drained soils (slowly infiltrating C soils, as well as D soils)
5. SG5: Wetlands soils (mucks)

Underlying soils in the Whipple Creek basin are a mix of SG3: Moderately Drained soils (hydrologic soil groups B & C) and SG4: Poorly Drained soils (slowly infiltrating C soils, as well as D soils).

See Figure 4 for a soils map.

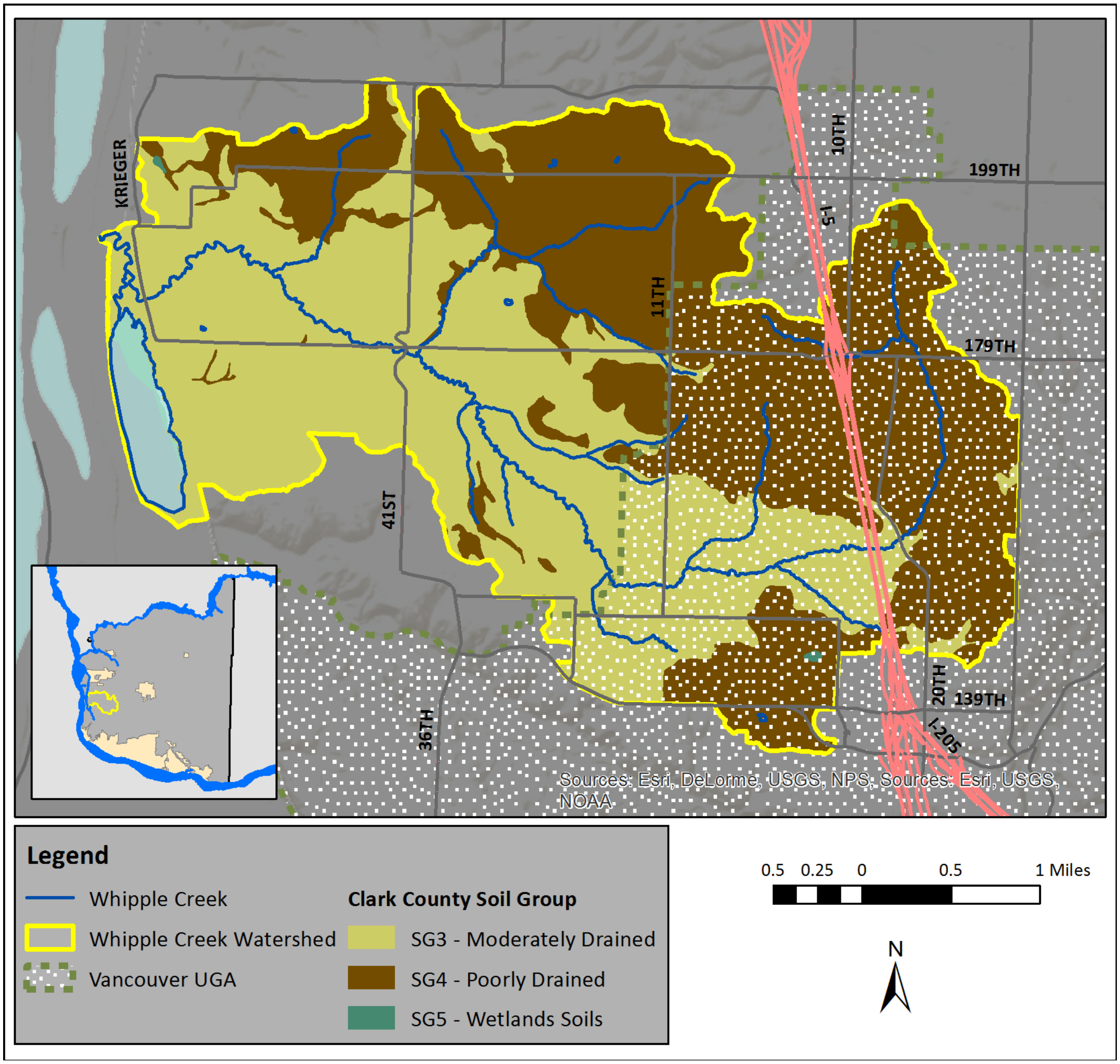

Figure 4: Whipple Creek Soils Map

3.2.3 Slope

HSPF also has the ability to model categories of ground slope. This feature is occasionally used to define different runoff rates, particularly when modeling till soils. However, the overall effect on the runoff timing and volume is usually insignificant. For the purpose of this project, ground slopes were measured from County's topographical maps and used in the updated HSPF model.

3.2.4 Flow Routing

The FTABLEs (or functional tables) in an HSPF model define the stage-storage-discharge relationship for a given stream reach. For areas of the watershed that have been defined in a HEC-RAS model, FTABLEs were developed by looking at the water surface elevation and overall channel storage for a range of flow rates. This method was used throughout the main stem of Whipple Creek and one branch of Packard Creek.

4. Calibration

Calibration of a watershed with HSPF is an iterative process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. Calibration looks at matching the annual water balance, groundwater contributions, and hydrograph shapes to stream gages throughout a watershed. The 2007 HSPF model developed by Otak was not calibrated. However, for development of the Whipple Creek HSPF model, Otak reviewed the parameters used in the Salmon Creek model and found them to be generally consistent with published HSPF modeling guidelines. The calibration model used Otak's original model as a starting point. The model was then updated with meteorological data, modified land use, and parameters from WWHM2012 for Clark County to improve model results. For the calibration period the observed and simulated streamflow was compared at the SARA gaging station in Whipple Creek, downstream of NW 179th Street (WPL050).

4.1 Calibration Modeling

The general objective of the HSPF modeling is to determine the long-term flood frequency, flow duration, and runoff characteristics of the watershed. Model calibration is necessary and critical step in any model application. For most watershed models, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest.

A review of the existing HSPF model developed by Otak in 2007 shows that the model contains sufficient detail to perform a long-term simulation. However, the model land use was based on 2002 land use. For the purpose of the Whipple Creek Watershed Study, the land use has been updated, using 2014 aerial photos and field verification of any changes within various catchments.

For the calibration precipitation data from Salmon Creek treatment plant was used. The Salmon Creek precipitation data set contained missing values for a few months during 2006 and 2007. This data gap was filled with precipitation values from a Gee Creek precipitation gage.

Evaporation data used in the calibration model was from Aurora, Oregon. Results of the calibration model are shown Section 4.3 below.

4.2 Calibration Parameters

Calibration parameters define how each land segment (pervious, impervious, bedrock grass, saturated forest, etc.) responds to rainfall events. They define how much water will run off the land segment as surface flow, move slowly as shallow subsurface flow (also called interflow), or contribute to the stream as base flow (from groundwater). In addition to the input meteorological data series, the critical HSPF parameters that affect components of the annual water balance include soil moisture storages, infiltration rates, vegetal evapotranspiration, and losses to deep groundwater recharge. Four parameters significantly influence the annual water balance: INFILT, LZSN, UZSN, and LZETP. The parameters INFILT, AGWRC, and BASETP significantly influence the low flow / high flow distribution. The parameters UZSN, INTFW, and IRC significantly influence stormflow volumes and hydrograph shape.

To develop the original HSPF model for Whipple Creek Otak staff reviewed the parameters used in the MGS Salmon Creek model and found them to be generally consistent with published HSPF Modeling guidelines. The initial Whipple Creek HSPF model was developed using the parameters used in the calibrated Salmon Creek model (October 2002, revised March 2003).

For Whipple Creek calibration model, the original Otak model was modified to reflect existing land use conditions. The model parameters were then adjusted using the parameters proposed by Clear Creek Solutions for Clark County WWHM version and EPA Basins Technical Note 6. Parameters used for the calibration model are included in Attachment B.

The revisions/modifications included the following:

- Land use based on 2014 aerial photo
- PERLND areas: used county soil types: SG3, SG4, and SG5
- Precipitation data from Salmon Creek Treatment Plant

The final calibration was conducted by Doug Beyerlein in March 2017 and consisted of making minor modifications to the original calibrated values for HSPF PERLND parameters LZSN, INFILT, AGWRC, INFEXP, and IRC.

4.3 Calibration Results

This section presents and discusses the comparison of model results with the observed Whipple Creek flow data at WPL050, performed for the calibration period.

The calibration results presented are based on the Department of Ecology's "Watershed Planning Guidance Memo" (dated March 29, 2016). Ecology recommended two types of graphical comparisons and at least one error statistic and one correlation test.

For the Whipple Creek hydrology calibration we have provided two graphical comparisons in the form of flow duration curves (Figure 5) and hydrographs (Attachment A). A hydrograph of the entire calibration period (water years 2004 through 2008) is included plus individual hydrographs for each water year and two-month period of record hydrographs for November through August for each water year. The flow duration graph and the hydrographs present a visual display of the accuracy of the calibration.

An error statistic is presented in the form of the annual runoff volume comparison for each water year and for the entire calibration period of record (water years 2004 through 2008), as shown in Table 2 below. An individual water year runoff volume error ranges from -13% to +8%; the overall calibration period runoff volume error is only 0.3%.

A correlation test is shown in Figure 5. The coefficient of determination (R squared) is calculated based on daily recorded and simulated streamflow values. The R squared value daily flows for the calibration period is 0.86. According to Donigian (2002) this R squared value is in the "Very Good" range for daily flow values.

4.3.1 Flow Duration Comparisons

The flow duration curve is a primary component of the weight-of-evidence assessing for model performance because it reflects the overall hydrologic regime of the contributing watershed. Figure 5 illustrates the percent chance of flow exceedance across the range of flows for the calibration period.

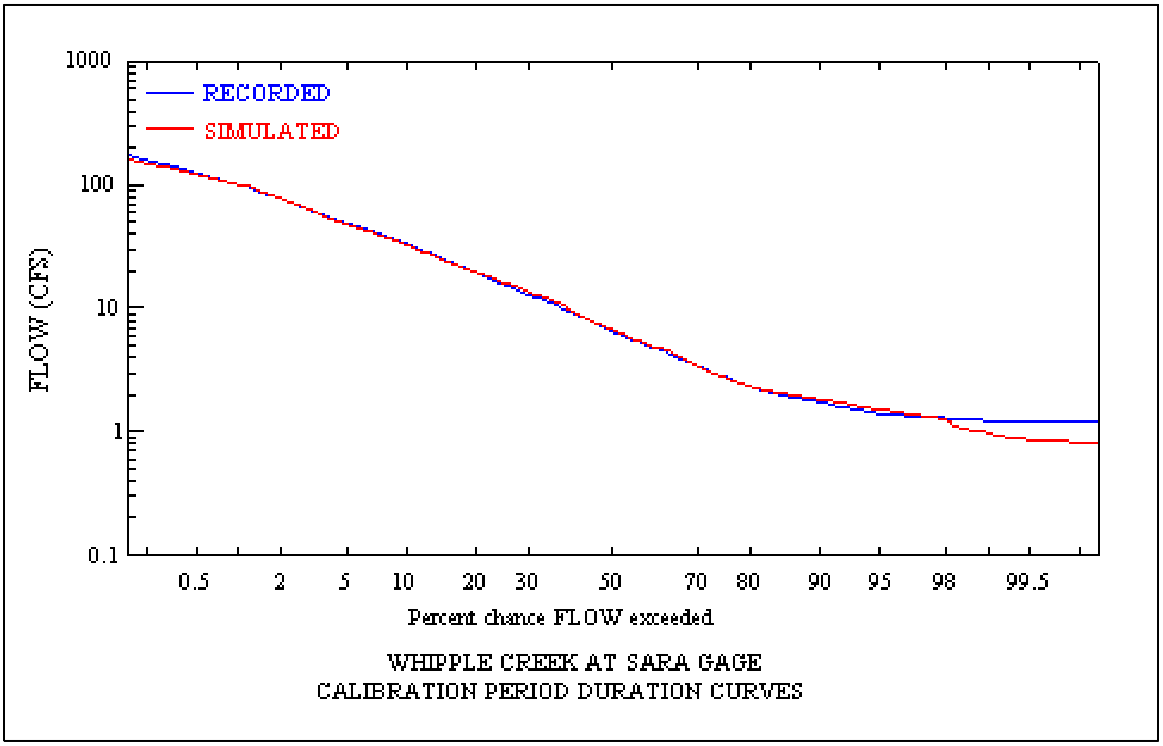

Figure 5: Whipple Creek Flow Durations – Calibration Period (WY 2004-2008)

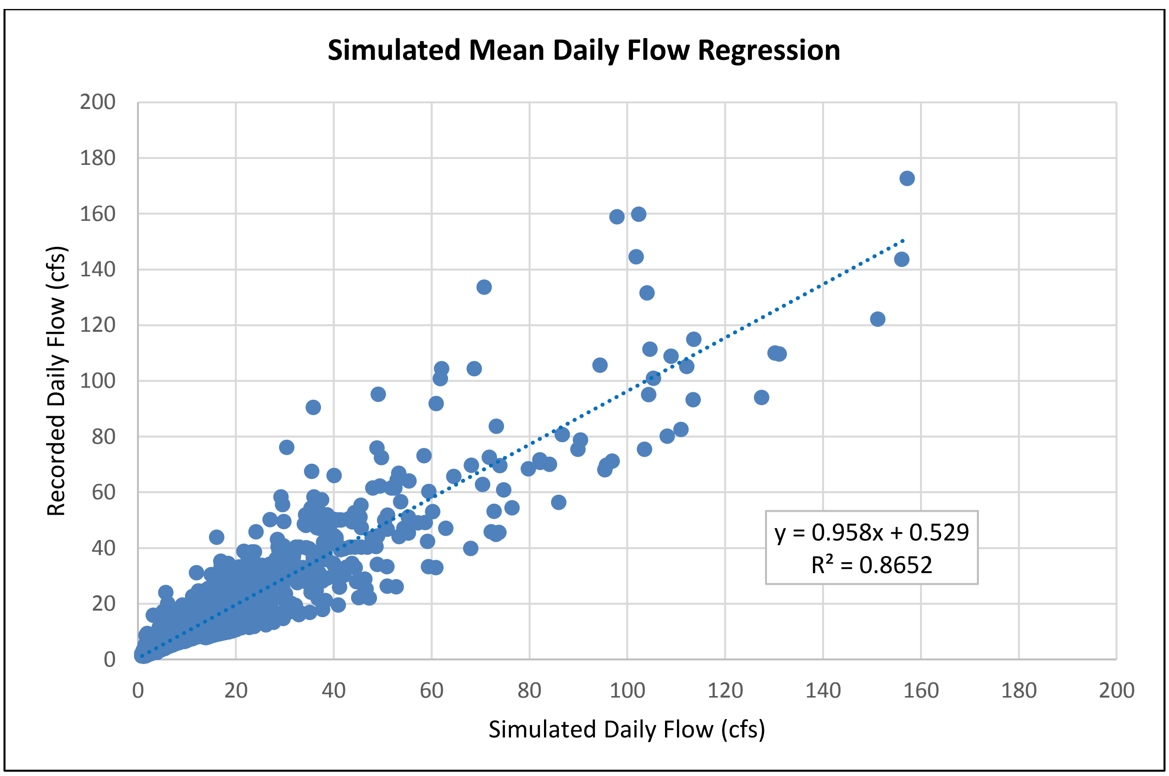

Figure 6: Regression of mean daily flows on simulated flows

Figure 6 includes the coefficient of determination (R squared) based on the daily recorded and simulated streamflow values. The R squared value daily flows for the five-year calibration period is 0.86. According to Donigian (2002), this R squared value is in the “Very Good” range for daily flow values.

4.3.2 Storm Event Comparisons

One important step is model calibration is to examine representation of individual storm hydrographs. Individual storm simulations often will show larger deviations from observed values than for daily and monthly totals, often due to dynamic variations in rainfall spatial distributions not accurately represented by the gage network. So, it is necessary to examine a number of flow events to assess the simulation accuracy; this is performed by reviewing the individual hydrographs at an hourly time interval.

A comparison of the Whipple Creek flows at the Sara Gage (WPL050) shows, in general, a very good match between the simulated and observed peak flow data. Graphical representation of storm events during the calibration period is shown in Attachment A.

Calibration periods where there is a very good match between the simulated and observed peak flow data include:

October 2004 through May 2005, February 2006 through May 2007, and January 2007 through April 2008. The model results do not demonstrate any specific bias.

4.3.3 Annual Volume Comparisons

Annual volume comparisons demonstrate the ability of the modeled flows to accurately simulate all of the components contributing to the annual water balance (stream flow, evaporation, loss to groundwater). Table 2 shows the annual precipitation, simulated flow, recorded flow and relative flow error for Whipple Creek for the calibration period.

For the Whipple Creek calibration period an error statistic is presented in the form of the annual runoff volume comparison for each water year and for the entire calibration period of record (water years 2004 through 2008), as shown in Table 2 below. An individual water year runoff volume error ranges from -13% to +8%; the overall calibration period runoff volume error is only 0.3%. According to Donigian 2002 this error statistic is in the “Very Good” range for annual flow values.

Table 2: Whipple Creek Annual Water Balance and Flow Error

Water Year	Precipitation (in)	Simulated Flow (in)	Recorded Flow (in)	Error (%)
2004	42.44	16.67	17.57	-5.1%
2005	39.74	13.41	15.49	-13.4%
2006	50.98	29.77	27.66	7.7%
2007	48.09	24.56	23.26	5.6%
2008	40.51	20.69	20.80	-0.6%
Average	44.35	21.02	20.96	0.3%

4.4 Calibration Results Summary

The observed and simulated stream flow was compared for the Whipple Creek watershed at the WPL050 stream gage.

Based on Ecology’s recommendations, two types of graphical comparisons and one error statistic and one correlation test were used to evaluate the calibration effort.

The Whipple Creek calibration results show a very good match at the WPL050 gaging site with regard to mean annual flow comparisons, flow duration, and storm hydrographs. Water balance analysis resulted in 0.3% difference between the simulated and observed values. Flow duration comparison between simulated and observed flows shows an excellent result.

4.5 Conclusions

The calibration was completed by manually adjusting the HSPF parameters and making other adjustments, as appropriate.

Table 3 provides a limited weight-of-evidence summary of the various model-data comparisons performed for the simulation of the Whipple Creek watershed model for the calibration period, as discussed above. The overall model performance, shown in the last column, reflects our assessment of very good to excellent model performance for the calibration period.

Table 3: Weight-of-Evidence for Model Performance

Calibration Period (WY 2004-2008)	Whipple Creek	Overall Model Performance
Annual Volume Error	Very Good	Very Good
Daily Flow R Squared	Very Good	Very Good
Flow Duration Curves	Excellent	Very Good
Hydrographs	Good to Very Good	Very Good

The calibration results, based on the weight-of-evidence approach described herein, demonstrates a good representation of the observed data. This is the outcome of a wide range of graphical comparisons and measures of the model performance for mean annual volume, flow duration, daily flow correlation, and individual storm event simulations. These comparisons demonstrate conclusively that the model is a good representation of the water balance and hydrology of the watersheds.

Based on the model results presented and discussed in this report, the HSPF application to the Whipple Creek watershed provides a sound, calibrated hydrologic watershed model. The resulting model parameters are appropriate for impact evaluation of hydromodification management alternatives and calibrating a water quality model. The calibration results, based on the weight-of-evidence approach described herein, demonstrate a good representation of the observed data.

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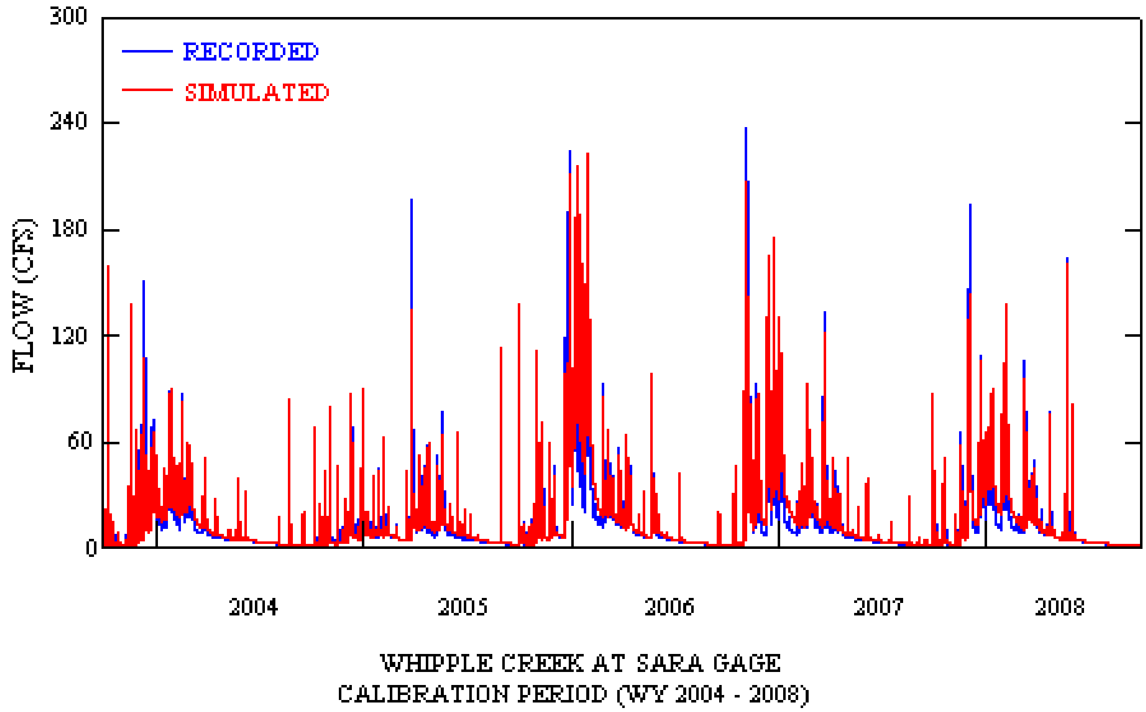
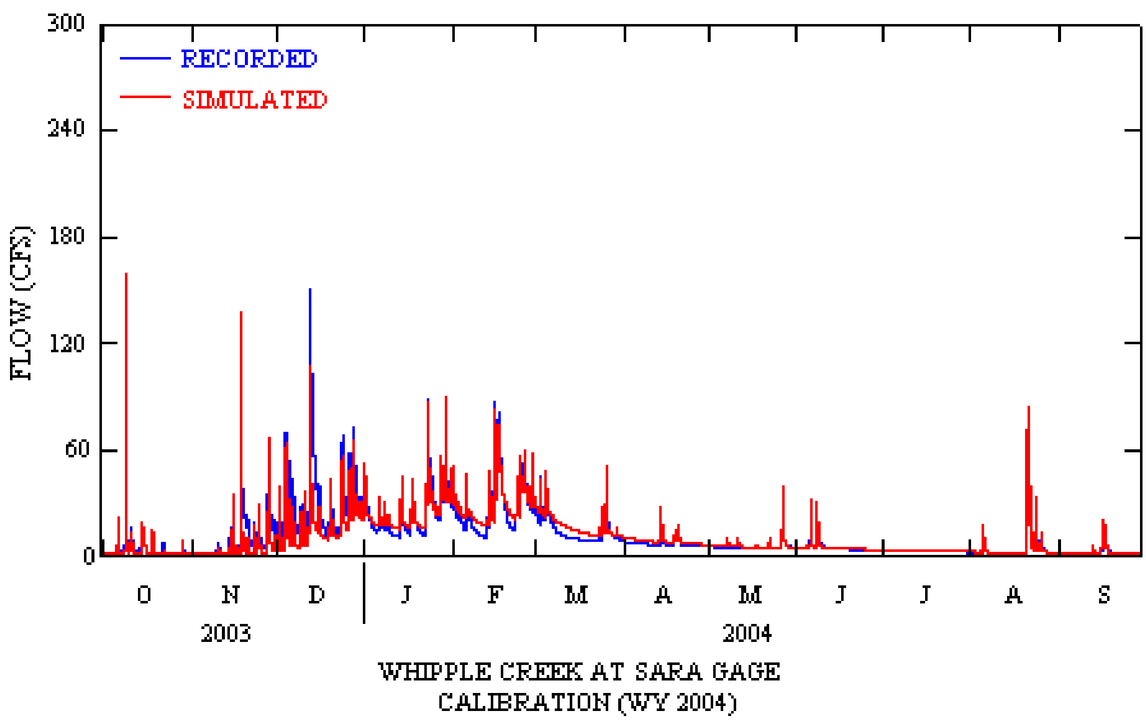
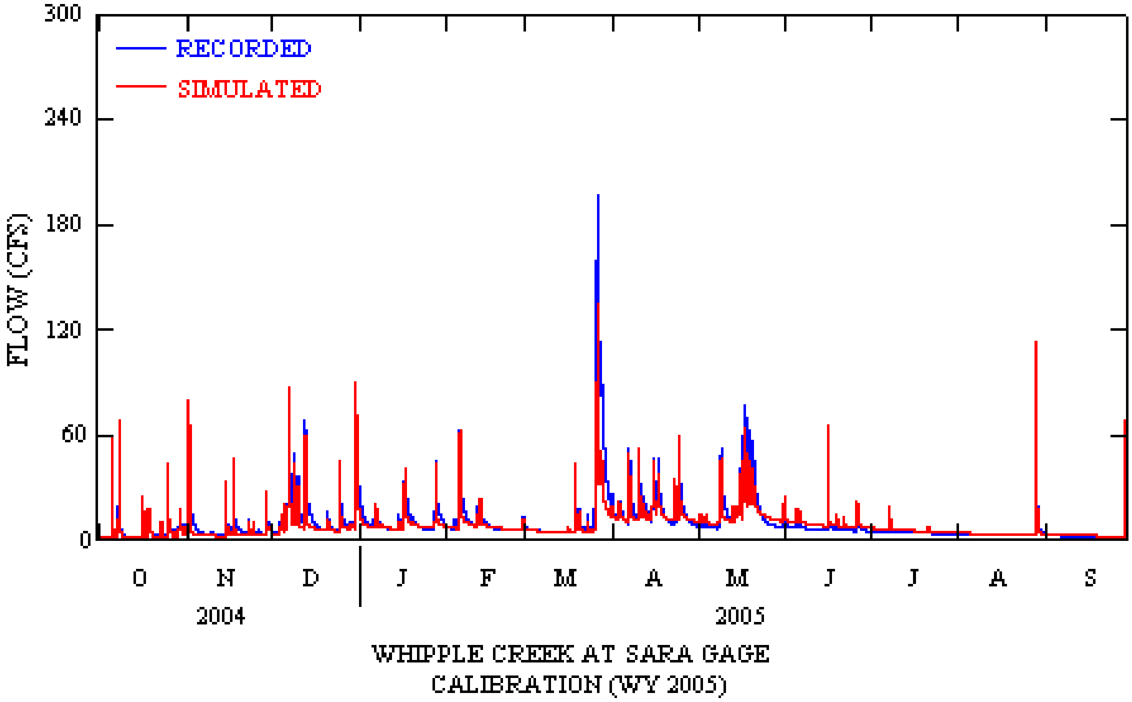
Attachment A: Hydrographs



Whipple Creek Streamflow (WY 2004-2008)



Whipple Creek Streamflow (WY 2004)



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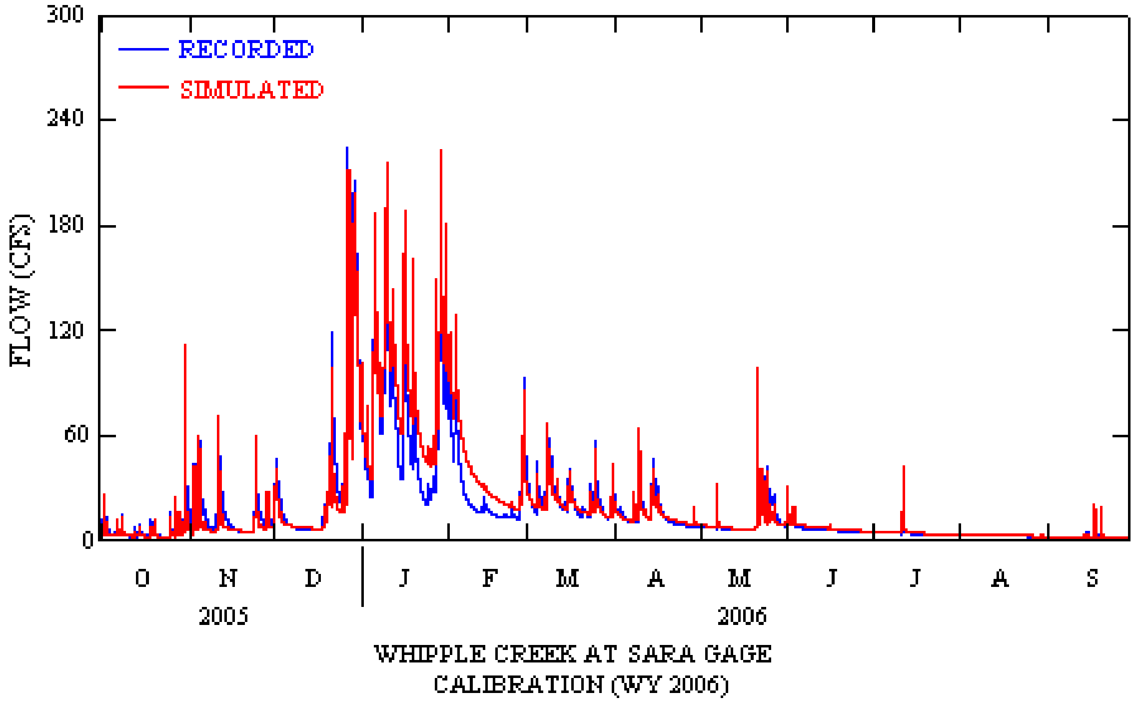

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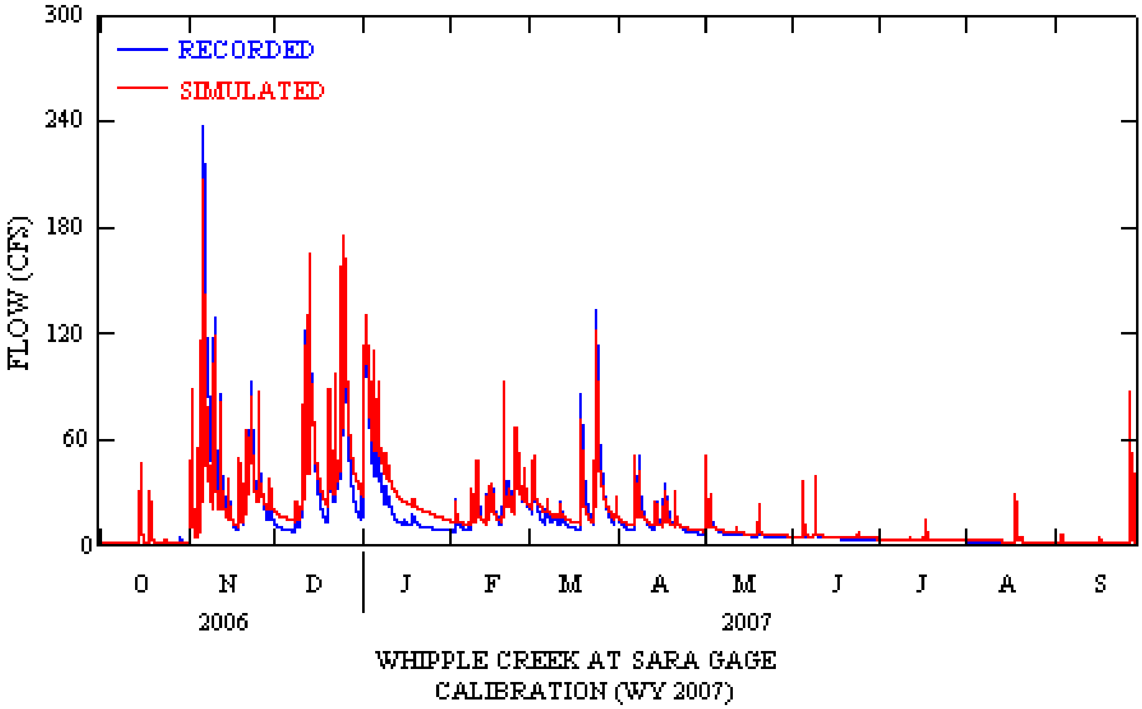

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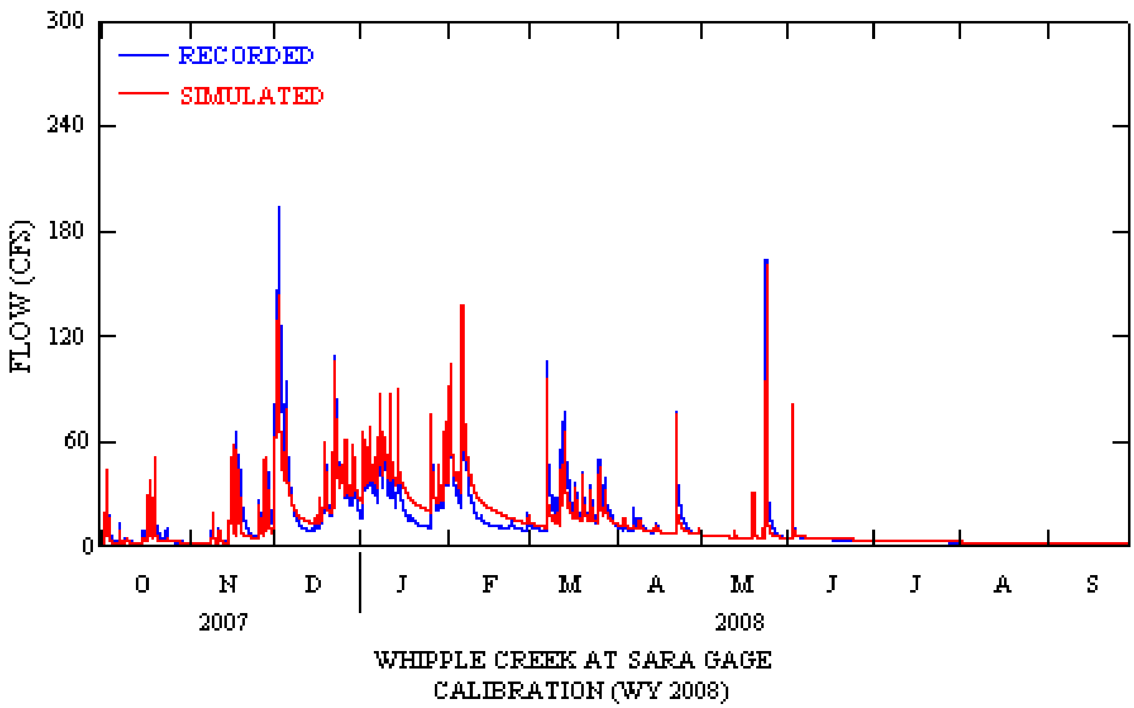

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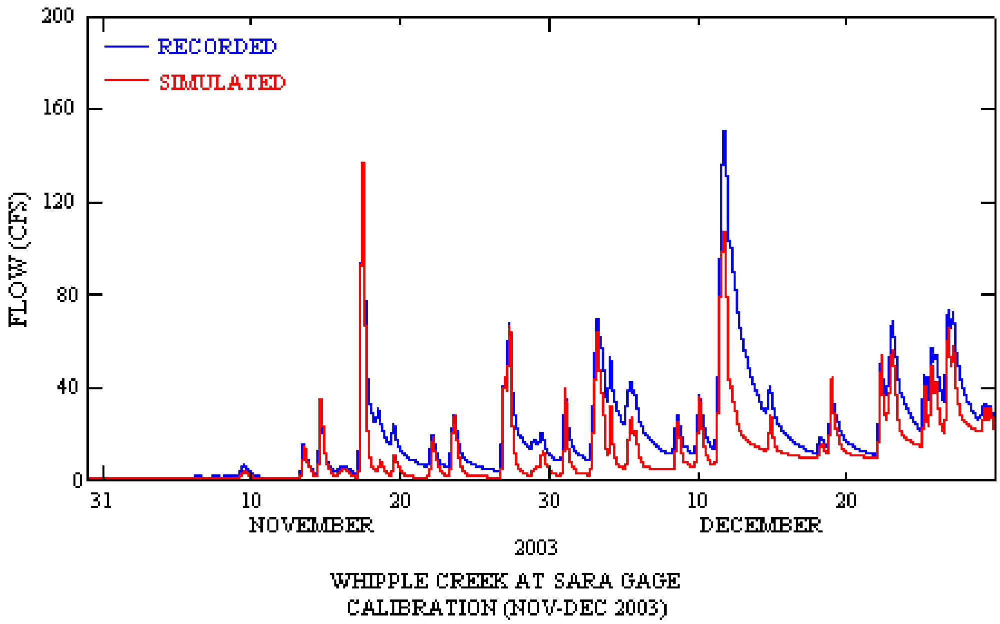
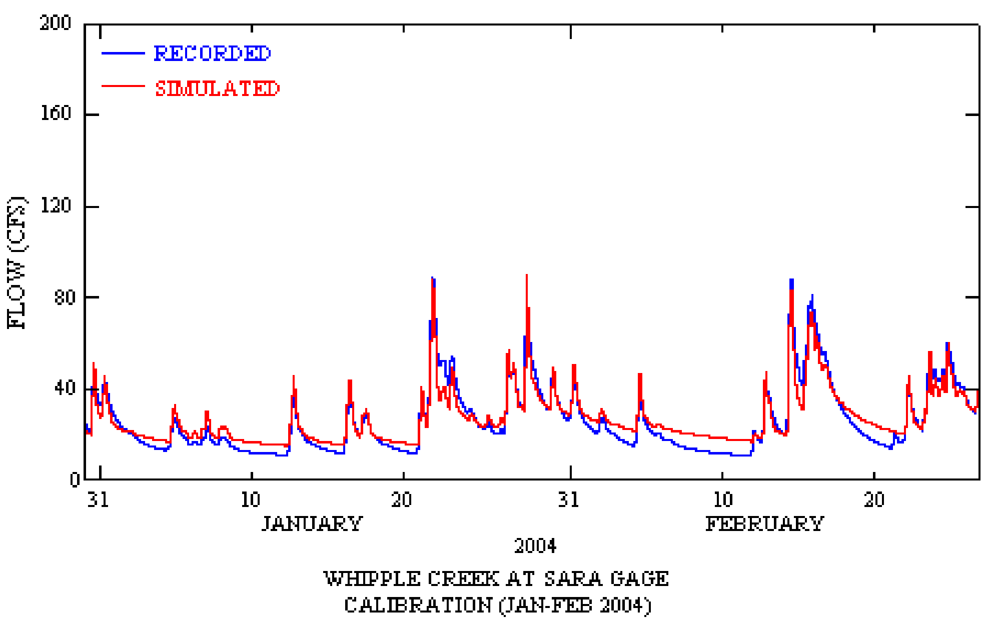
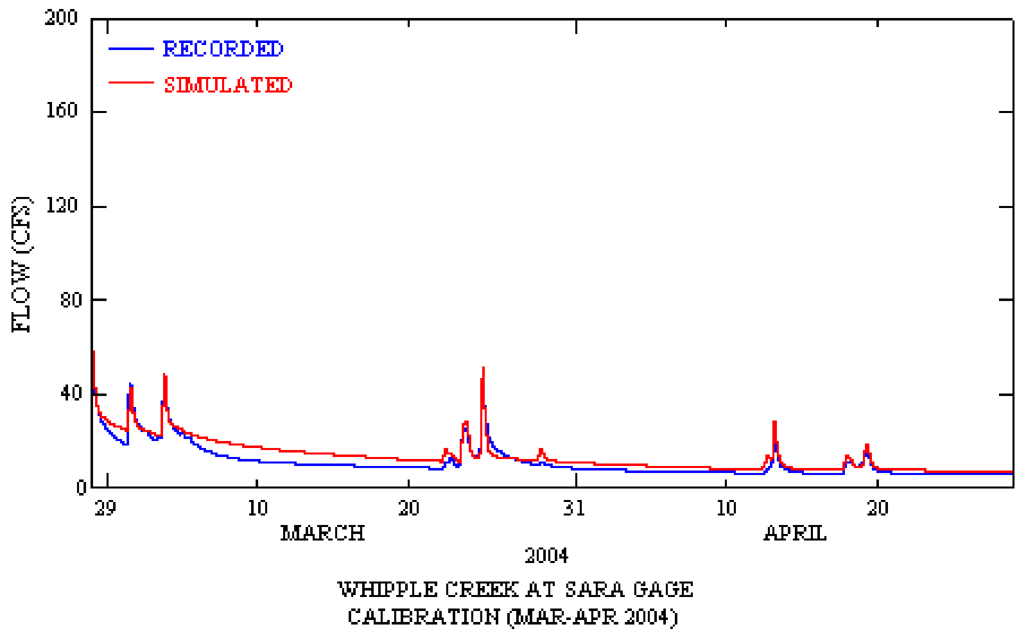


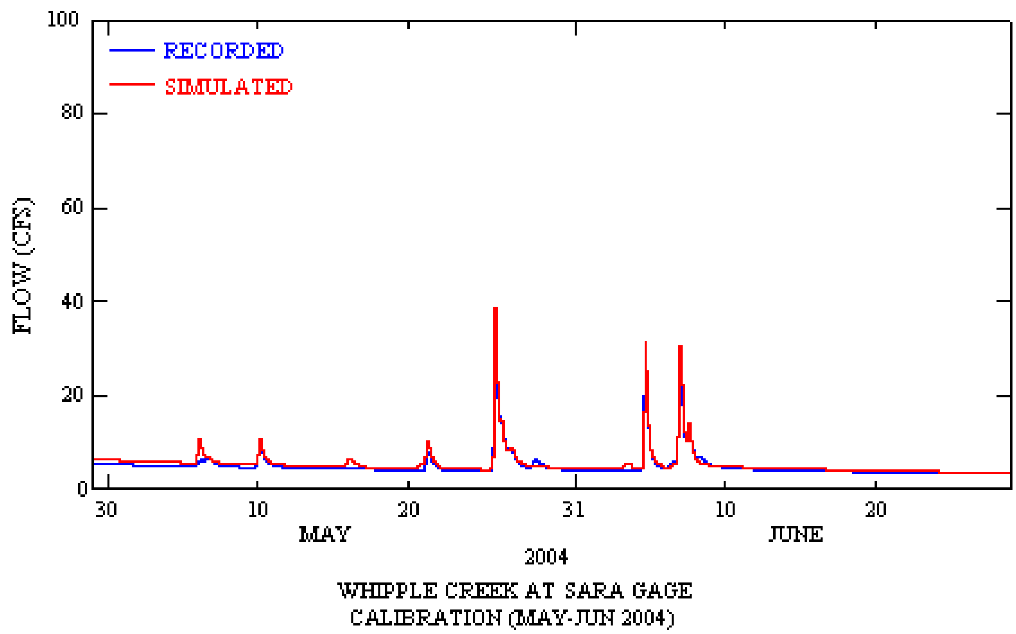
Whipple Creek Streamflow (November – December 2003)



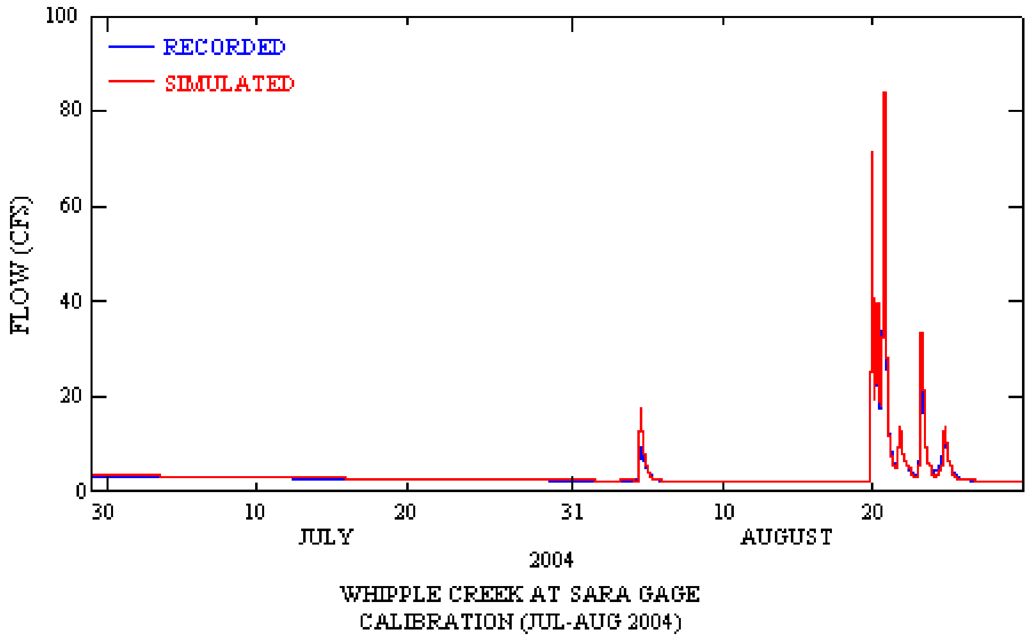
Whipple Creek Streamflow (January – February 2004)



Whipple Creek Streamflow (March – April 2004)



Whipple Creek Streamflow (May – June 2004)



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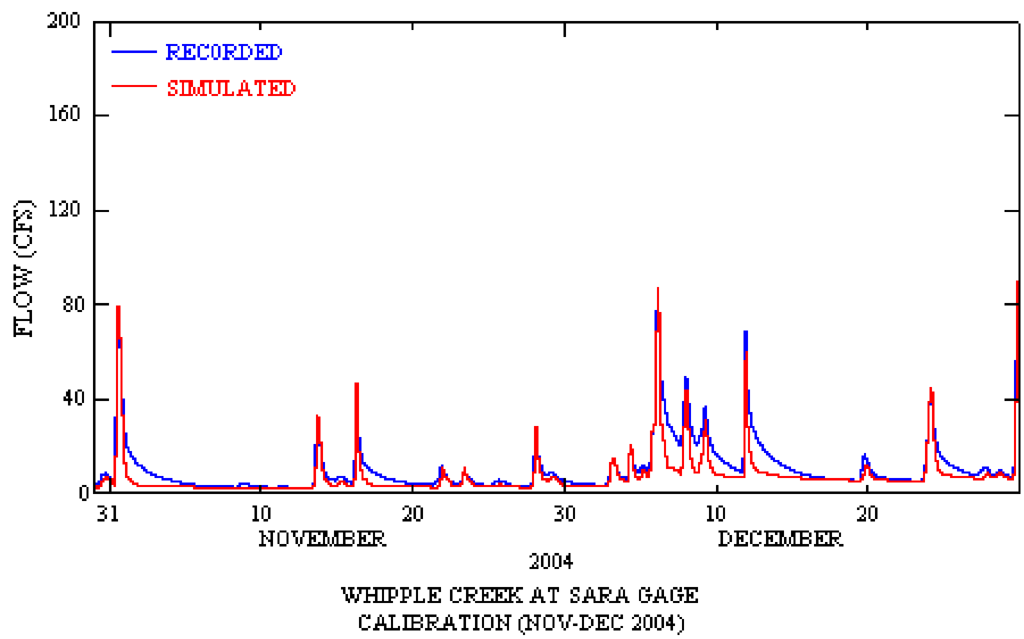

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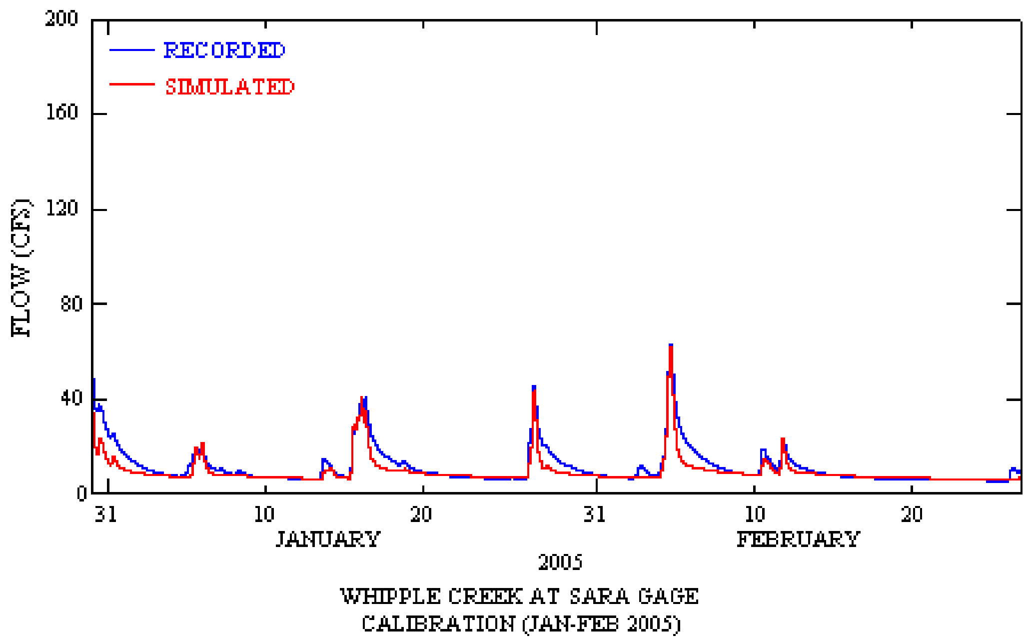

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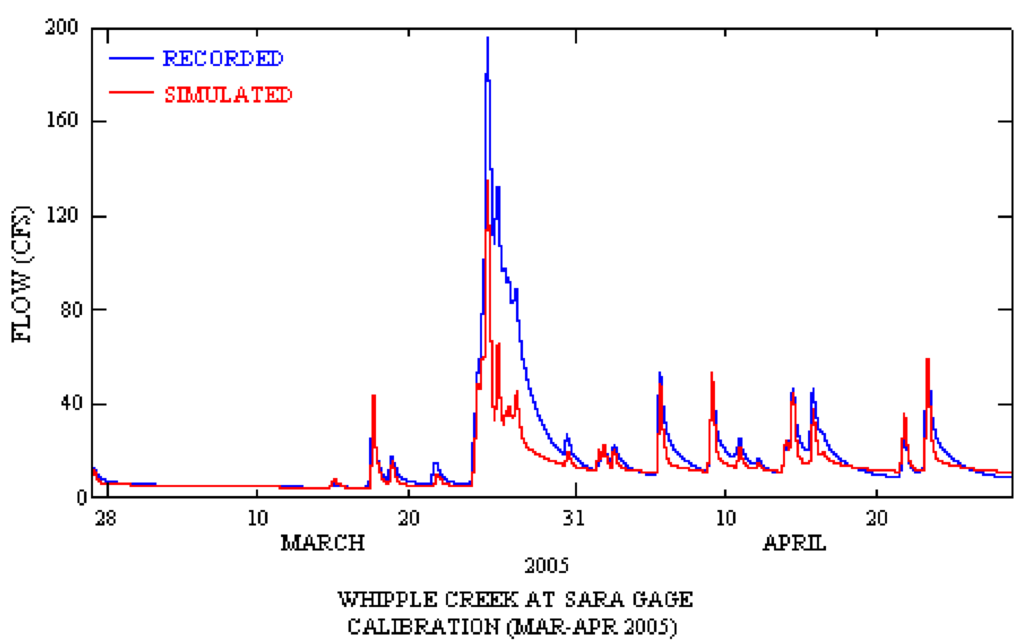

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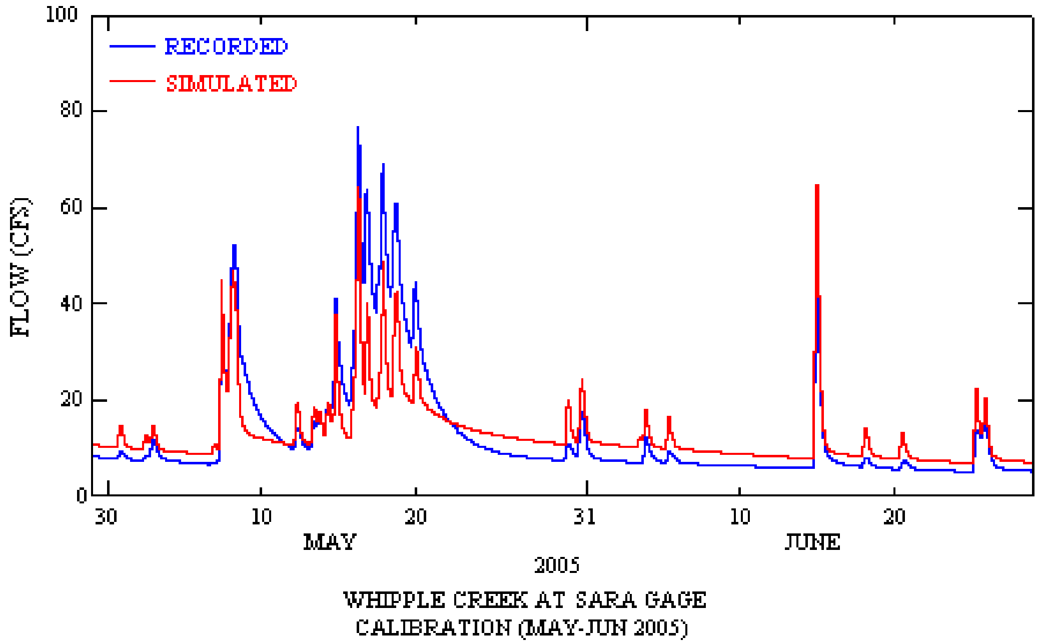

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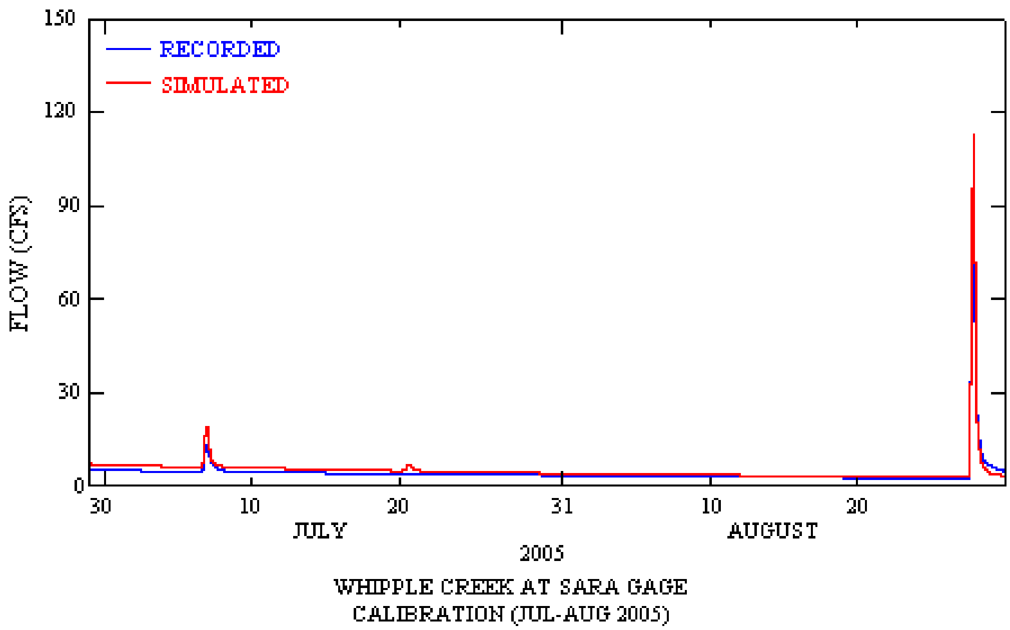

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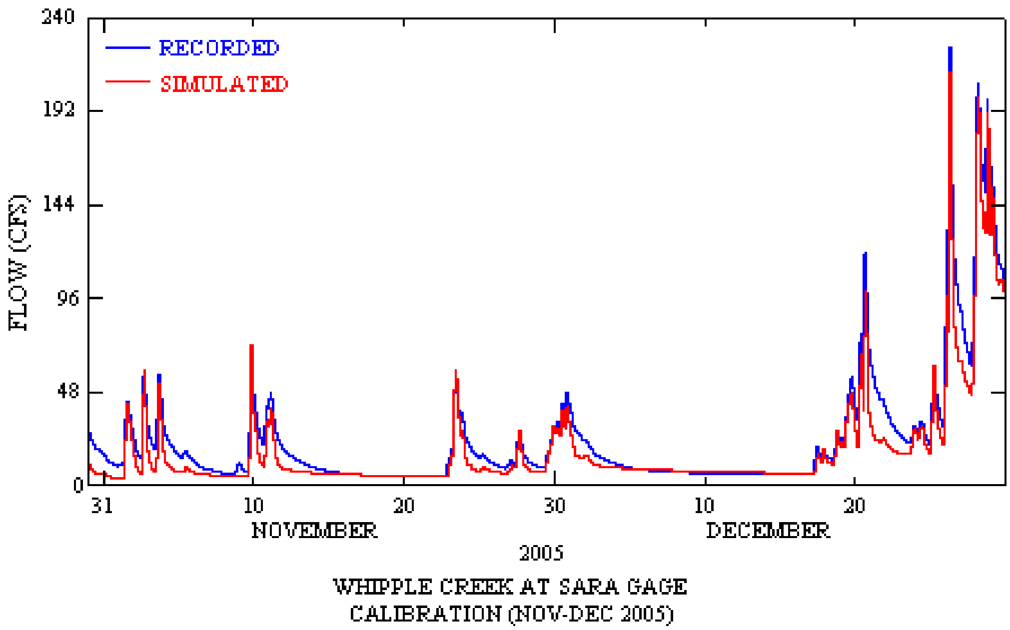

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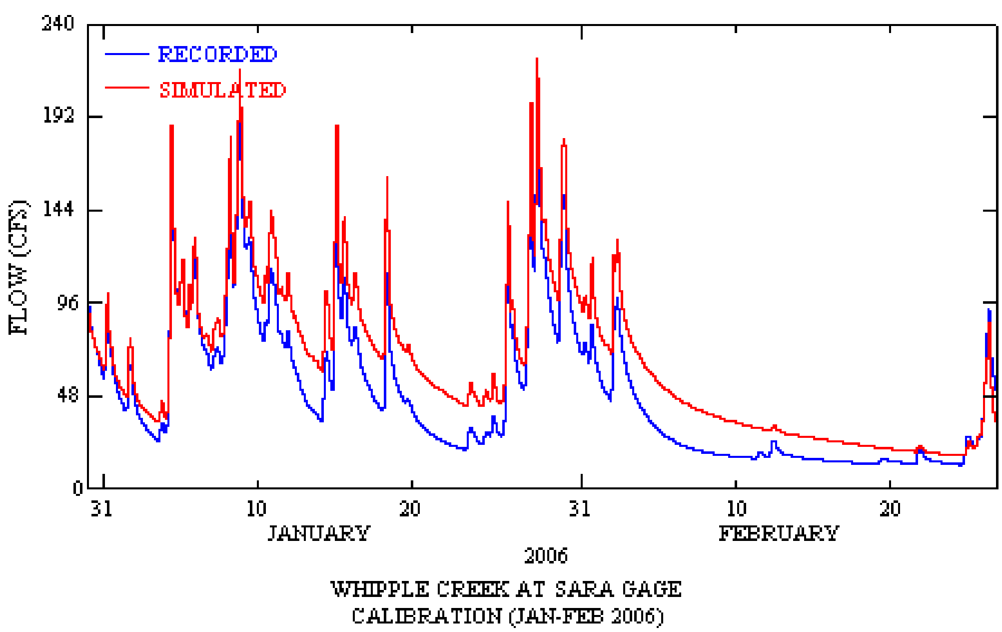

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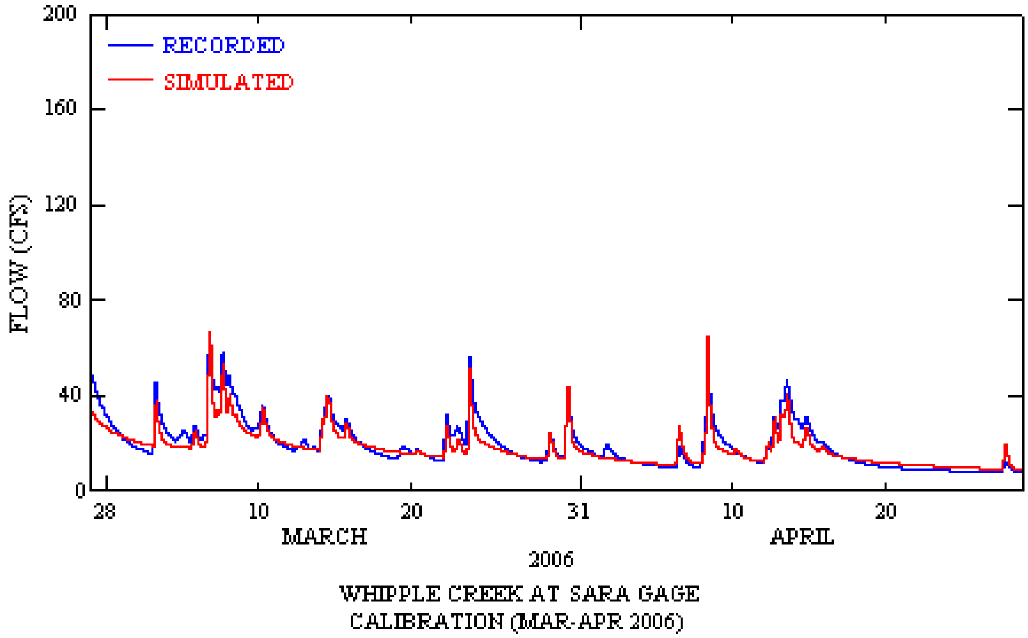

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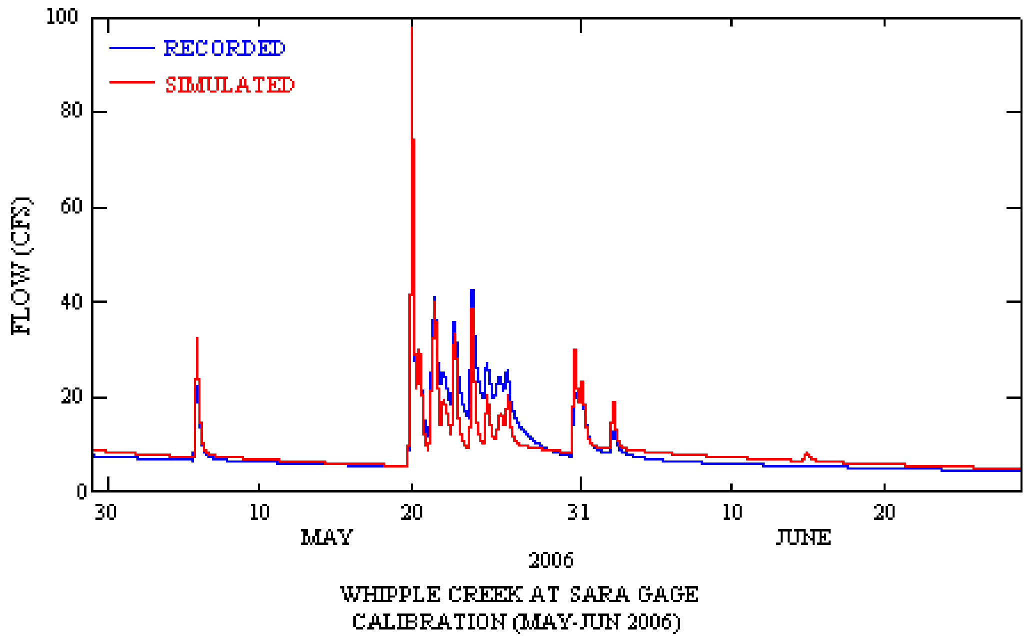

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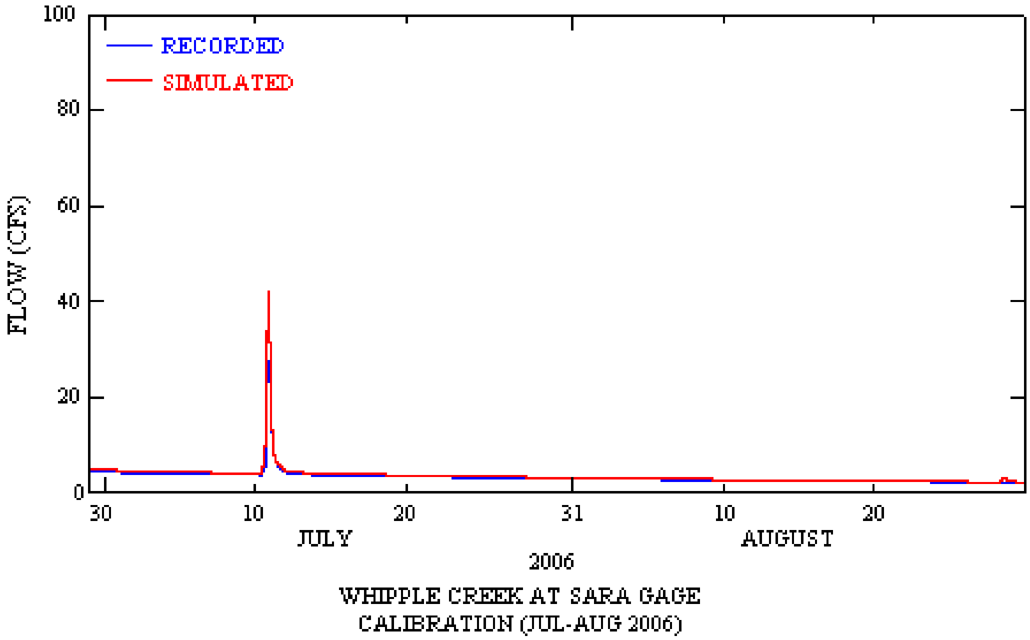

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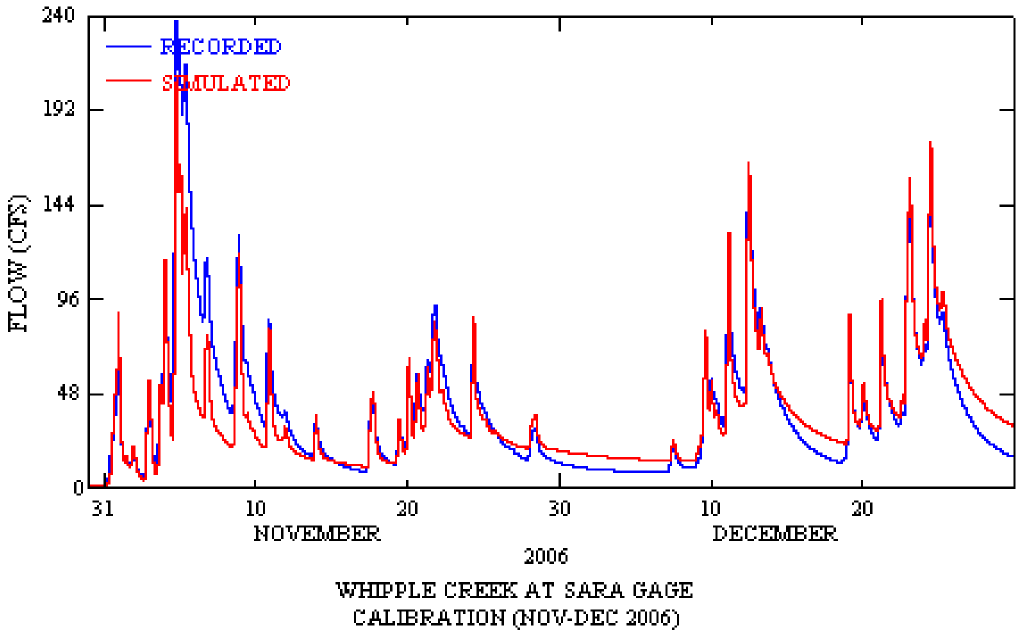

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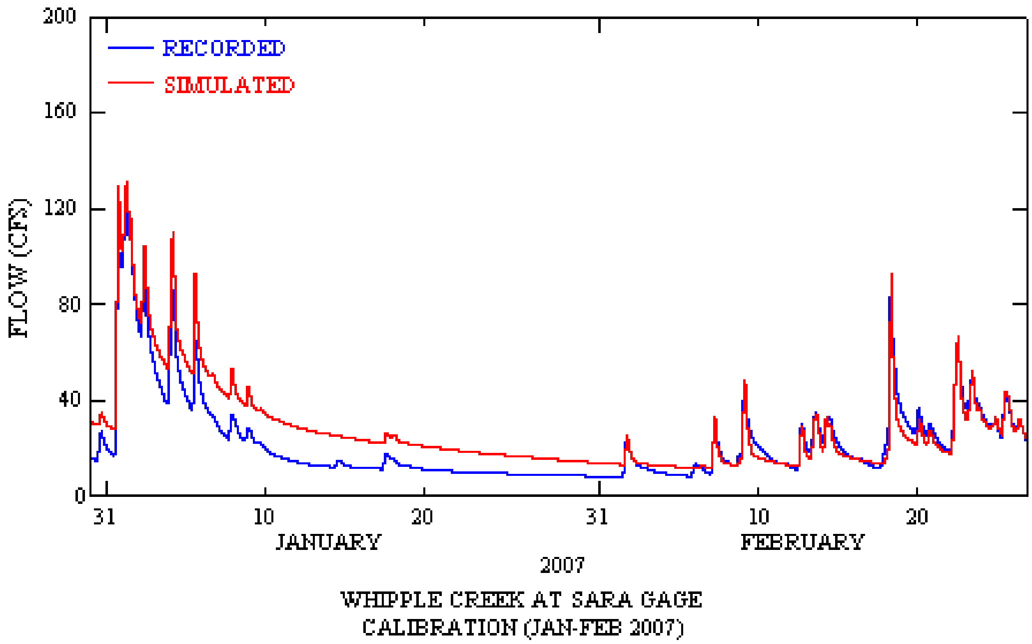

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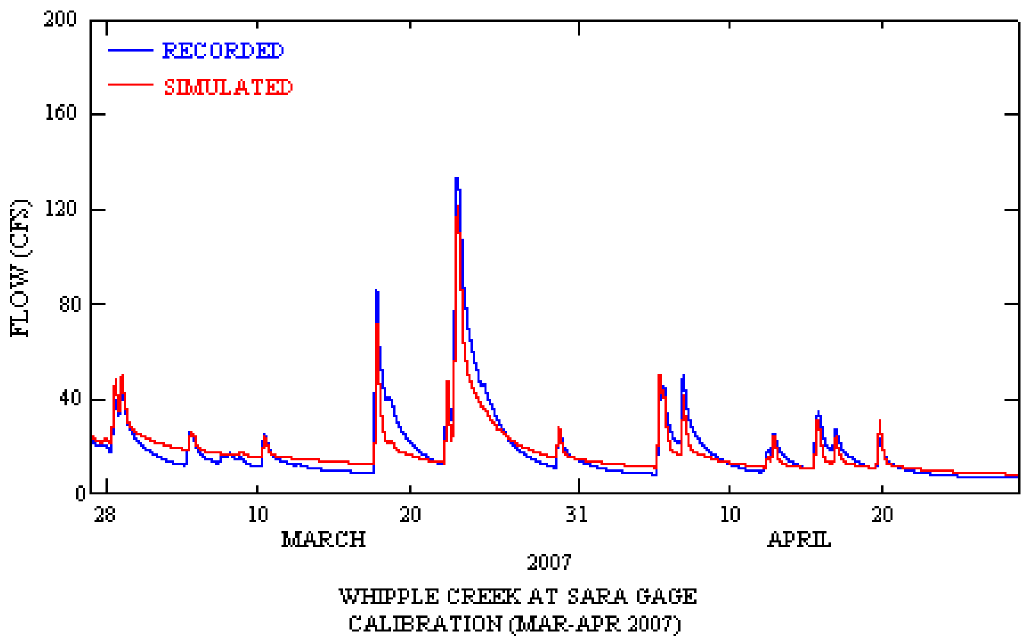

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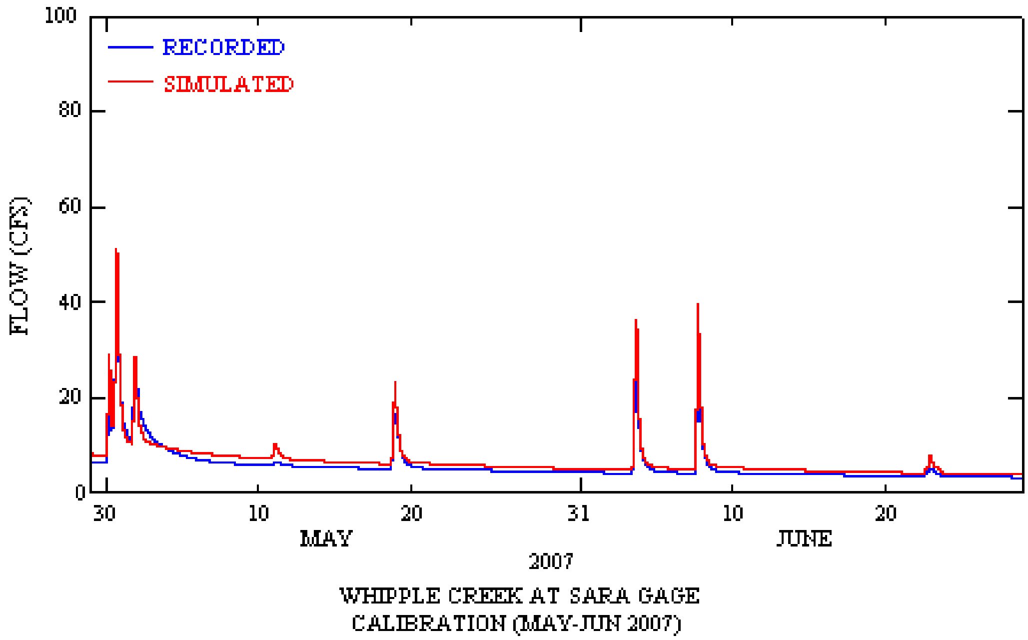

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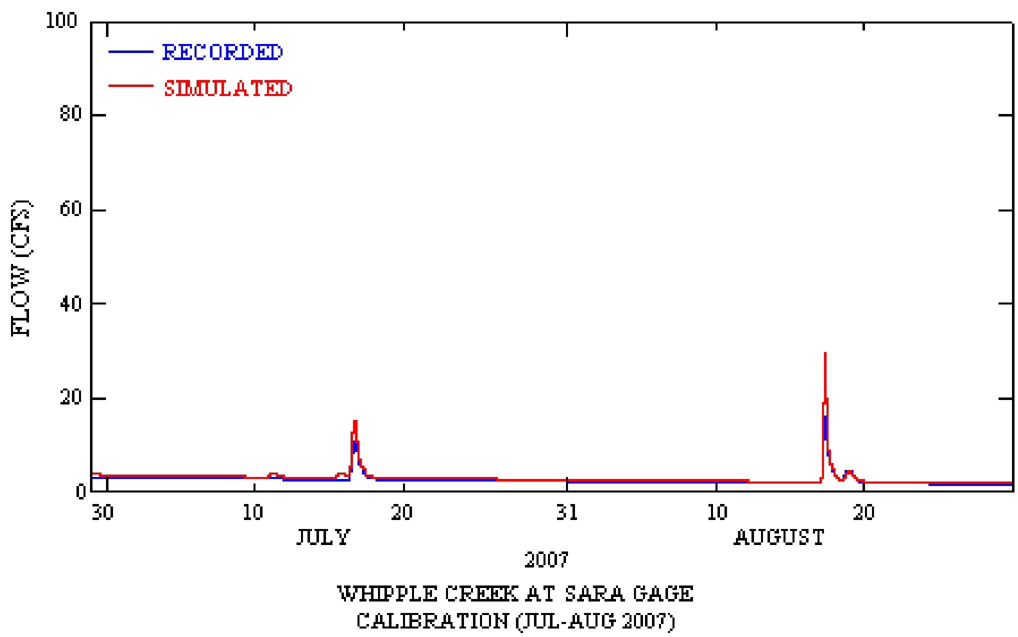
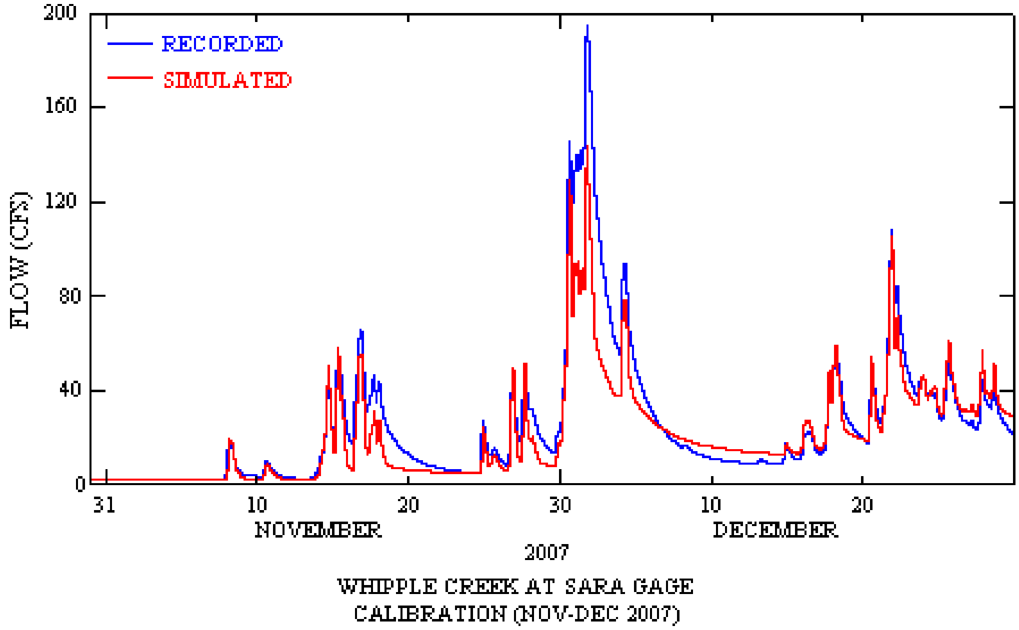
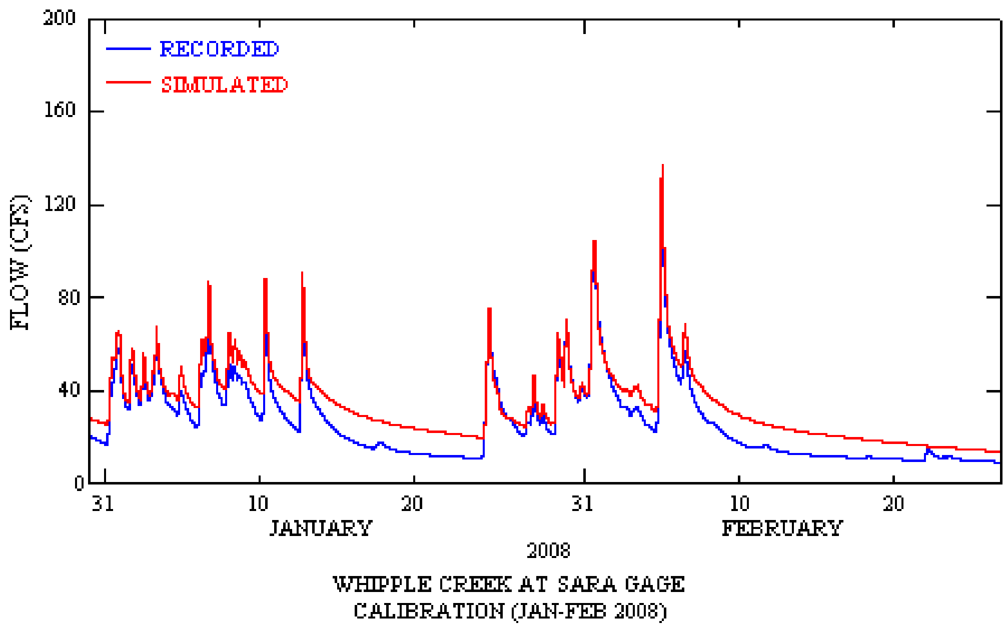


Whipple Creek Streamflow (July – August 2007)



Whipple Creek Streamflow (November – December 2007)



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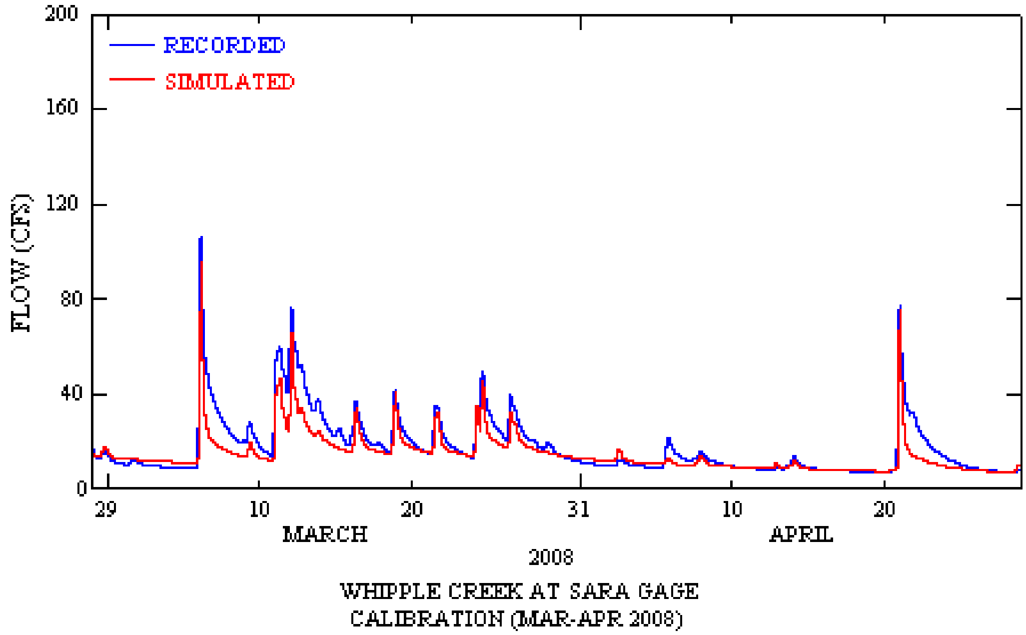

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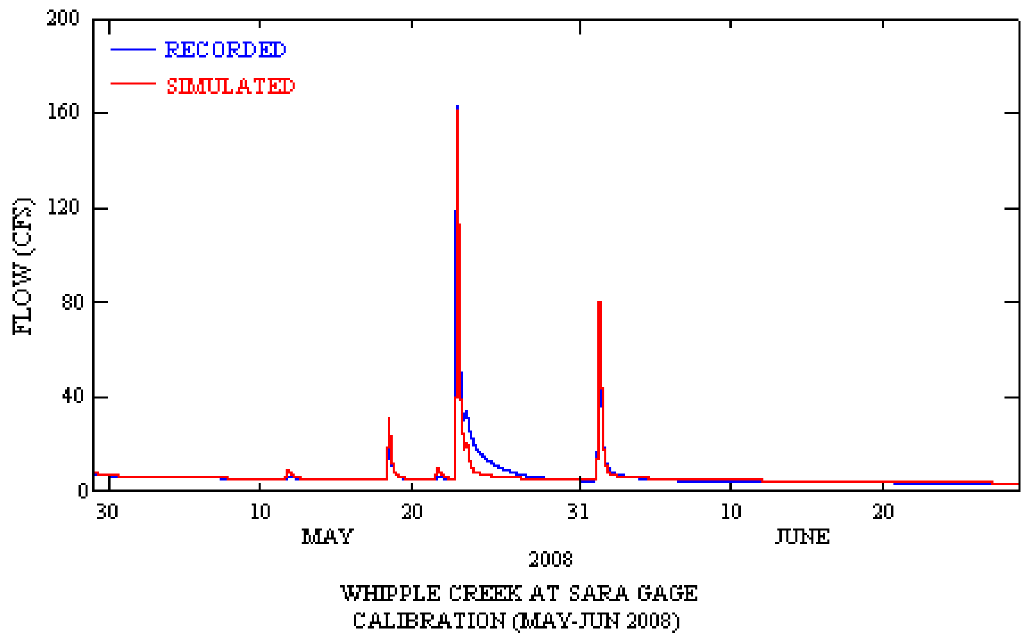

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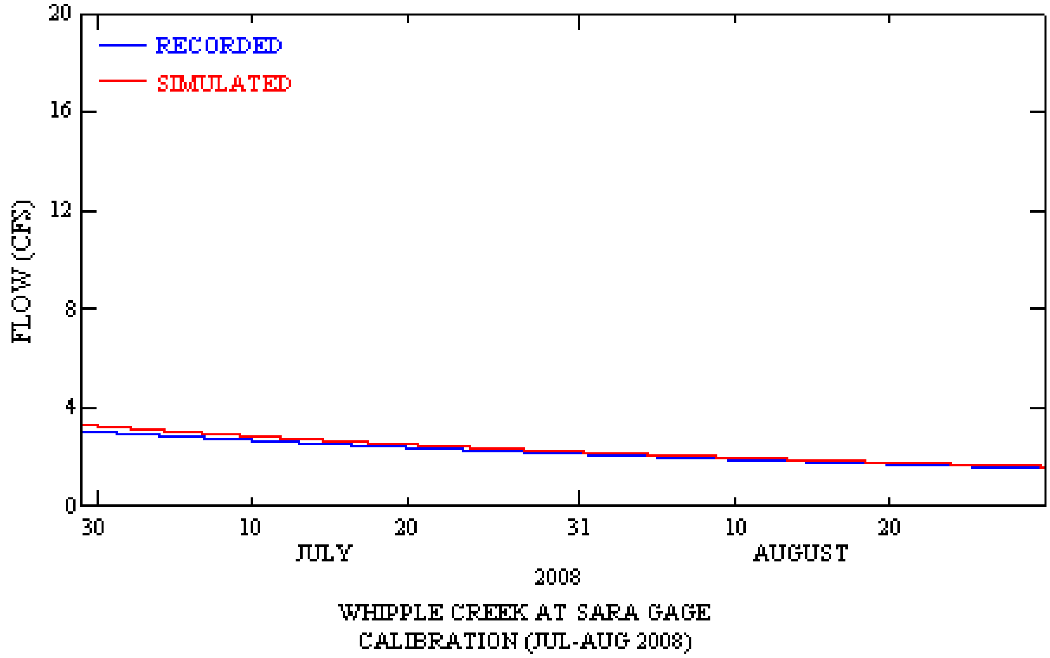

Whipple Creek Streamflow (July – August 2008)

Attachment B: Model Parameters

PERLND	SOIL	VEGETATION	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
200	SG3	Forest	10.00	0.12	400	0.0570	0.50	0.991
210	SG3	Pasture	10.00	0.10	400	0.0570	0.50	0.991
220	SG3	Lawn	10.00	0.08	400	0.0570	0.50	0.991
260	SG4	Forest	8.00	0.10	400	0.0639	0.50	0.991
270	SG4	Pasture	8.00	0.08	400	0.0639	0.50	0.991
280	SG4	Lawn	8.00	0.06	400	0.0639	0.50	0.991
300	SG5	Forest	8.00	0.08	100	0.0100	0.50	0.991
310	SG5	Pasture	8.00	0.06	100	0.0100	0.50	0.991
320	SG5	Lawn	8.00	0.04	100	0.0100	0.50	0.991

PERLND	SOIL	VEGETATION	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
200	SG3	Forest	2.00	2.00	0.00	0.00	0.00
210	SG3	Pasture	2.00	2.00	0.00	0.00	0.00
220	SG3	Lawn	2.00	2.00	0.00	0.00	0.00
260	SG4	Forest	2.00	2.00	0.00	0.00	0.00
270	SG4	Pasture	2.00	2.00	0.00	0.00	0.00
280	SG4	Lawn	2.00	2.00	0.00	0.00	0.00
300	SG5	Forest	10.00	2.00	0.00	0.00	0.70
310	SG5	Pasture	10.00	2.00	0.00	0.00	0.50
320	SG5	Lawn	10.00	2.00	0.00	0.00	0.35

PERLND	SOIL	VEGETATION	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
200	SG3	Forest	0.20	1.30	0.35	4.00	0.60	0.70
210	SG3	Pasture	0.15	1.30	0.30	4.00	0.60	0.40
220	SG3	Lawn	0.10	1.10	0.25	4.00	0.60	0.25
260	SG4	Forest	0.20	1.20	0.35	5.00	0.60	0.70
270	SG4	Pasture	0.15	1.20	0.30	5.00	0.60	0.40
280	SG4	Lawn	0.10	1.00	0.25	5.00	0.60	0.25
300	SG5	Forest	0.20	3.00	0.50	2.00	0.60	0.80
310	SG5	Pasture	0.15	3.00	0.50	2.00	0.60	0.60
320	SG5	Lawn	0.10	3.00	0.50	2.00	0.60	0.40

PERLND	SOIL	VEGETATION	CEPS	SURS	UZS	IFWS	LZS	AGWS	GWVS
200	SG3	Forest	0.00	0.00	0.00	0.00	1.00	0.50	0.00
210	SG3	Pasture	0.00	0.00	0.00	0.00	1.00	0.50	0.00
220	SG3	Lawn	0.00	0.00	0.00	0.00	1.00	0.50	0.00
260	SG4	Forest	0.00	0.00	0.00	0.00	1.00	0.50	0.00
270	SG4	Pasture	0.00	0.00	0.00	0.00	1.00	0.50	0.00
280	SG4	Lawn	0.00	0.00	0.00	0.00	1.00	0.50	0.00
300	SG5	Forest	0.00	0.00	0.00	0.00	1.00	0.50	0.00
310	SG5	Pasture	0.00	0.00	0.00	0.00	1.00	0.50	0.00
320	SG5	Lawn	0.00	0.00	0.00	0.00	1.00	0.50	0.00

Appendix G

Whipple Creek Watershed-Scale Stormwater Plan Report

Water Quality Model Calibration Report

Prepared by

Fereidoon Safdari, Engineering Services Manager

Clark County Department of Public Works

Clean Water Division

and

Doug Beyerlein

Otak, Inc.

August 2017

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1. INTRODUCTION

1.1 Background

The Whipple Creek basin has been adversely impacted by changes in stormwater, a result of development that mainly occurred over the last three decades, in some areas with limited, or no stormwater controls. Consequently, Whipple Creek's designated beneficial use of salmon habitat is seriously degraded.

The Washington State Department of Ecology issued a 2013-2018 Phase I Municipal Stormwater Permit (Permit) that requires Clark County (County) to select a watershed and perform watershed-scale stormwater planning as outlined in section S5.C.5.c. This section states that "the objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support 'existing uses' and 'designated uses', as those terms are defined in WAC 173-201A-020, throughout the stream system."

Whipple Creek is not specifically listed in WAC 173-201A-602. The designated uses for streams not specifically listed are:

- Salmonid spawning, rearing, and migration;
- Primary contact recreation;
- Domestic, industrial, and agricultural water supply;
- Stock watering;
- Wildlife habitat;
- Shellfish harvesting;
- Commerce and navigation;
- Boating; and
- Aesthetic values.

Among these, the salmonid uses are the most challenging to maintain and restore, typically requiring habitat conditions equivalent to those found in a predominantly forested watershed.

The 2010 Clark County Stream Health Report rated Whipple Creek as poor for flow, water quality, and biological health (Department of Environmental Services, 2010). The Washington State Department of Ecology (Ecology) includes Whipple Creek in its 303(d) Category 5 list (polluted waters requiring a TMDL) for fecal coliform bacteria, temperature and bio-assessment (B-IBI) and Category 2 list (waters of concern) for dissolved oxygen (Ecology, 2015).

1.2 Study area

Whipple Creek watershed is located in southwest Clark County, draining west from low hills to the Columbia River flood plain. The watershed was once dominated by rural and agricultural land uses. It is currently moderately developed with a mix of rural, urban, and urbanizing areas at the northern edge of the Vancouver Urban Growth Area (UGA). Approximately 4.4 square miles of the 12.1 square mile basin is inside the UGA. Historic clearing and development impacts have degraded stream habitat and caused areas of severe channel instability and erosion. Impacts from these changes to land cover are consistent with those documented elsewhere around Washington State for channel stability, water quality, and overall ecological function. General land use in Whipple Creek includes developed urban areas, low density rural residential, and some agriculture.

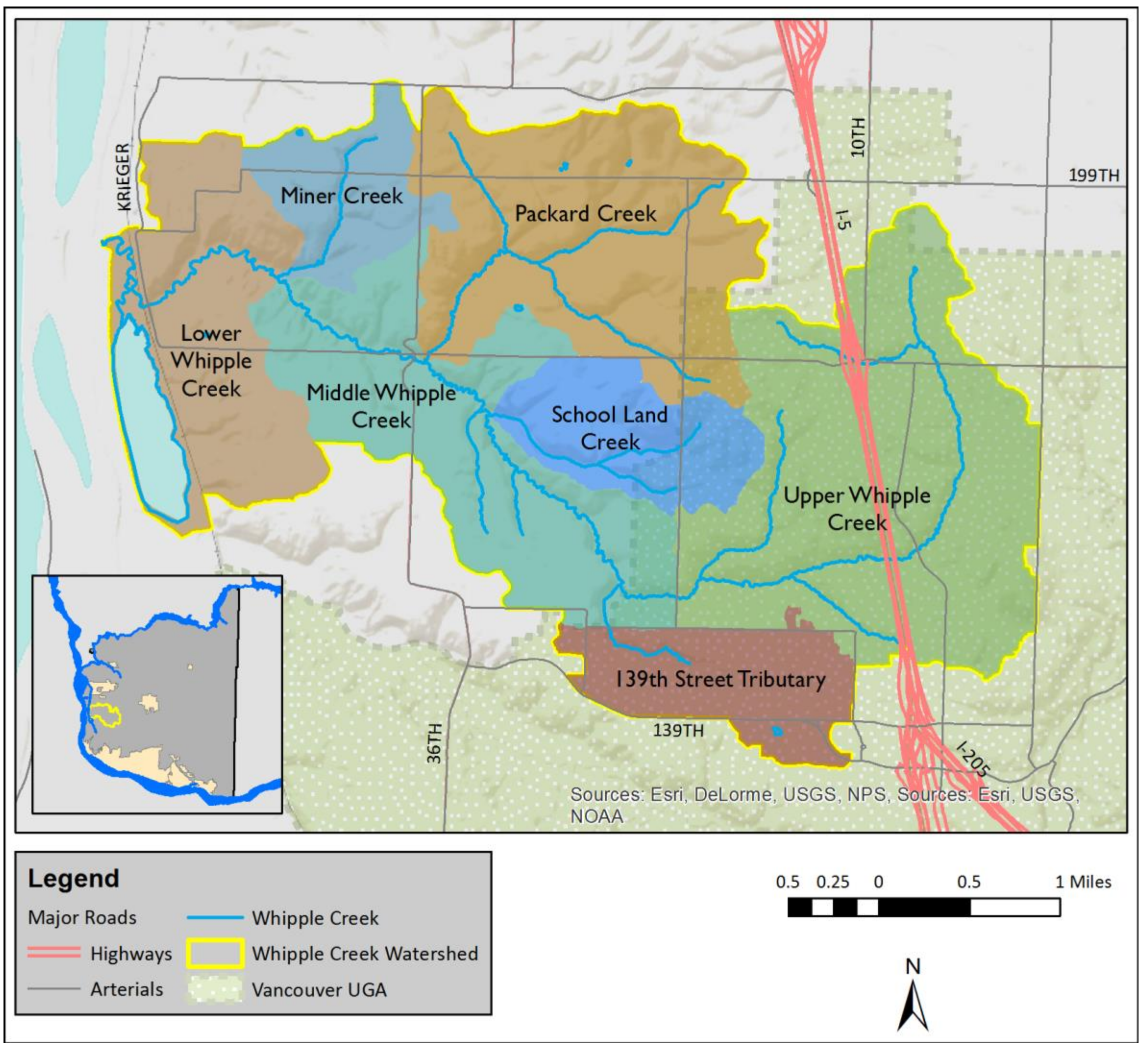

Figure 1. Map of Whipple Creek Basin

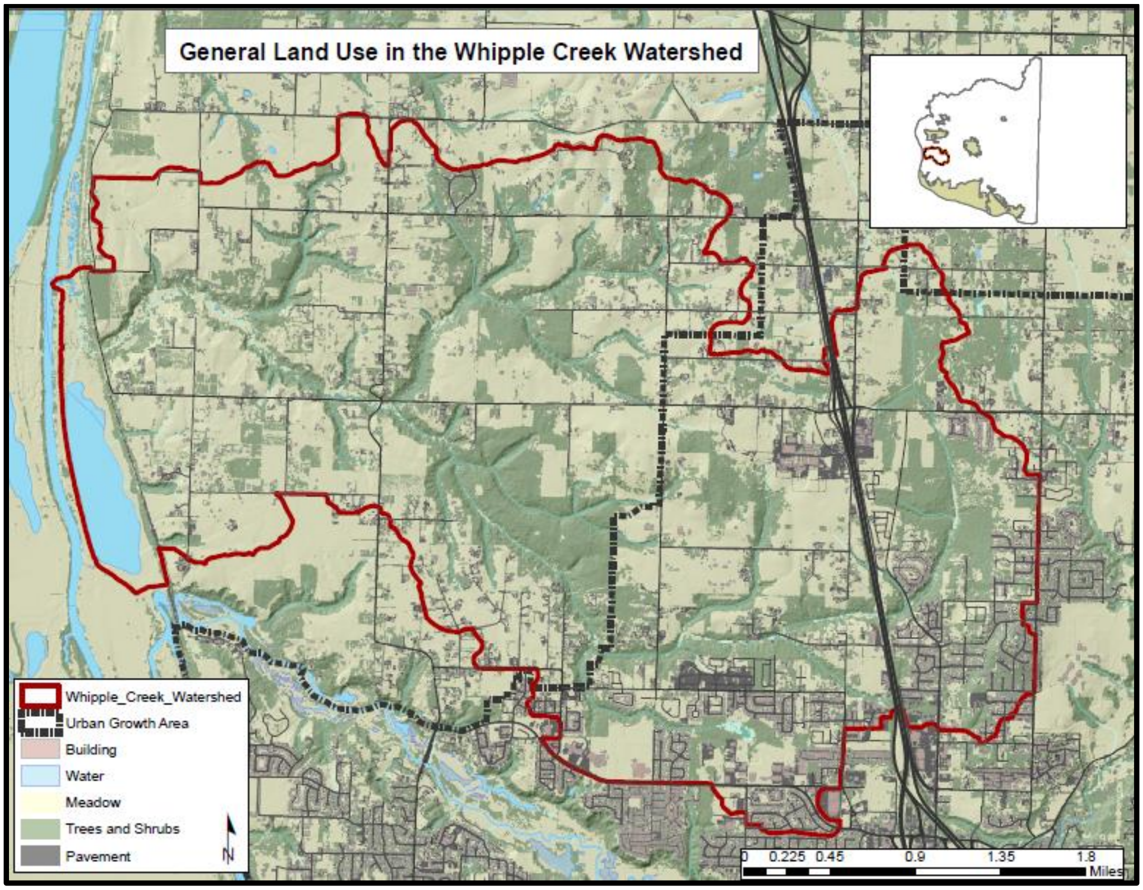

Figure 2. General Land Use in the Whipple Creek Watershed

Table 1. Current Land Use of Whipple Creek Study Area, 2014

Land Use	Acres	Percent of Total Area
Impervious	731.34	9.5%
Forest	2397.14	31.0%
Pasture	2640.19	34.2%
Lawn	1761.78	22.8%
Water	191.62	2.5%
Total	7722.07	100.0%

1.3 Objectives

The objective of the water quality model is to simulate four water quality constituents (water temperature, dissolved copper, dissolved zinc, and fecal coliform) in Whipple Creek and develop a calibrated HSPF model for the watershed.

Clark County Clean Water Division conducted the Long-term Index Site Project (LISP) to monitor stream water quality beginning in 2002. The project collected information about stream health status and trends at 10 stations along 10 streams including Whipple Creek. The LISP station in the Whipple Creek watershed, named WPL050, is located in the main stem near NW 179th Street. WPL050, along with either other monitoring stations used at various times to collect data, is shown in Figure 3.

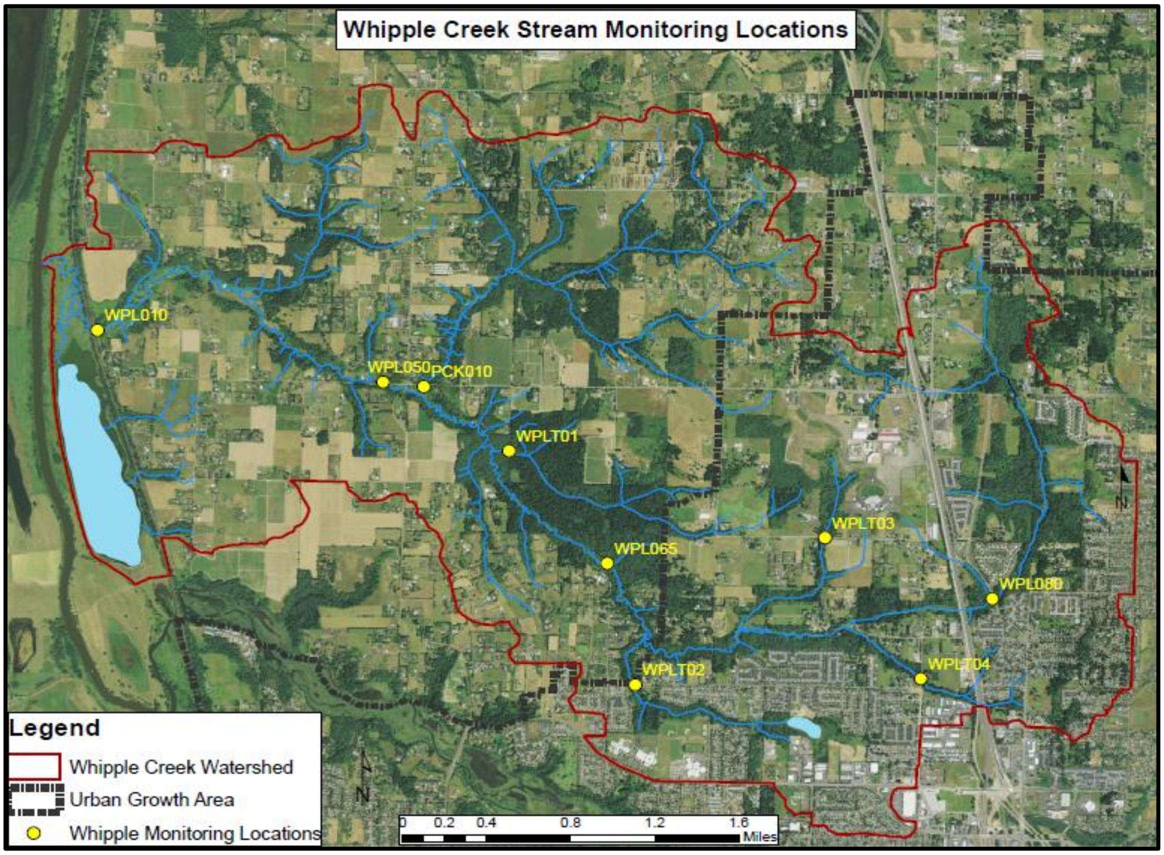

Figure 3: WPL050 and Other Monitoring Station Locations

Physiochemical and bacteria samples and measurements were collected monthly. Temperature data loggers were typically deployed during late spring and summer months from May through September. As part of Whipple Creek watershed planning, Clean Water Program staff also collected water quality data (water temperature, dissolved copper, dissolved zinc, and fecal coliform) from May 2014 to 2015.

The HSPF model water quality calibration used the same period of record as the hydrology calibration (water years 2004 through 2008).

1.4 Washington State Water Quality Standards

1.4.1 Temperature

Stream temperature is one of the most important environmental influences on salmon biology. Under the state water quality stream standards, temperature is measured as the 7-day average of the daily maximum temperatures (7DADMax). The highest 7DADMax temperature allowed to meet standards for Whipple Creek's beneficial uses is 63.5°F (17.5°C).

1.4.2 Metals (copper and zinc)

Washington State's dissolved metals' acute and chronic water quality criteria are targeted toward high frequency sampling applying 1-hour and 4-day average concentrations, respectively, that are not to be exceeded more than once every three years on the average. The concentration thresholds are determined by an equation as a function of water hardness.

1.4.3 Fecal Coliform

The Washington State standards utilize two criteria for bacteria: 1) not exceeding a geometric mean value of 100 colonies / 100 mL and 2) not more than 10 percent of all samples (or any single sample when less than ten sample points exist) exceeding 200 colonies / 100 mL.

1.4.3 Summary

Table 2.Whipple Creek watershed state designated uses and water quality standards criteria

Parameter	Applicable Designated Use	State WQ Standard Criteria
Temperature	Aquatic Life: salmonid spawning, rearing, and migration	7-Day Average Daily Maximum (7-DADMax) of 17.5°C
Dissolved Copper	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Dissolved Zinc	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Fecal Coliform	Primary contact recreation	< geometric mean of 100 colonies / 100 mL and <10% of samples: 200 colonies / 100 mL

2. METHODOLOGY

2.1 Water Quality Model Development

In HSPF, a watershed is represented by a group of hydrologically similar areas referred to as hydrologic response units (HRUs) that drain to a stream segment, lake, or reservoir referred to as a RCHRES (composed of open or closed channels). HRUs reflect areas in a sub-watershed of similar land covers, surficial geology, and other factors deemed important to produce a similar hydrologic response to rainfall and potential evapotranspiration. HRUs are categorized as either pervious or impervious land segments, termed PERLND (PERvious LaND) or IMPLND (IMPervious LaND), respectively.

A PERLND is represented conceptually within HSPF by three interconnected water storage zones—an upper zone, a lower zone, and a groundwater zone.

An IMPLND is represented by surface storage, evaporation, and runoff processes. The hydraulics of stream reaches is simulated using storage routing (Donigian, Imhoff, & Ambrose 1995).

The HSPF model of the Whipple Creek watershed was developed by 1) compiling and processing required input data, 2) configuring the model to represent the watershed, and 3) calibrating the model to improve simulation accuracy.

The Whipple Creek water quality model was developed based on a previously calibrated HSPF hydrology model (see Appendix F for details). The HSPF hydrology model was expanded by adding several water quality blocks or modules to all pervious (PERLND) and impervious (IMPLND) lands within the watershed. The water quality modules include several parameters to represent production, removal, and transport of sediment and pollutants. The HSPF model uses several built-in equations to calculate soil detachment and soil washoff.

The Whipple Creek hydrologic model is divided into 27 sub-basins and 28 stream reaches. Land covers within each sub-basin are: forest, pasture, lawn, wetlands (only 1%) and impervious areas (rooftops, sidewalks and roadways). See Table 3 and Figure 4.

Table 3. Five Land Covers and Acres within Each Sub-basin of Whipple Creek

Sub-basin	Impervious	Forest	Pasture	Lawn	Water	Total
GL	21.51	140.74	271.28	32.27	184.85	650.65
WC1	28.62	146.62	234.87	95.33	1.78	507.22
WC1A	21.71	145.38	190.22	82.40	0.00	439.71
WC2	23.50	127.58	253.21	92.49	0.00	496.78
WC3	5.11	63.38	82.42	17.81	0.44	169.16
WC3A	10.96	43.70	140.85	35.14	0.00	230.65
WC4	8.84	167.20	77.35	29.33	0.00	282.72
WC4A	16.04	258.89	168.15	79.22	0.00	522.30
WC5	19.77	77.47	35.97	44.48	0.00	177.69
WC5A	116.27	83.06	60.81	298.77	2.53	561.44
WC6	37.08	49.31	6.91	42.24	0.00	135.54
WC6A	32.75	35.80	80.82	52.69	0.50	202.56
WC6B	38.52	19.15	21.28	40.51	0.00	119.46
WC7	10.13	52.61	50.90	25.97	0.22	139.83
WC7A	7.84	24.42	14.93	16.91	0.00	64.10
WC7B	17.23	12.17	18.93	18.53	0.00	66.86
WC7C	29.93	28.13	9.19	74.21	0.00	141.46
WC7D	35.86	23.44	3.09	90.50	1.30	154.19
WC75	32.26	14.31	35.22	57.27	0.00	139.06
WC8	67.30	179.85	68.29	144.39	0.00	459.83
WC9	35.20	99.05	107.10	77.69	0.00	319.04
WC9A	55.87	44.34	47.41	76.89	0.00	224.51
PC1	8.93	109.20	84.36	17.27	0.00	219.76
PC1A	6.87	74.26	92.84	35.88	0.00	209.85
PC1B	6.98	63.73	79.12	27.53	0.00	177.36
PC2	21.28	196.59	212.73	87.46	0.00	518.06
PC2A	14.98	116.76	191.94	68.60	0.00	392.28
Total	**731.34**	**2397.14**	**2640.19**	**1761.78**	**191.62**	**7722.07**

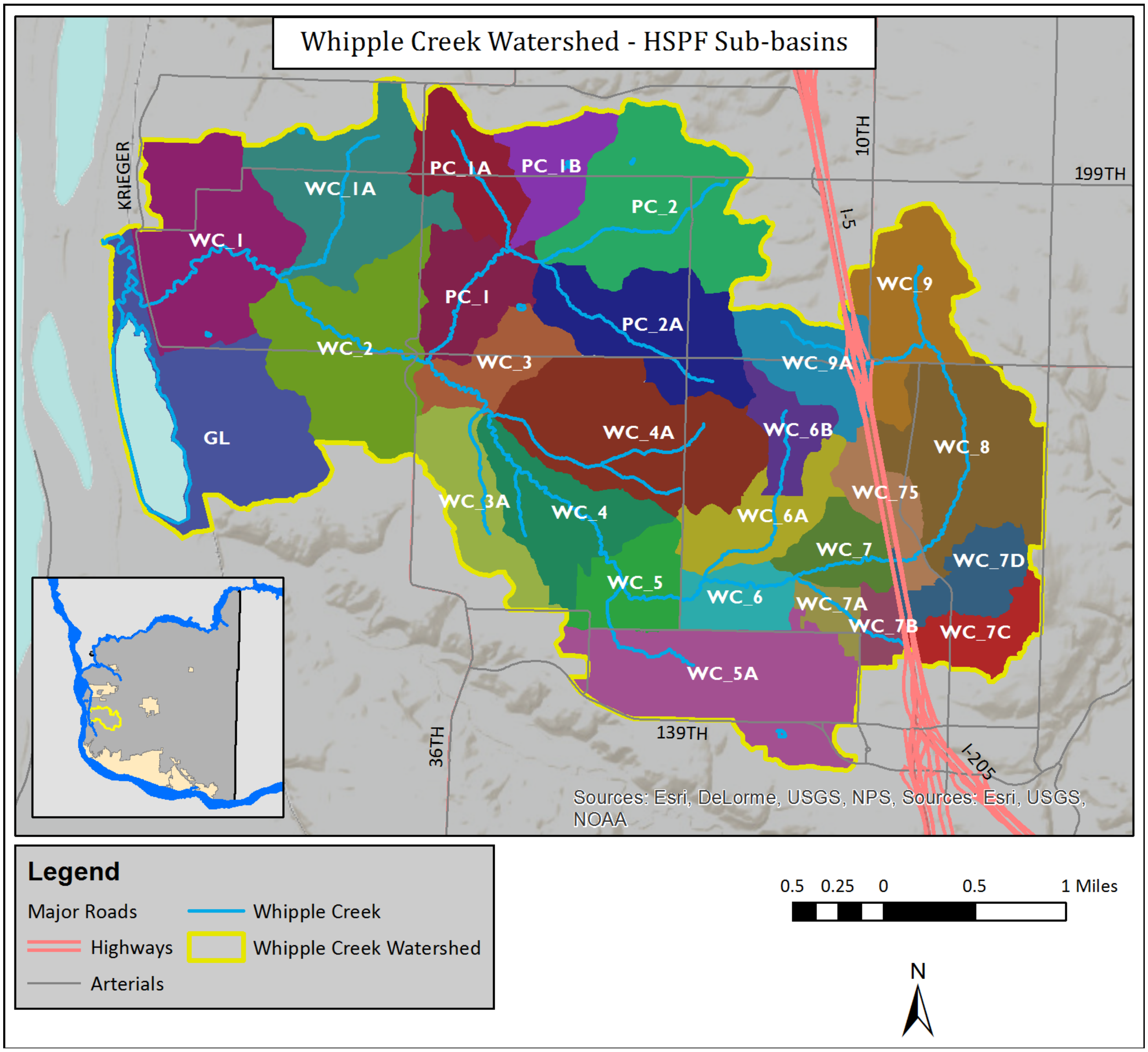

Figure 4. Whipple Creek Sub-basins

2.2 Water Quality Model Input

Input data for the HSPF model includes spatial data (land cover, topography, geology, and soils), hydraulic characteristics of stream segments (RCHRESs), meteorological data, streamflow, and water quality data. Spatial data were used to develop model HRUs (PERLNDs, IMPLNDs) and RCHRESs. Hydraulic characteristics for each stream segment were estimated from a HEC-RAS model of the Whipple Creek watershed developed by West Consultants in 2008.

Other meteorological data required for the Whipple Creek model simulations comprise air temperature, dew point temperature, wind speed, solar radiation, cloud cover, and evaporation. These data (except evaporation) were obtained from data used to support the

Whipple Creek water quality model on 6/23/2015 and 3/3/2016 from atmospheric data gages maintained by MesoWest at the University of Utah. Using GEMPAK (General Environmental Meteorological Package) parameters, raw data was obtained from the KVOU (Vancouver, WA), KPDX (Portland, OR), and POBO (Portland, OR) gages from 2002-2015.

Continuous streamflow and discrete temperature and water-quality data were used to calibrate model parameters pertaining to constituent simulations. Streamflow and water quality data were collected at the stream monitoring stations shown above in Figure 3**Error! Reference source not found.**.

2.3 Model Configuration

In addition to hydrologic model input data, several modules of water quality data were added to the Whipple Creek HSPF model to simulate water quality constituents. The following is a list of input blocks used in the water quality model:

- PERLND: ATEMP, SED, PSTEMP, PWTGAS, PQUAL
- IMPLND: ATEMP, SLD, IWTGAS, IQUAL
- RCHRES: HTRCH, SEDTRN, GQUAL

Copper, zinc, and fecal coliform each had their own PQUAL, IQUAL, GQUAL blocks in the HSPF input file.

3. DEVELOPMENT OF INPUT DATA

3.1. Water Quality Time Series Data Sources

HSPF requires time series input data which include weather data and soil temperature data.

HSPF Weather Data Requirements:

- PRECIPITATION - Surface runoff is directly dependent on precipitation.
- POTENTIAL EVAPOTTRANSPIRATION - Evaporation directly from soil layers and vegetative surface and transpiration through plants.
- AIR TEMPERATURE - Function of elevation – conductive-convective heat transport.
- WIND SPEED - Heat exchange rate – heat balance in water bodies.
- SOLAR RADIATION - Heat balance in water bodies – snow melt – plankton growth rate.
- DEWPOINT TEMP - Determines when precipitation is considered as snow.
- CLOUD COVER - Cloud cover affects long-wave radiation balance.

Data used to support the Whipple Creek water quality model were obtained on 6/23/2015 and 3/3/2016 from atmospheric data gages maintained by MesoWest at the University of Utah. Using GEMPAK (General Environmental Meteorological Package) parameters, raw data was obtained from the KVOU (Vancouver, WA), KPDX (Portland, OR), and POBO (Portland, OR) gages from 2002-2015. The variables collected included air temperature, relative humidity, wind speed, dewpoint temperature, and three measurements of cloud cover data. The data contained several duplicate measurements, instances where multiple measurements were taken per hour, and data gaps. HSPF requires one measurement per hour, so the data were formatted in Microsoft Excel to match the organizational structure required by HSPF.

The methodology used to format the data consisted of the following: An hourly date time list was created for the period of record as an indexed comparison. A VLOOKUP table was made to assign measurements to the ordered list of dates and times from main list. All gaps in the data were identified. Data gaps in the KVOU data set were compared to and replaced by the KPDX gage data. Each data series was exported in a space delimited file and uploaded to a WDM file through SARA Time Series, developed by AQUA TERRA for the San Antonio River Authority. MesoWest database documentation can be found in Appendix A of the N-AWIPS 5.6 User's Guide.

3.2. HSPF Application and Utility Modules

Soil temperature (heat transfer through soil surface) data were retrieved from the AgWeatherNet database, maintained by Washington State University. The gage station, WSU Vancouver RE records meteorological data on a 15-minute time step. Soil temperature measurements are taken at an eight-inch depth. Monthly average soil temperatures and air temperature data were retrieved for the entire period of record of the station, from July 2008 to October 2015. A scatter plot of air temperature and soil temperature data was used to find a linear regression for each month over the approximately 9-year period. This linear regression equation was used to populate the coefficients in the PSTEMP section of the PERLND module to represent monthly ground temperature fluctuations. Specifically, the ASLT and BSLT input coefficients were populated using the slope and y-intercept from the regression equation. The model assumes the upper layer soil temperature (ULTP1 and ULTP2) follows the same regression as the surface soil temperature in relation to air temperature. The lower/ groundwater layer (LGTP1) was assumed constant at 48 degrees Fahrenheit.

To model fecal coliform bacteria, a debase EPA excel spreadsheet was utilized to estimate initial values for critical parameters such as SQOLIM (asymptotic limit for the storage of fecal coliform bacteria on the land surface) and WSQOP (daily buildup limit).

4. CALIBRATION AND VALIDATION RESULTS

This section represents a summary of watershed model simulation results. The presentation of water quality modeling results focused on the main stem stream reaches, where the calibrated model exhibited the best fit to the available data.

As described earlier in the report, water quality and quantity monitoring included data collection of water temperature, fecal coliforms, dissolved copper, and dissolved zinc at multiple sites. However, the model calibration focused on site WPL050.

4.1 Temperature

Stream temperature is one of the most important environmental influences on salmon biology. Under the state water quality stream standards, Whipple Creek is designated “Salmonid Spawning, Rearing, and Migration” and has the aquatic life temperature criteria highest 7DADMax temperature of 63.5°F (17.5°C). Summer stream temperature data collected approximately at river mile 3.1 of Whipple Creek (WPL050) show that this criterion is often exceeded, especially in the hotter months of July and August.

Water temperature simulations are accomplished in HSPF by the HTRCH section of the RCHRES (simulate heat exchange and water temperature) module. Changes in RCHRES water temperature are simulated by three major processes:

(1) heat transfer through movement of water into and out of each RCHRES;

(2) heat transfer across the air-water interface; and

(3) heat transfer across the water-streambed boundary.

Many parameters can be adjusted in temperature calibration, including PSTEMP (ASLT, BSLT, ULTP1, and ULTP2), IWTGAS (AWTF and BWTF) and RCHRES (KATRAD, KCOND, KEVAP, etc.). The temperature of overland flow will generally come into a dynamic equilibrium with the in-stream flow due to the heat capacity within the stream being much larger than that in the surface flow. BASINS/HSPF training Exercise 10 indicated that the RECRES parameters KATRAD, KCOND, KEVAP and CFSAEX are generally the most important calibration parameters.

Spot measurements of water temperature are available for RCHRES 120 (WPL050), for the period of 2007 and 2008. The data from this station were compared with the simulated water temperature to calibrate the HSPF model. RCHRES 120 is the only reach with water temperature data available for the model calibration period. The calibrated values of parameters related to RCHRES water temperature at WPL050 (RCHRES 120) were applied to all other stream reaches in the model.

A long-term simulation of water temperature showed a range between 40 °F and 69 °F and a mean temperature of 54 °F for water years 2007 and 2008. The observed (recorded) water temperature ranged between 39 °F and 68 °F for the same period (See Figure 5). A comparison between the simulated and observed/recorded temperatures shows a good match. Based on the limited recorded data the water temperature results are considered a very good to excellent calibration.

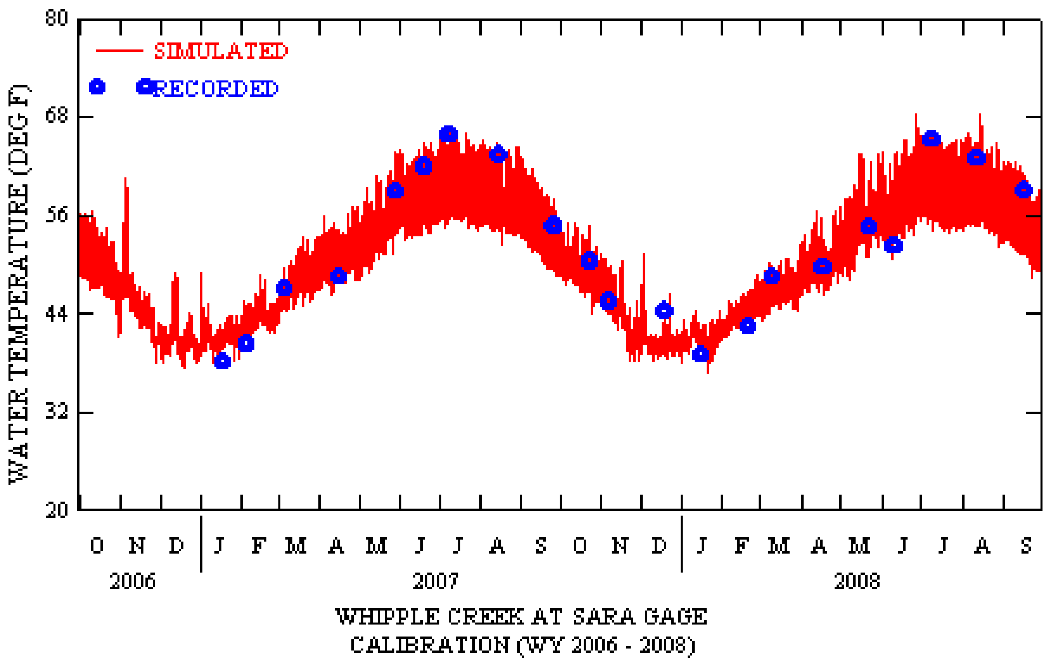

Figure 5: Whipple Creek Simulated and Recorded Water Temperature at WPL050

4.2 Dissolved Copper and Zinc

The fate of heavy metals in a water system is determined primarily by partitioning to water and particulate matter (including phytoplankton) and by transport. Partitioning is described in general by sorption to particulates, precipitation in minerals, and complexation in solution. The kinetic constant for sorption is not temperature-dependent.

Copper and zinc transport from land surfaces is simulated by accumulation and washoff of the dissolved form and the constituent associated with sediment. These processes are accomplished by the PQUAL and IQUAL modules (within PERLND and IMPLND modules, respectively).

Interflow and groundwater inflow of copper and zinc are simulated by input of constant concentration values assigned to simulated interflow and groundwater inflow. Instream changes in metals concentrations are simulated by the GQUAL module within the RCHRES module. GQUAL simulates dissolved constituent concentrations and concentrations associated with sand, silt, and clay. Process-related parameters affecting distribution of metals between the dissolved phase and sediment adsorption include partitioning coefficients and adsorption/desorption rate parameters (Allison and Allison, 2005).

Initial estimates for daily accumulation of copper and zinc onto land surfaces were obtained from King and Snohomish County HSPF models. Calibration was accomplished by comparing simulated concentrations and observed concentrations measured at site WPL050.

A limited number of recent monthly dissolved copper and dissolved zinc samples have been collected from Whipple Creek's WPL050 main stem stream monitoring station starting in water year 2014. Because the water quality simulation period ended in 2008 the simulated values could not be compared directly with the recorded (monitored) data, but general ranges and trends could be reproduced for comparison purposes.

Numeric water quality criteria are published chapter 173-201A WAC. They specify the levels of pollutants allowed in receiving water to protect drinking water uses, aquatic life, and recreation in and on the water. Narrative water quality criteria (e.g. WAC 173-201A-240(1)) limit the toxic, radioactive, or other deleterious material concentrations that may be discharged to levels below those that have the potential to:

- Adversely affect designated water uses (beneficial uses)
- Cause acute or chronic toxicity to biota
- Impair aesthetic values
- Adversely affect human health

Washington State's dissolved metals' acute and chronic water quality criteria are targeted toward high frequency sampling applying 1-hour and 4-day average concentrations, respectively, that are not to be exceeded more than once every three years on the average.

Based on limited available Whipple Creek metals data set, dissolved metals do not appear to be a significant water quality issue at this time, even when applying the relatively conservative estimate of water hardness from one of the county's low density residential runoff monitoring sites.

Figure 6 and Figure 7 boxplots show that none of the dissolved copper or dissolved zinc monthly samples collected to date exceed either of their respective state standard's acute or chronic criteria.

The highest dissolved copper sample value of 3.37 ug/L (depicted in Figure 6 as a red asterisk outlier) represents only 69% and 92% of the acute and chronic criteria levels, respectively.

The highest dissolved zinc sample value of 2.24 ug/L (depicted in Figure 7) is only about 6% and 7% of its criteria, respectively, representing even lower proportions. Median and mean WPL050 dissolved copper values are only about one-third of even the chronic criterion.

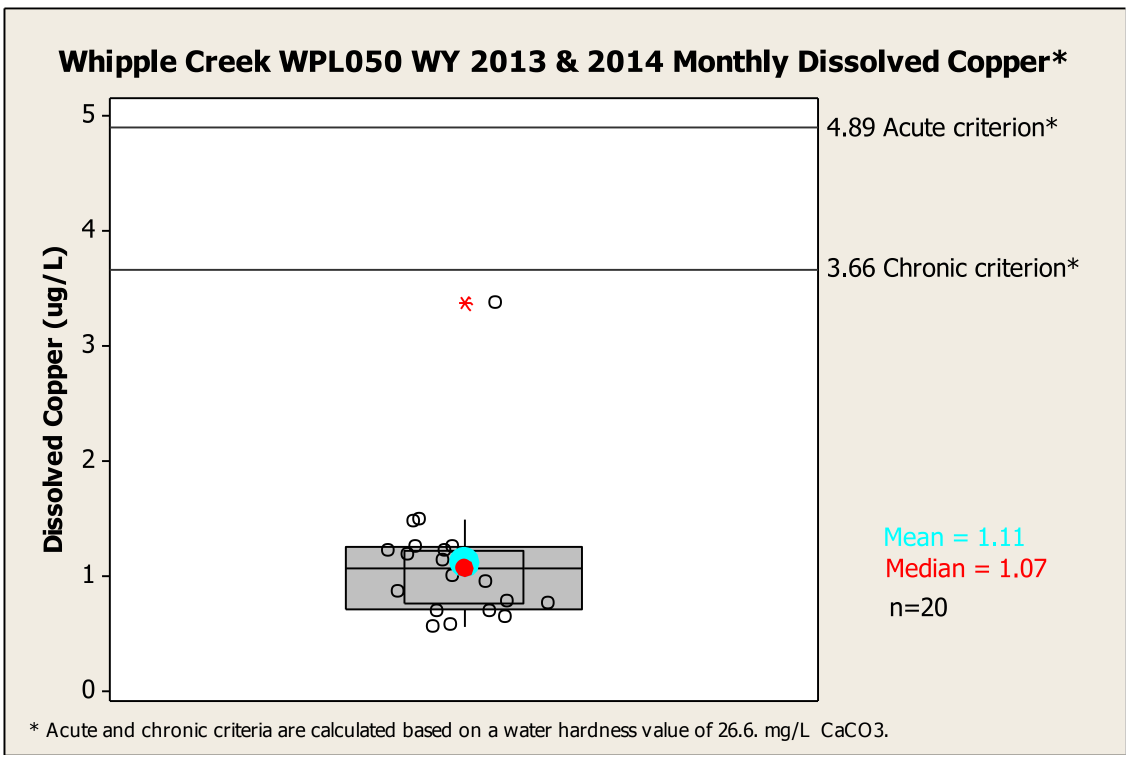

Figure 6. Whipple Creek WPL050 water years 2013 and 2014 monthly dissolved copper values with state criteria based on median LDR hardness

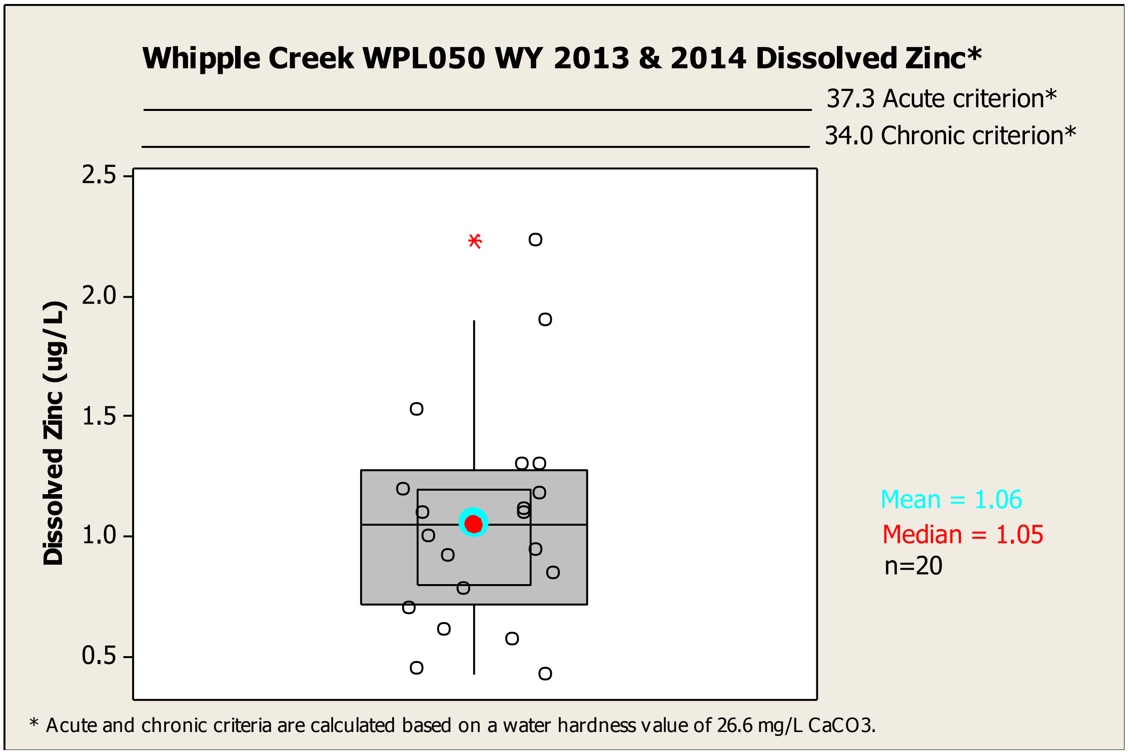

Figure 7. Whipple Creek WPL050 water years 2013 and 2014 monthly dissolved zinc values with state criteria based on median LDR hardness

Since sediment plays an important role in modeling dissolved copper and zinc, the parameters of sediment block were adjusted several times based on existing water quality models and published data in EPA Technical Note 8 until the model produced results that were within a reasonable limit (Donigian, Bicknell, Love & Duda, 2006).

The water quality model was then run many times until the simulated values appeared to be within acceptable range. Since only less than two years of water quality data for dissolved copper and zinc is available, none of which is in the calibration period, the model results were only compared with observed data on a graphical basis. (The simulated results are for the water quality calibration period of October 2003 through September 2008; while the observed/recorded copper and zinc are for the period of January 2013 through April 2015.)

The recorded copper data are shown in Figure 8.

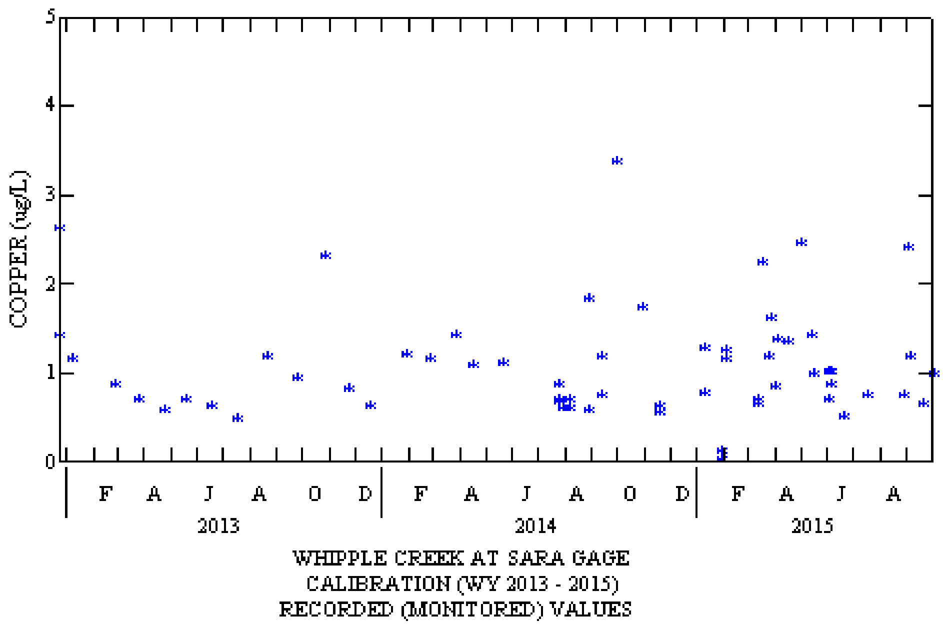

Figure 8: Observed dissolved copper at WPL050.

The simulated daily dissolved copper values are shown in Figure 9.

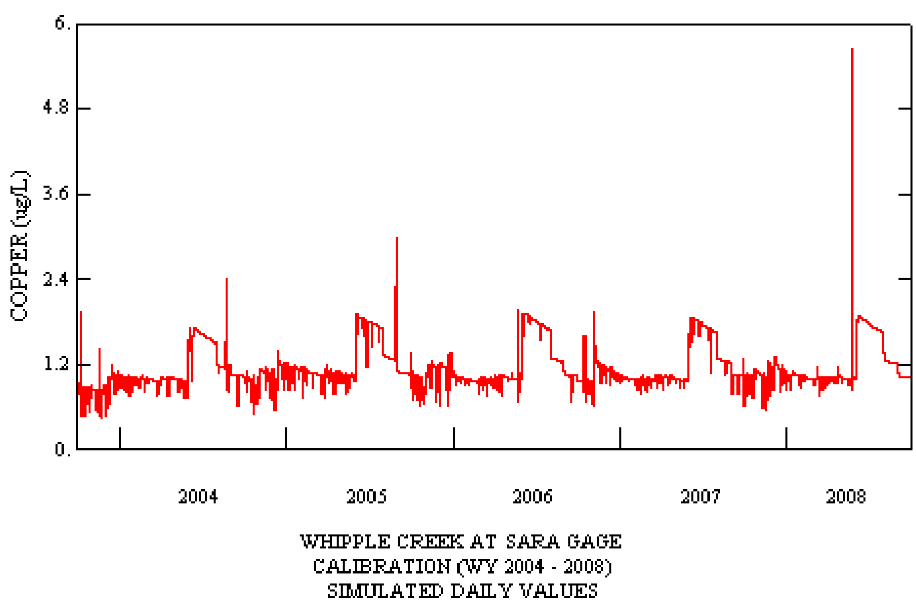

Figure 9: Simulated daily dissolved copper at WPL050.

The simulated annual average dissolved copper values are shown in Figure 10.

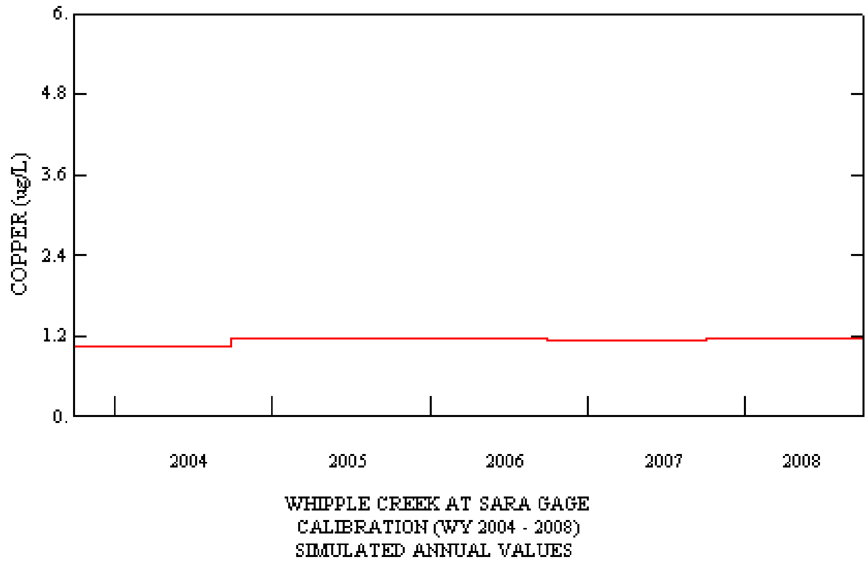

Figure 10: Simulated annual average dissolved copper at WPL050.

Comparable results for zinc are shown in Figures 11, 12, and 13.

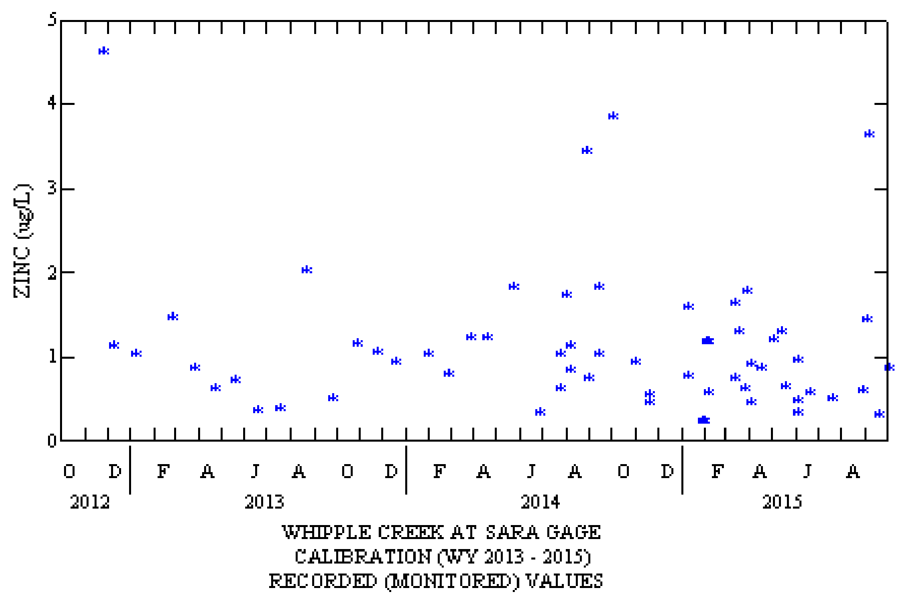

Figure 11: Observed dissolved zinc at WPL050.

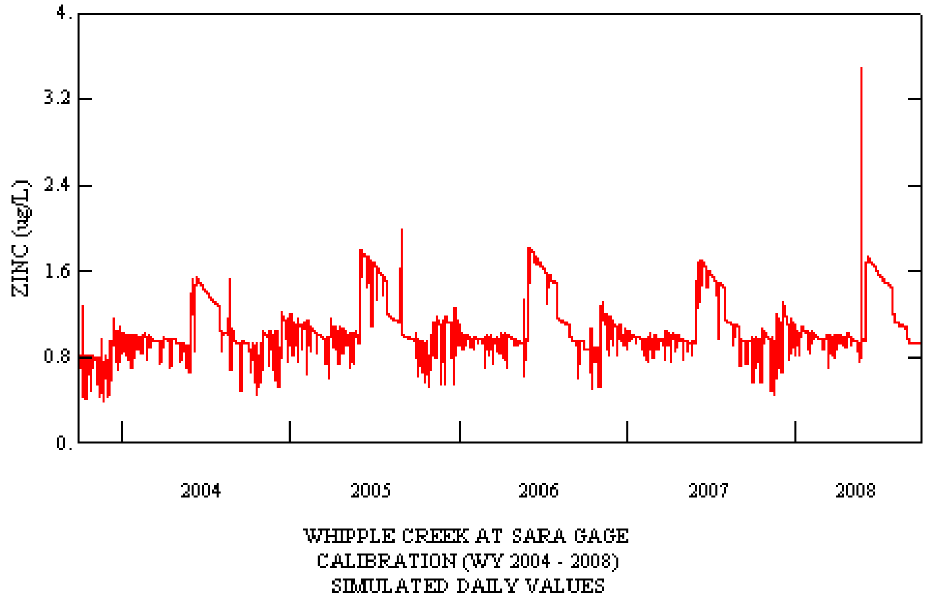

Figure 12: Simulated daily dissolved zinc at WPL050.

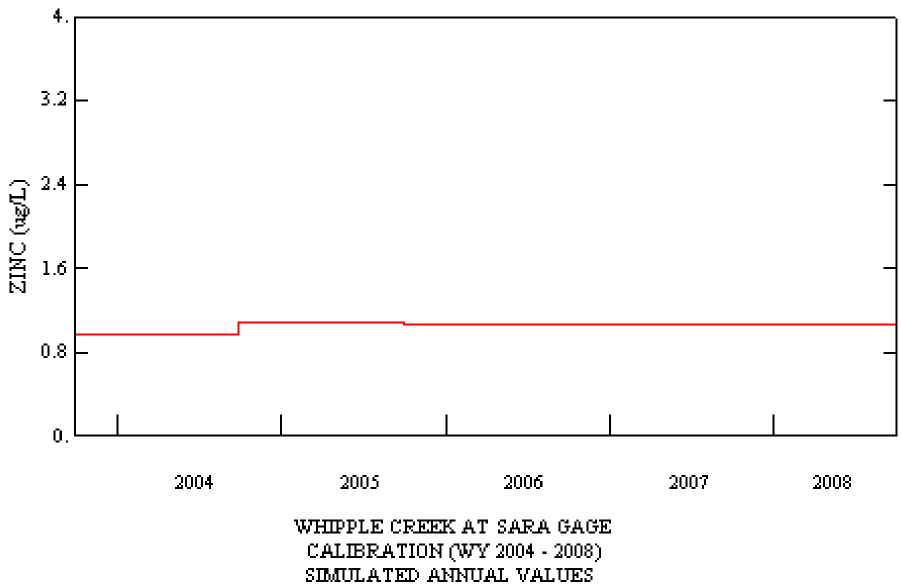

Figure 13: Simulated annual average dissolved zinc at WPL050

4.3 Fecal Coliform

Using the Whipple Creek's calibrated hydrology model, a watershed-scale bacterial transport model was generated to simulate the transport of bacteria from the land surface to the stream channel. In HSPF, this is accomplished by linking the fecal coliform simulation to the streamflow simulation. The following sections summarize the simulation of fecal coliform bacteria in the PERLND, IMPLND, and RCHRES modules.

The PQUAL module is used to simulate the transport of fecal coliform bacteria from pervious land segments. This module simulates storages and fluxes of bacteria along three flow paths: overland flow, interflow, and base flow. There are 11 model parameters used to simulate fecal coliform bacteria (

Table 4). Collectively, these parameters govern the total fecal coliform loading from each HRU to a given stream reach.

The processes by which the transport of fecal coliform bacteria is simulated can be split into two categories: surface and subsurface (interflow and base flow) (see Figure 14).

The surface processes begin with deposition of animal wastes containing fecal coliform bacteria onto the land surface by numerous sources in the watershed (people, pets, livestock, and wildlife). Fecal coliform deposition is established by the accumulation rate (ACCUM). These bacteria are stored on the surface (SQO) and are allowed to accumulate until the storage limit (SQOLIM) is reached.

Bacteria are removed from surface storage by either die-off or washoff. The removal rate (REMQOP) of the stored bacteria through die-off is defined by the ratio of the accumulation rate (ACCUM) and the storage limit (SQOLIM). Bacteria remaining in storage are removed through washoff by overland flow.

The amount of bacteria removed from surface storage (SOQUAL) during a given storm event is controlled by both the amount of overland flow generated (SURO) and the susceptibility of the bacteria to washoff by overland flow (WSFAC). SURO is identified for each HRU during the hydrologic calibration. WSFAC is a function of the rate of runoff that results in 90 percent washoff of stored fecal coliform bacteria in a given hour (WSQOP).

Table 4. Parameters used in the simulation of the transport and storage of fecal coliform bacteria

Parameter	Definition	Unit
ACCUM	Accumulation rate of fecal coliform bacteria on the land surface.	number of colonies per acre per day
AOQUAL	Transport of fecal coliform bacteria through base flow (ground-water discharge).	number of colonies per day
AQO	Storage of fecal coliform bacteria in active ground water.	number of colonies per ft^3
IOQUAL	Transport of fecal coliform bacteria through interflow.	number of colonies per day
IQO	Storage of fecal coliform bacteria in interflow.	number of colonies per feet
REMQOP	Removal rate (die-off) for fecal coliform bacteria stored on the land surface. Removal rate is based on the ratio of ACCUM/SQOLIM.	1 per day
SOQUAL	Transport of fecal coliform bacteria through overland flow.	number of colonies per acre per day
SQO	Storage of fecal coliform bacteria on the land surface.	number of colonies per acre
SQOLIM	Asymptotic limit for the storage of fecal coliform bacteria on the land surface if no washoff occurs.	number of colonies per acre
WSFAC	Susceptibility of fecal coliform bacteria to washoff. Susceptibility is defined by 2.30/WSQOP.	per inch
WSQOP	Rate of surface runoff that results in 90-percent washoff of the stored fecal coliform bacteria in one hour.	inches per hour

IQUAL is used to simulate the transport of fecal coliform bacteria from impervious land segments. The IQUAL module only simulates surface washoff of fecal coliform bacteria because impervious land segments do not have a subsurface component. The transport processes in IQUAL are identical to those used in the surface washoff component of PQUAL. Generally, bacteria stored on an impervious land segment are more susceptible to washoff than those stored on pervious land segments.

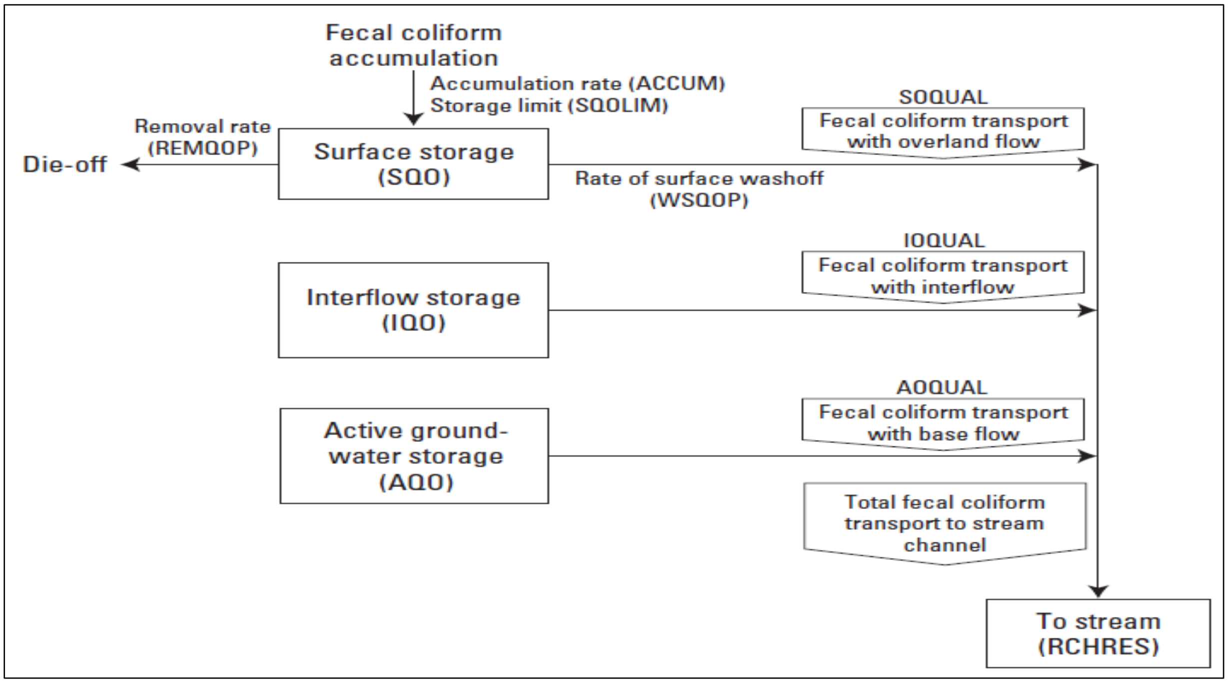

Figure 14: Routing processes by the HSPF for the simulation of fecal coliform bacteria transport

Monthly fecal coliform samples were collected for over ten years at WPL050, from February 2004 through April 2014. One year of monthly fecal coliform samples were also collected at other water quality sites, WPL010, WPL080, and PCK010 during water year 2012 from October 2011 through September 2012 (see Figure 3).

In addition to a general summary of their overall pattern in the watershed, fecal coliform results were also evaluated seasonally using Washington State's current surface water quality standards for the designated beneficial use of primary contact recreation (Ecology, 2016).

The standards utilize two required criteria for bacteria: 1) not exceeding a geometric mean value of 100 colonies per 100 mL and 2) not more than 10 percent of all samples (or any single sample when less than ten sample points exist) exceeding 200 colonies per 100 mL. Geometric means are based on the antilogarithm of the arithmetic mean of the season's individual sample logarithms (base 10) values. To help meet the standard's preference of five or more data collection events within a season for evaluation of the geometric mean, this assessment defines wet seasons as extending 7 months from October through the following April and dry seasons as extending 5 months from May through September.

Fecal coliform were detected in all samples from baseflow and storm events. The geometric mean of all baseflow event samples was 262 CFU/100 ml while the geometric mean during storm events was 1865 CFU/100 ml.

Fecal coliform concentrations are extremely difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur not only during storms, but also during somewhat random but "catastrophic" events, such as failure or illicit sewer connections of waste disposal facilities, which can produce large, unpredictable concentrations. Therefore, efforts were made to attain general agreement between the simulated concentrations by adjusting loading rates, both surface and subsurface runoff-associated by land cover.

Model accuracy simulating fecal concentrations is substantially less than the other water quality parameters, but, as shown in Figure 15, the simulated results follow the general trend and range of observed/recorded fecal coliform concentrations for water years 2004 through 2008.

The fecal coliform results should be viewed in terms of the number of water quality standard exceedances rather than just the calculated concentrations. Note that number of exceedances was reported when comparing future scenario fecal coliform results in the watershed-scale report.

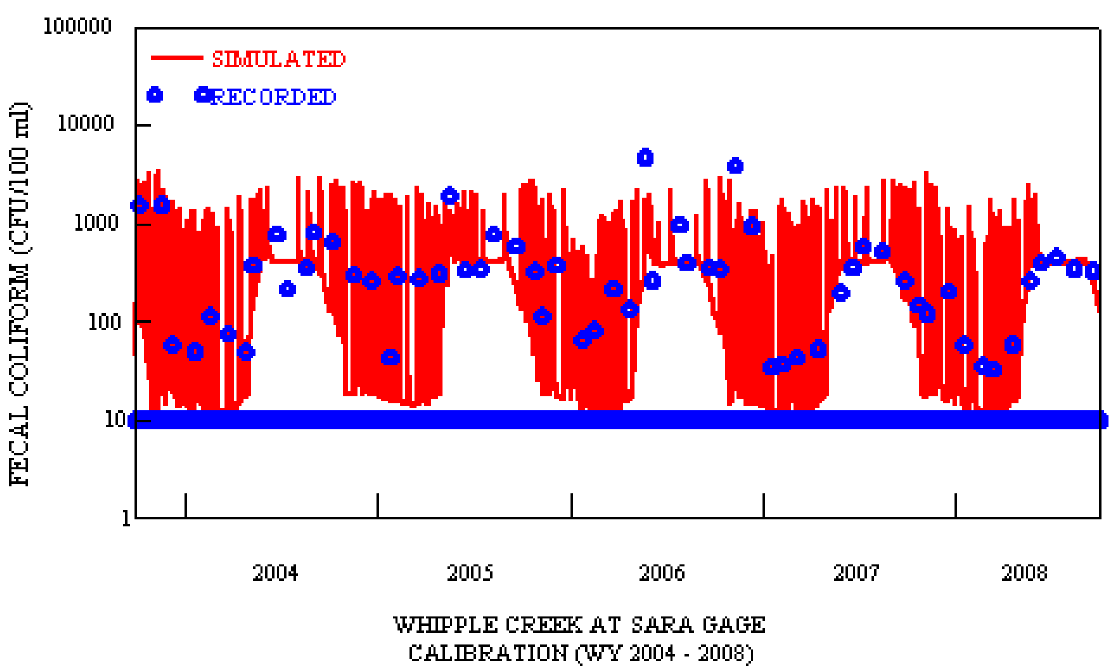

Figure 15: Simulated and observed fecal coliform concentrations (ug/L) at WPL050.

5. CONCLUSIONS

The water quality calibration results show a good match between the simulated and observed/ recorded water temperature and fecal coliform values for the calibration period of record.

There were no observed copper and zinc concentration values for the calibration period, but the general concentration range for both copper and zinc was between 0 and 5 ug/L, and the simulated values were also within the same range.

Overall, the water quality calibration is considered good to very good. The water quality calibration model can be used to model water quality for both existing land covers and future development conditions and scenarios. For fecal coliform, the number of exceedances should be reported due to the difficulty in predicting high concentrations. For temperature, copper and zinc, the model can be used to report actual value.

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Appendix H

Whipple Creek Watershed-Scale Stormwater Plan Report

Clark County Stream B-IBI Versus Hydrologic Metrics Relationships

Prepared by

Bob Hutton, Natural Resource Specialist

Clark County Department of Public Works

Clean Water Division

May 2015

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Introduction / Summary

The relationships between local streams' biological health and regionally appropriate hydrologic metrics are examined in this study to help address Clark County's 2013-2018 NPDES Phase I Municipal Stormwater Permit (permit) section S5.C.5.c. watershed-scale stormwater planning requirements (WA Dept. of Ecology, 2012). The applicability of several hydrologic metrics with documented Pacific Northwest use in scientific literature is evaluated primarily using local monitoring data. As referenced in the permit, evaluations emphasized metrics from research done on Puget Sound Lowland Streams (DeGasperi *et al*. 2009) calculated mostly from daily average flows and that have the greatest potential for ecological relevance as resource management tools.

This study recommends using the statistically significant linear relationship found between the Benthic Index of Biotic Integrity and the T_{Qmean} hydrologic metric based on local data. This will allow estimating future biological conditions under full build-out scenarios for Clark County's Whipple Creek watershed planning area. Estimates would apply the relationship's linear regression to metric values derived from predicted hydrology based on simulations from a continuous runoff / water quality model calibrated to Whipple Creek. Finding acceptable values for hydrologic metrics, reflecting hydrologic change between pre-disturbance and post-disturbance watershed conditions, would ideally become a focus for watershed management rather than a one-size-fits-all approach or infeasible requirements to completely restore the pre-disturbance flow regime (DeGasperi *et al*., 2009 p. 514).

Methods

The statistical evaluation of relationships used five years (2005-2009) of data from systematically collected annual aquatic macroinvertebrate samples and monitored continuous flow for multiple Clark County streams. Stream health was evaluated using Pacific Northwest Benthic Index of Biotic Integrity (B-IBI) scores. Stream macroinvertebrate samples were collected and preserved using standardized methods (Clark County, 2004) primarily by trained county staff with periodic assistance from volunteers (Figure 3). The samples were then processed, enumerated, and summarized into B-IBI scores using standardized protocols by an independent, qualified professional laboratory (Aquatic Biology Associates, Inc.). Flows were derived from recorded 15-minute interval continuous stream stages (example hydrology station setups are shown in Figure 1 and Figure 2). The finalized continuous stage records were converted to flows using maintained ratings for each flow gage site (Clark County, 2003; Clark County, 2014) with data management via time series software (Aquarius, 2013). Statistical relationships between stream health B-IBI scores (response variable) and hydrologic metrics (predictor variable) were analyzed by county staff using MINITAB (Minitab, 2003) statistical software and widely accepted regression statistical procedures.

Relationship evaluations used respective pairs of multi-year average B-IBI scores and hydrologic metric values from a watershed's monitoring stations usually located within a couple hundred feet of each other. Stream station name codes (e.g. WPL048) are based on the relative percent upstream from the mouth of the watershed's main stem or subwatershed tributary stream, as applicable.

Figure 1 Whipple Creek hydrology monitoring station (WPL048) staff gages, transducer pipe, and accessible equipment shelter

Figure 2 Cougar Creek hydrology monitoring station (CGR018) staff gage, diagonal pipe housing pressure transducer, and secure equipment shelter

Figure 3 B-IBI stream macroinvertebrate field sampling in Gee Creek

Several issues needed addressing prior to statistical evaluations to select the most locally appropriate B-IBI stream health versus hydrologic metric regression relationship. Issues examined included addressing limitations of local data and choosing regionally applicable hydrologic metrics that are ecologically relevant flow management tools (DeGasperi *et al*., 2009, p. 514). The hydrologic metrics evaluated in this current study were narrowed down to three: 1) T_{Qmean} - previously used by Clark County and in the Puget Sound area (Booth *et al.*, 2001); 2) High Pulse Count; and 3) High Pulse Range. All three metrics also have documented use in the permit referenced and more recent Puget Sound Lowland study (DeGasperi, *et al.*, 2009). Table 1 provides definitions for each of these three hydrologic metrics evaluated along with that for high flow pulse.

Table 1 Hydrologic metric definitions

Hydrologic Metric	Definition
T_{Qmean} *	Fraction of a year that the daily mean discharge rate exceeds the annual mean discharge rate
High Flow Pulse ~	Occurrence of daily average flows that are equal to or greater than a threshold set at twice (two times) the long-term daily average flow rate
High Pulse Count (HPC) ~	The number of days each water year that discrete *high flow pulses* occur
High Pulse Range (HPR) ~	The range in days between the start of the first *high flow pulse* and the end of the last *high flow pulse* during a water year

Sources: Booth *et al*. (2001, pp. 19-20) * and DeGasperi *et al*. (2009, pp. 512 and 518) ~

Additionally, the number of local monitoring station data sets fully analyzed was reduced to help minimize potential confounding effects on the relationships between any of the hydrologic metrics and B-IBI subwatershed scores as well as help meet hydrologic metric assumptions (DeGasperi *et al*., 2009, p. 527 and Booth *et al*., 2001, pp. 37-38). Watershed physiographic factors such as basin size, relative topographic relief, broad floodplains, geologic settings (Booth, 2001, pp. 20-21) could contribute to potential confounding effects on relationships. All Clark County monitoring locations with available B-IBI scores and multiple years of continuous hydrology data were screened based on their upstream watershed's relative size and physiographic / climate factors using previous subwatershed characterization and classification analyses by Clark County (Clark County / Wierenga, 2005, p. 8). With no human impact, subwatershed main stem streams classified in the same subwatershed group likely would have comparable water quantity, water quality, and biological structure.

In this previous classification work, Clark County subwatersheds were classified into 14 groups to help evaluate the effects of the stormwater management program on receiving waters (Clark County, 2005, pp. 8-9). The classification thresholds applied to the subwatershed attribute values were derived from literature and staff knowledge related to watershed management for stormwater and fisheries conservation. Each subwatershed was assigned to a category for each of the classifying characteristic factors. A nested sort of category values, by characteristic, was performed on the subwatershed dataset (based on results from statistical cluster analysis) in the following order: stream size, hydrogeology, soil hydrology, topography, and annual precipitation. Subwatersheds were assigned to a common subwatershed group (SWG) if they had the same relative classifications' category results across stream size, hydrogeology, soil hydrology, topography, and precipitation. Table 2 shows the themes, classifying characteristics, attributes for categories, and threshold values used to classify county subwatersheds. The three possible dominant hydrogeologic categories are unconsolidated sedimentary material (PctUSR), Troutdale gravels (PctTroutdale), and older rock (PctRock). Dominant soil hydrology subwatershed classifications were consolidated by combining soil units' associated hydrologic groups into either "A/B Soil" or "C/D Soil" categories representing mostly moderately to well-drained soils or poorly drained soils, respectively.

Table 2 Clark County subwatershed classification characteristics, thresholds, and categories (from Clark County, 2005, p.9)

Theme	Classifying Characteristic	Attribute	Threshold Values
Hydrology	Stream size	Maximum observed stream order	Small: 1st – 4th order, Large: > 4th order
Soils and Geology	Dominant hydrogeologic category	Percent hydrogeologic category	NA
Soils and Geology	Dominant hydrologic soil group	Percent A/B soil, Percent C/D soil	>50% subwatershed area
Physical Properties	Topography	Average subwatershed slope	Low: <5%, Medium: 5-30%, High: > 30%
Climate	Annual precipitation	Average annual precipitation	Low: <65", Medium: 65-90", High: > 90"

Results and Discussion

Among Clark County subwatersheds having both annual B-IBI and continuous flow monitoring data, Table 3 highlights by color those screened for similarity to the Whipple Creek watershed (assumed represented by the upper Whipple Creek subwatershed) for use in statistical evaluations of relationships. The subwatersheds in Table 3 are presented mostly in relative order of similarity (with those subwatershed letter designated groups closer alphabetically being most similar) to Upper Whipple Creek subwatershed. Green-shading indicates subwatersheds most similar to Upper Whipple Creek's based on having very similar small stream order size, the same dominant hydrogeology of unconsolidated sedimentary material (PctUSR), the same dominant C/D soil hydrology, and low annual precipitation. The yellow-shaded subwatersheds were also deemed similar enough overall to the Whipple Creek subwatershed for further evaluation. The adequately similar designation of the yellow-coded subwatersheds is supported by their consistent small stream order size, their individual group's mainly physiographically driven classifications being within 4 out of a possible 14 alphabetically labeled subwatershed groups of Whipple Creek's "M" classification, and professional judgment based on knowledge about each of them.

The purple shaded subwatersheds in Table 3 are interpreted as most dissimilar to Whipple Creek's subwatershed. The Upper, Middle, and Lower Lacamas Creek and the Lower Little Washougal River subwatersheds (along with their much smaller nested non-flow monitored subwatersheds) are not considered similar enough because their B-IBI monitored upstream drainages have much larger combined flows and areas than Whipple Creek's. Curtin and Yacolt Creeks are also dissimilar to Whipple Creek due to both their predominantly sandy bottom substrates impacting B-IBI scores and relatively large year-round groundwater contribution to their flow (hydrological outliers compared to most county streams) which is likely not reflected in their respective "L" and "I" classifications. Jones Creek subwatershed is quite unlike Whipple Creek across multiple characteristics due to is 100% older rock hydrogeology, substantial 99% A/B soil hydrology, relatively steep 29% average subwatershed slope, and very high average annual precipitation of 105".

Table 4 provides an overall assessment of similarity for the twelve B-IBI subwatersheds considered for further evaluation of their B-IBI score versus hydrologic metric relationships. It presents each subwatershed's upstream drainage area, subwatershed group classification, overall similarity to the Whipple Creek watershed, and inclusion or rationale for exclusion. Three high (green), three moderate (yellow), and six very low (purple) color-coded subwatersheds designate their overall similarity compared to the Whipple Creek watershed. Importantly, the Whipple Creek subwatershed is assumed representative of the entire Whipple Creek watershed.

Moderate similarity subwatersheds were retained for further evaluation because limiting more involved statistical relationship evaluations to just the three most similar subwatersheds to Whipple Creek's would not allow enough data points to develop representative relationships across a broader geographic area. Whereas, including the very low similarity subwatersheds could overly confound relationships (DeGasperi, *et al*., 2009, p. 527). Therefore, it was determined that a compromise of including the three moderately similar subwatersheds with the three high similarity subwatersheds would allow for a reasonable evaluation of the B-IBI score versus hydrologic metric relationships.

Table 3 Clark County B-IBI and discharge monitored subwatersheds' characteristic categories (values) and group classifications*

Subwatershed	Stream Order Size	Dominant Hydrogeology	Dominant Soil Hydrology	Topography	Annual Precipitation	Subwatershed Group (SWG)
Matney Creek	Small (3)	PctRock (66%)	A/B Soil (62%)	Medium (13%)	Medium (70")	I
Brezee Creek	Small (3)	PctTroutdale (96%)	C/D Soil (80%)	Medium (14%)	Low (53")	J
Cougar Creek	Small (1)	PctUSR (~100%)	A/B Soil (87%)	Medium (6%)	Low (42")	K
Whipple Creek - upper	***Small (3)***	***PctUSR (87%)***	***C/D Soil (54%)***	***Medium (8%)***	***Low (42")***	***M***
Gee Creek - upper	Small (4)	PctUSR (91%)	C/D Soil (94%)	Medium (6%)	Low (46")	M
Mill Creek	Small (3)	PctUSR (89%)	C/D Soil (88%)	Low (4%)	Low (48")	N
Non-comparable T_{Qmean} Subwatersheds due to Too Large of an Upstream Watershed or Dissimilar Hydrology						
Lacamas Creek - lower	Small (4)	PctUSR (88%)	C/D Soil (61%)	Medium (5%)	Low (46")	M
Lacamas Creek - middle	Small (4)	PctUSR (61%)	C/D Soil (98%)	Low (4%)	Low (49")	N
Curtin Creek	Small (2)	PctUSR (100%)	A/B Soil (88%)	Low (4%)	Low (44")	L
Yacolt Creek	Small (3)	PctRock (60%)	A/B Soil (90%)	Medium (13%)	Medium (80")	I
Lacamas Creek - upper	Small (4)	PctRock (89%)	A/B Soil (91%)	Medium (19%)	Medium (88")	I
Jones Creek (Little Washougal River - upper)	Small (4)	PctRock (100%)	A/B Soil (99%)	Medium (29%)	High (105")	H
Little Washougal River -lower	Large (5)	PctRock (60%)	A/B Soil (NA) (68%)	Medium (15%)	Medium (NA)(66")	B

* Based on previous Clark County classification work (Wierenga, 2005)

Table 4 Monitored subwatersheds drainage area, classification group, Whipple Creek similarity, and evaluation rationale

Subwatershed B-IBI Station (Identifier)	Upstream Drainage Area (sq. km^2)	Sub-watershed Group	Overall Similarity to Whipple Creek Watershed	Inclusion / Exclusion Rationale for Further Evaluation
Whipple Creek (WPL050)	***17***	***M***	***High (Assumed Same)***	Included
Gee Creek -upper (GEE050)	23	M	High	Included
Mill Creek (MIL010)	30	N	High	Included
Cougar Creek (CGR020)	8	K	Moderate	Included
Brezee Creek (BRZ010)	9	J	Moderate	Included
Matney Creek (MAT010)	17	I	Moderate	Included
Lacamas Creek-lower (LAC050)	148	M	Very Low	Excluded - Large Upstream Drainage
Curtin Creek (CUR020)	28	L	Very Low	Excluded - Groundwater Contribution / Substrate
Yacolt Creek (YAC005)	20	I	Very Low	Excluded - Groundwater Contribution/ Substrate
Lacamas Creek-upper, (LAC090)	35	I	Very Low	Excluded -Large Upstream Drainage
Jones Creek (JNS060) [Little Washougal River – upper]	18	H	Very Low	Excluded – Hydrogeology, Soil, Slope, Precipitation
Little Washougal River – lower (LWG015)	63	B	Very Low	Excluded - Large Upstream Drainage

Figure 4 shows the location within Clark County of subwatersheds screened, their relative similarity, and the monitoring station locations for high and moderate similarity subwatersheds. The relative position of monitoring stations within subwatersheds or their larger watersheds reflect the portion of upstream drainage basin represented by both the B-IBI scores and hydrologic metrics. All of the B-IBI and flow monitoring stations are located near the outlet of their respective subwatersheds except for Gee Creek. Gee Creek's B-IBI station is at the outlet of the upper Gee Creek subwatershed while its flow monitoring station is located further downstream. However, use of this downstream Gee Creek flow gage is justified because it has relatively little additional contributing drainage area compared to the Upper Gee Creek subwatershed and Gee Creek's upper and lower subwatersheds are similar physiographically.

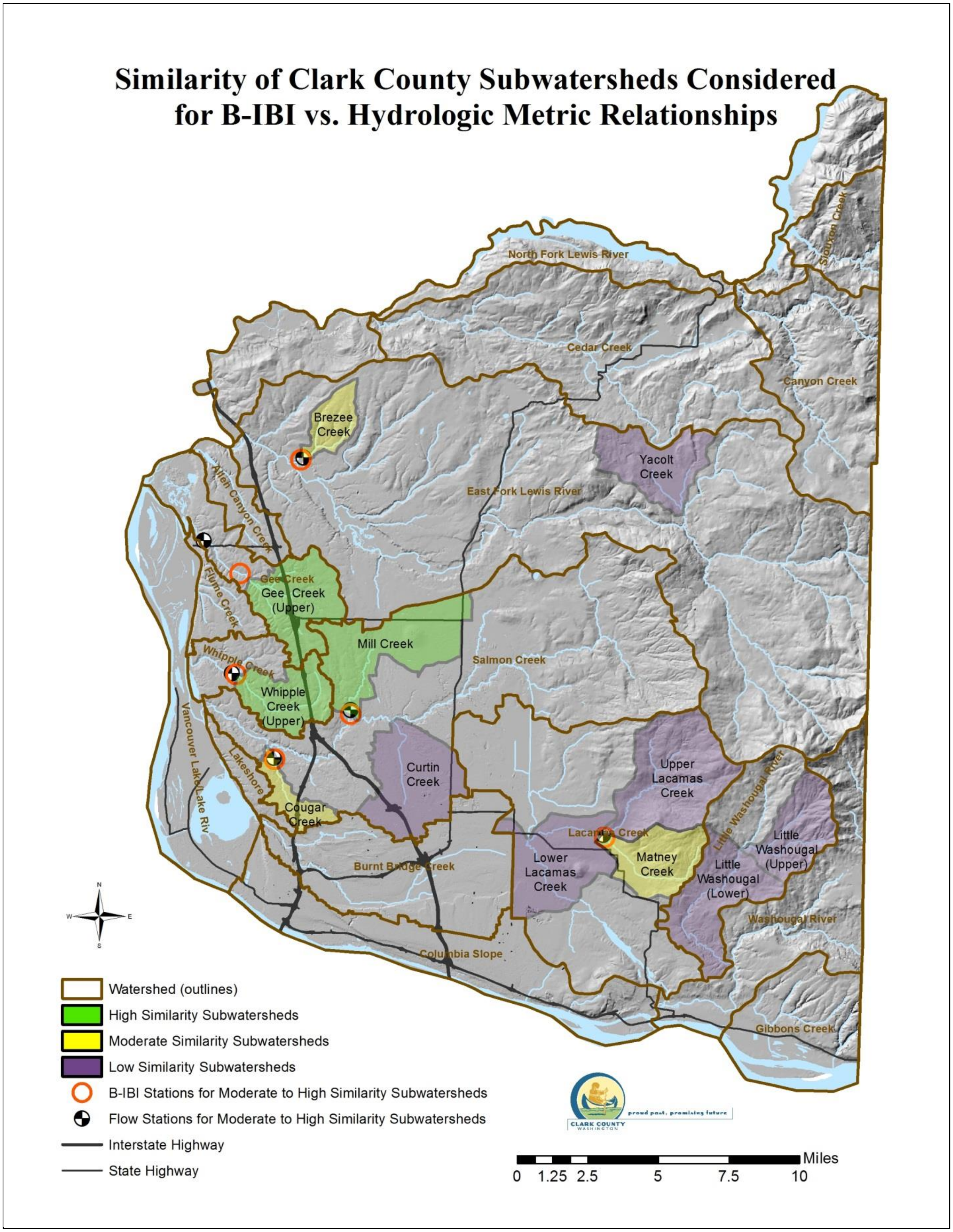

Figure 4 Clark County subwatersheds considered for B-IBI versus hydrologic metric relationships and monitoring station locations for high and moderate similarity subwatersheds

Booth *et al*. developed several hydrologic measures for an EPA study based in the Puget Sound area "that identify both hydrologic changes in streams and differences between streams that result from urban development and are likely to have ecological effects" (Booth *et al*., 2001, pp.19-20). One of the metrics they developed was T_{Qmean}. Individual stream T_{Qmean} statistics were based on each stream's overall average of annual fractions of a year that daily mean flow rate exceeded respective annual mean flow rate. Mean annual discharge was exceeded approximately 30% of the time across the Puget Lowland streams.

At a more detailed analysis level of the Puget Sound Lowland stream data (Booth *et al*., 2001, pp. 37-38), significantly lower mean T_{Qmean} values were found for urban than suburban drainage areas of less than 20 km^2. Additionally, T_{Qmean} varied little from year to year for streams with stable land use (coefficient of variation of 17% during 1989-1998) and can be estimated reliably from a relatively short (e.g., ~10 years) stream flow record. Generally, T_{Qmean} for urban streams was less than 30% (n=11, mean 0.29) and statistically less than that for suburban streams for which it was greater than 30% (n=12, mean 0.34). Additionally, independent of the level of urban development, larger streams (drainage area > 30 km^2) typically have more attenuated stream flow patterns and thus higher T_{Qmeans} than smaller streams (< 30 km^2). The mean T_{Qmean} for larger streams (0.35) was significantly greater than that for smaller streams (0.28).

DeGasperi *et al*. (2009) analyzed daily average flow values and stream biological responses (B-IBI scores) from 16 monitored streams in King County, Washington to evaluate relationships between fifteen hydrologic metrics and B-IBI scores across a gradient of urbanization (DeGasperi, et. al., 2009, pp. 512 and 518). Of the fifteen metrics evaluated for ecological relevance, HPC and HPR were found to best meet the four criteria of: "(1) sensitive to urbanization consistent with expected hydrologic response, (2) demonstrate statistically significant trends in urbanizing basins, (3) be correlated with measures of biological response to urbanization, and (4) be relatively insensitive to potentially confounding variables like basin area."

Based on the literature and to address issues noted earlier, the hydrologic metrics evaluated in this current Clark County study for their relationships to B-IBI scores are limited to: T_{Qmean}, High Pulse Count (HPC), and High Pulse Range (HPR). B-IBI was shown to have a statistically significant linear relationship with T_{Qmean} in the Puget Lowland region (Booth *et al*., 2001, DeGasperi *et al*., 2009, p. 528). HPC and HPR were found to have best met criteria for ecological relevance in the stormwater permit referenced 2009 DeGasperi paper. Table 5 presents the calculated multi-year averages for B-IBI scores (reflecting stream biological health) as well as $T_{Qmean,}$, HPC (and log base 10 equivalents), and HPR hydrologic metrics for all Clark County subwatersheds considered for further evaluation.

While T_{Qmean} is a reliable indicator of hydrologic change over time in a stream basin, it varies with drainage area and other physiographic conditions. Thus, T_{Qmean} should only be used to compare similar stream basins (Booth *et al*., 2001, p.41). This report's appendix presents exploratory data analyses results from regressing B-IBI on T_{Qmean} based on various combinations of data from all available Clark County and other referenced Puget Sound Lowland (DeGasperi *et al*., 2009) monitored watersheds. However, to improve consistency and reduce potential confounding for further evaluations in this current Clark County study, the subwatersheds focused on for more involved statistical analyses of relationships are limited to those considered moderate to high in overall similarity to the Whipple Creek subwatershed (color coded yellow and green in Table 5).

Table 5 Clark County subwatersheds' average B-IBI and hydrologic metrics (T_{Qmean}, High Pulse Count and Logs, and High Pulse Range)

Clark County B-IBI Station (Identifier)	Water Years	Average B-IBI	Average T_{Qmean}	Average High Pulse Count	Average High Pulse Count (log 10)	Average High Pulse Range
Whipple Creek (WPL050)	***2005 - 2009***	***22***	***0.27***	***12***	***1.079***	***160***
Gee Creek –upper (GEE050)	2005 - 2009	24	0.25	11	1.041	137
Mill Creek (MIL010)	2005 - 2009	27	0.27	9	0.954	140
Cougar Creek (CGR020)	2005 - 2009	20	0.26	19	1.279	261
Brezee Creek (BRZ010)	2005 - 2009	28	0.29	6	0.778	138
Matney Creek (MAT010)	2005 - 2008	34	0.33	10	1.000	151
Lacamas Creek-lower (LAC050)	2003 - 2009	22	0.27	8	0.903	144
Curtin Creek (CUR020)	2004 - 2009	22	0.33	6	0.778	138
Lacamas Creek-upper (LAC090)	2004 - 2009	30	0.26	9	0.954	168
Yacolt Creek (YAC005)	2004 - 2009	42	0.31	5	0.699	93
Jones Creek (JNS060) [Little Washougal River – upper]	2004 - 2009	46	0.35	8	0.903	200
Little Washougal River – lower (LWG015)	2004 - 2009	32	0.23	8	0.903	162

Table 6 summarizes and Figure 5, Figure 6, and Figure 7 depict the statistical relationships between the more similar Clark County subwatersheds' individual average B-IBI scores (response variable) and each of the three Pacific Northwest hydrologic metrics (predictor variable) evaluated more fully in this study. The ranges of these and many appendix figures' x and y axes are comparable to those in DeGasperi *et al*. (2009) paper's figure 6 to facilitate comparisons with those found for the Puget Sound urbanizing basins.

The analyses results are important for Clark County because T_{Qmean} was the only evaluated hydrologic metric found to have a statistically significant (R^2 of 82.2%, p-value of 0.013 versus as an acceptable Type I error rate of 0.05) and reasonable linear relationship when B-IBI was regressed on it. Given the small sample size of six subwatersheds, evaluations of the best-fit linear regression relied primarily on visual interpretation of graphics with some statistical testing of regression assumptions. For example, scatterplots and residual plots (in the appendix) were evaluated for outliers and non-constant variance in the residuals versus the predictor (Ott, pp. 365-366) hydrologic metrics.

Table 6 Summary of B-IBI linear regressions on hydrologic metrics for moderate and high similarity Clark County subwatersheds

Hydrologic Metric	Linear Regression Equation	Pearson Correlation R^2 (% of B-IBI Variation Explained by Regression Equation)	Significance of Association between B-IBI and Hydrologic Metric (Ho: slope = 0): p-value	Predictor Hydrologic Metric Significantly Explains B-IBI Variation ($\alpha = 0.05$)	Assessment of Linear Regression: Fit Reasonable / Generally Meets Regression Assumptions (Violations)
T_{Qmean}	Avg BIBI = - 16.7 + 154 Avg TQmean	82.2%	0.013	Yes	Yes /Mostly
High Pulse Count (Log10)	Avg BIBI = 45.2 – 18.9 Log10 Avg HPC	38.5%	0.189	No	Marginal Fit (Outlier - Matney) / No (Residuals Non-normal & Non-constant Variance)
High Pulse Range	Avg BIBI = 35.7 – 0.06 Avg HPR	33.1%	0.232	No	Marginal Fit (Outlier - Matney) / Marginally Meets (Residuals Non-constant Variance)

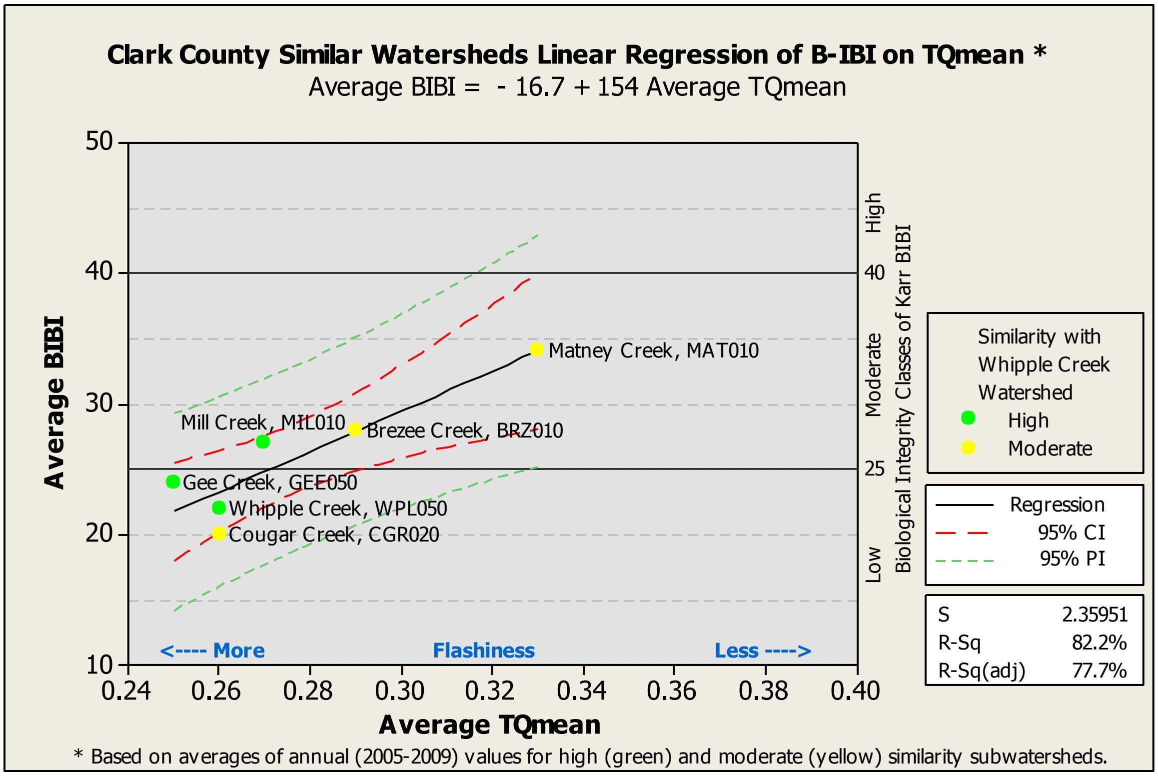

Figure 5 Linear regression of average B-IBI on average TQmean across similar subwatersheds

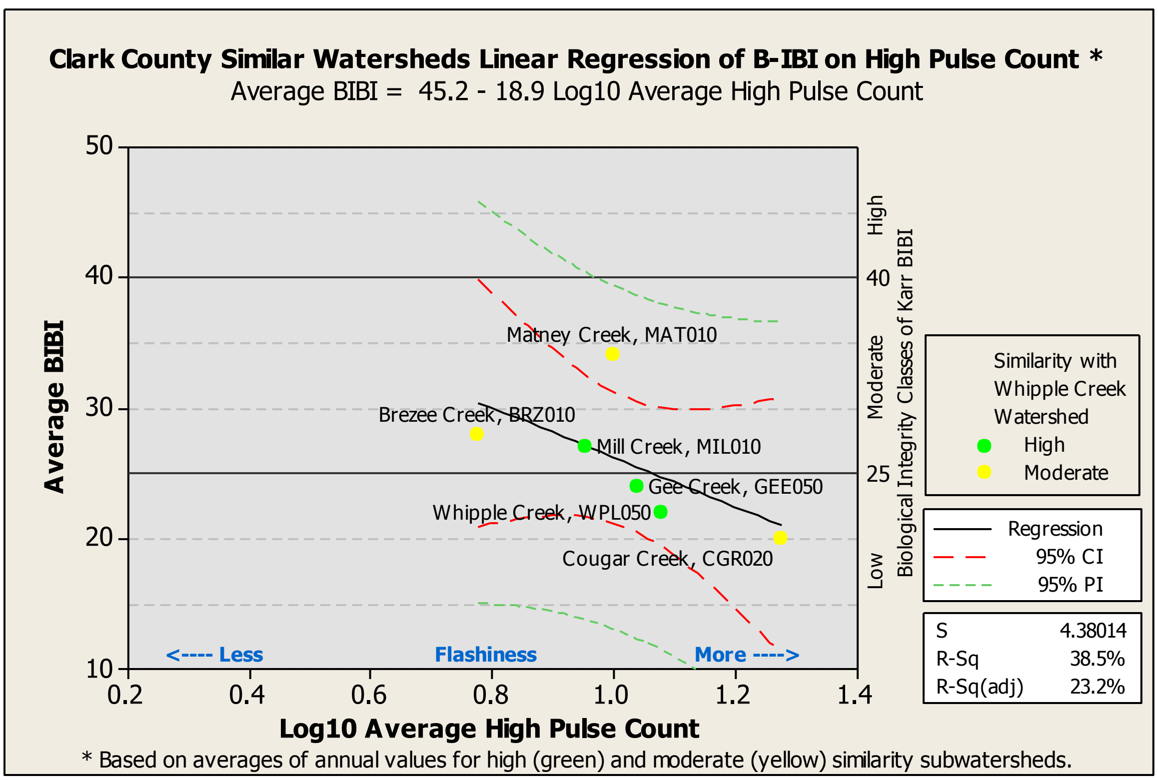

Figure 6 Linear regression of average B-IBI on average High Pulse Count (Log10) across similar subwatersheds

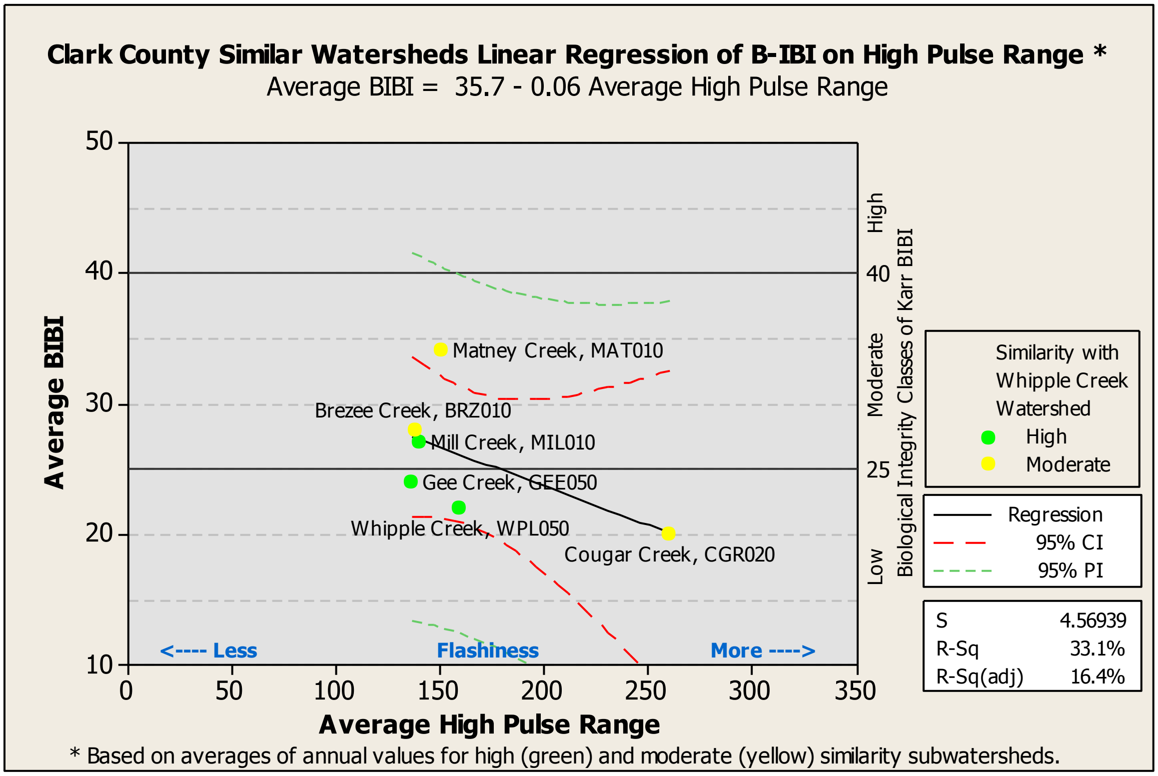

Figure 7 Linear regression of average B-IBI on average High Pulse Range across similar subwatersheds

Charts in the appendix of this document summarize exploratory data analyses and general evaluations of the goodness of linear regression model fit and assumptions. The exploratory data analyses scatterplots of Clark County B-IBI or hydrologic metrics versus water year depict how subwatershed average yearly values varied over time. There does not appear to be any obvious trends for these values over the 5-year (2005 - 2009) timeframe evaluated. The scatterplot of Clark County subwatershed B-IBI versus T_{Qmean} fitted with both Lowess smoothing and least squares regressions shows that the linear model order appears to adequately fit the observed data. The distributions of differences (residuals or errors) between response variable observed values and their respective predicted or fitted values (MiniTab Release 14.1 software Help) are depicted in the plots showing B-IBI residuals across the individual subwatersheds. The variation of Clark County stream residuals appears to be fairly constant and random across the range of average T_{Qmean} predictors and fitted values from the regression model thus likely does not violate the assumptions of homogeneous error variances and independence (Ott, pp. 365-366). The “Residual Versus the Order of the Data” plot is not applicable since there is no meaning to the order of the subwatershed B-IBI values. The other linear regression assumption of normally distributed errors was also evaluated for the similar Clark County watersheds. Both the T_{Qmean} residuals’ near linear plotted values on the normal probability plot and Anderson-Darling normality test statistic’s relatively large p-value of 0.55 suggest that the null hypothesis of normality can not be rejected (MiniTab Release 14.1 software Help). Overall, the linear regression assumptions are generally assumed to have been satisfied at an acceptable level given the sample size of six moderate to high similarity Clark County subwatersheds whose relationships were evaluated in more depth.

Also presented in the appendix are brief exploratory analyses on the linear relationships between B-IBI (response) and T_{Qmean} (predictor) for mostly combined data from Clark and King Counties’ streams (based on additional data downloaded from the 2009 DeGasperi research from the American Water Resources Association journal web page). These analyses showed poorer correlation coefficients (usually much lower R^2) than the similar Clark County watersheds for several combinations of Clark and / or King County stream data, even when only smaller watersheds (drainage areas of < 30 km^2) were evaluated.

Conclusions

Amongst the twelve Clark County subwatersheds having both adequate amounts of annual B-IBI and continuous flow monitoring data, six were found to be either moderately or highly similar to the Whipple Creek watershed that is the subject of watershed planning. Further analyses was performed on the linear regression relationships between these six watersheds’ average B-IBI scores and three Pacific Northwest hydrologic metrics: T_{Qmean}, High Pulse Count, and High Pulse Range. The analyses of the Clark County data showed that only T_{Qmean} had a significant linear relationship (significantly explained B-IBI variation, R^2 of 82%, p-value of 0.013). It is recommended that this linear regression of B-IBI on T_{Qmean} be used in Clark County’s Whipple Creek watershed planning effort for estimating future biological conditions in conjunction with model simulations of predicted hydrology.

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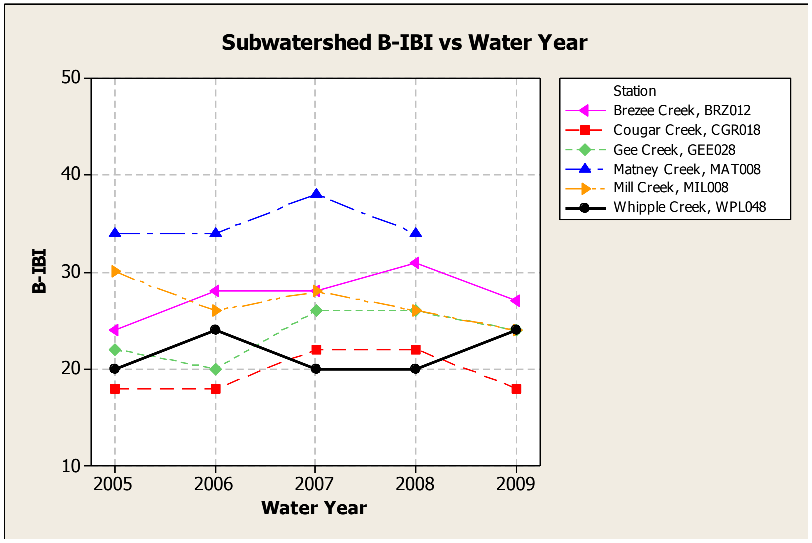
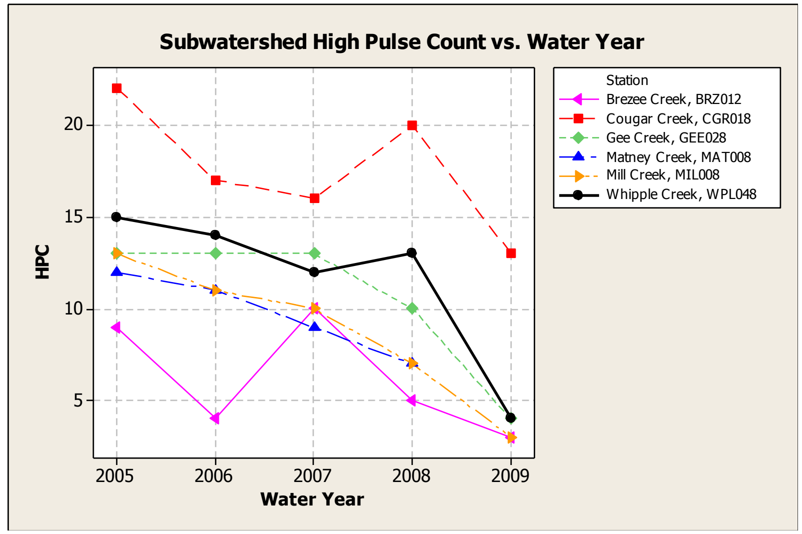
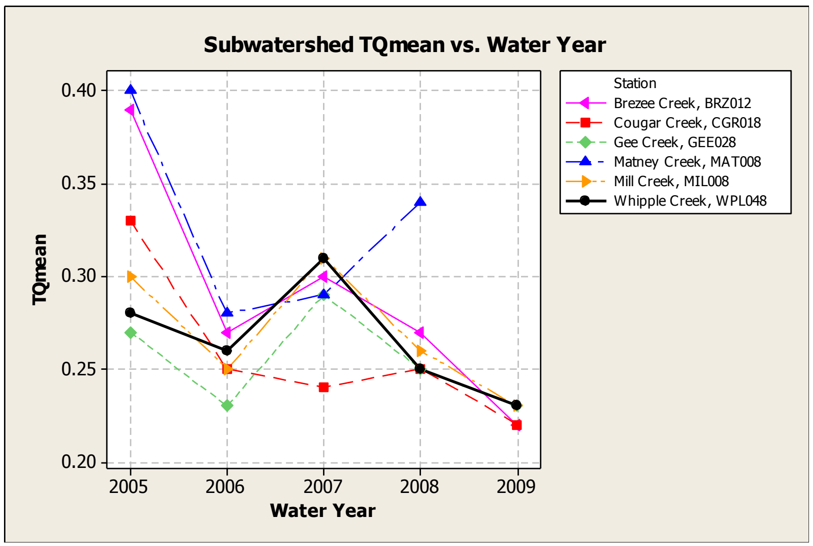
Appendices

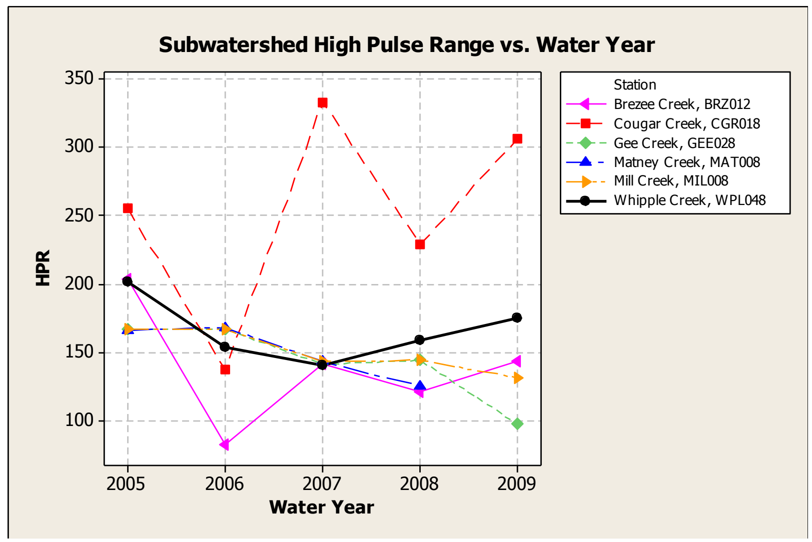
Exploratory Data Analyses:

Clark County Subwatershed B-IBI, T_{Qmean}, High Pulse Count, and High Pulse Range values across water years



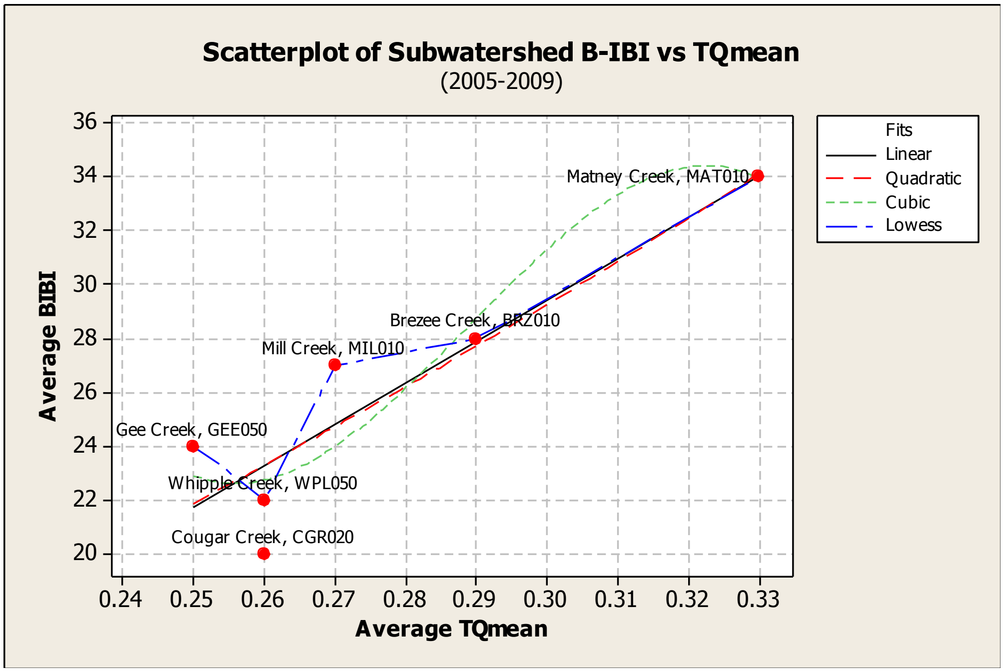




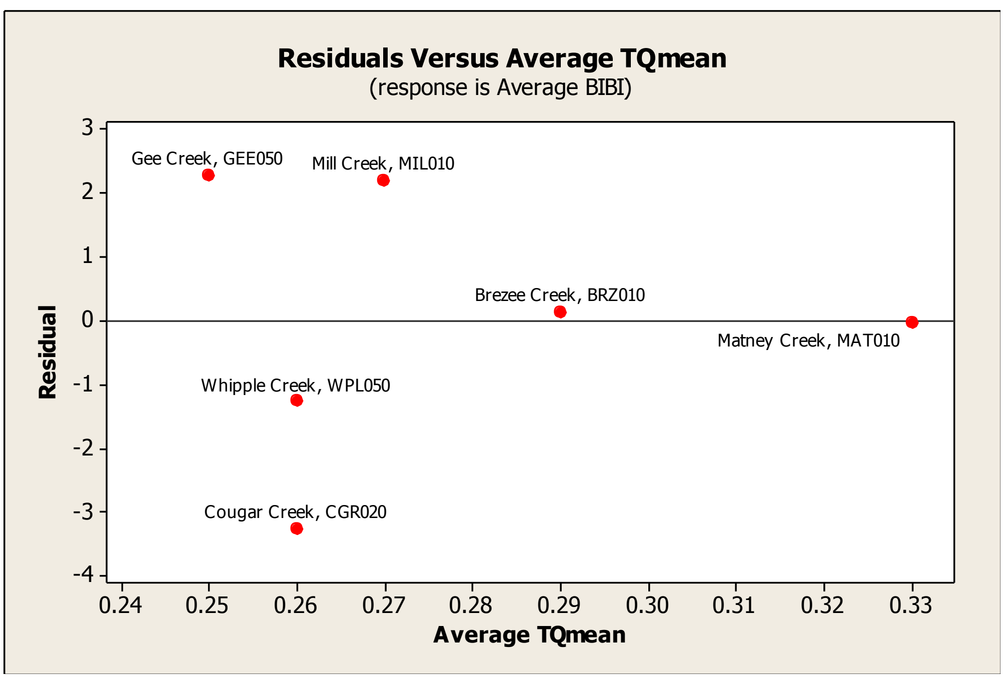


Clark County Similar Watersheds Assumption Evaluations:

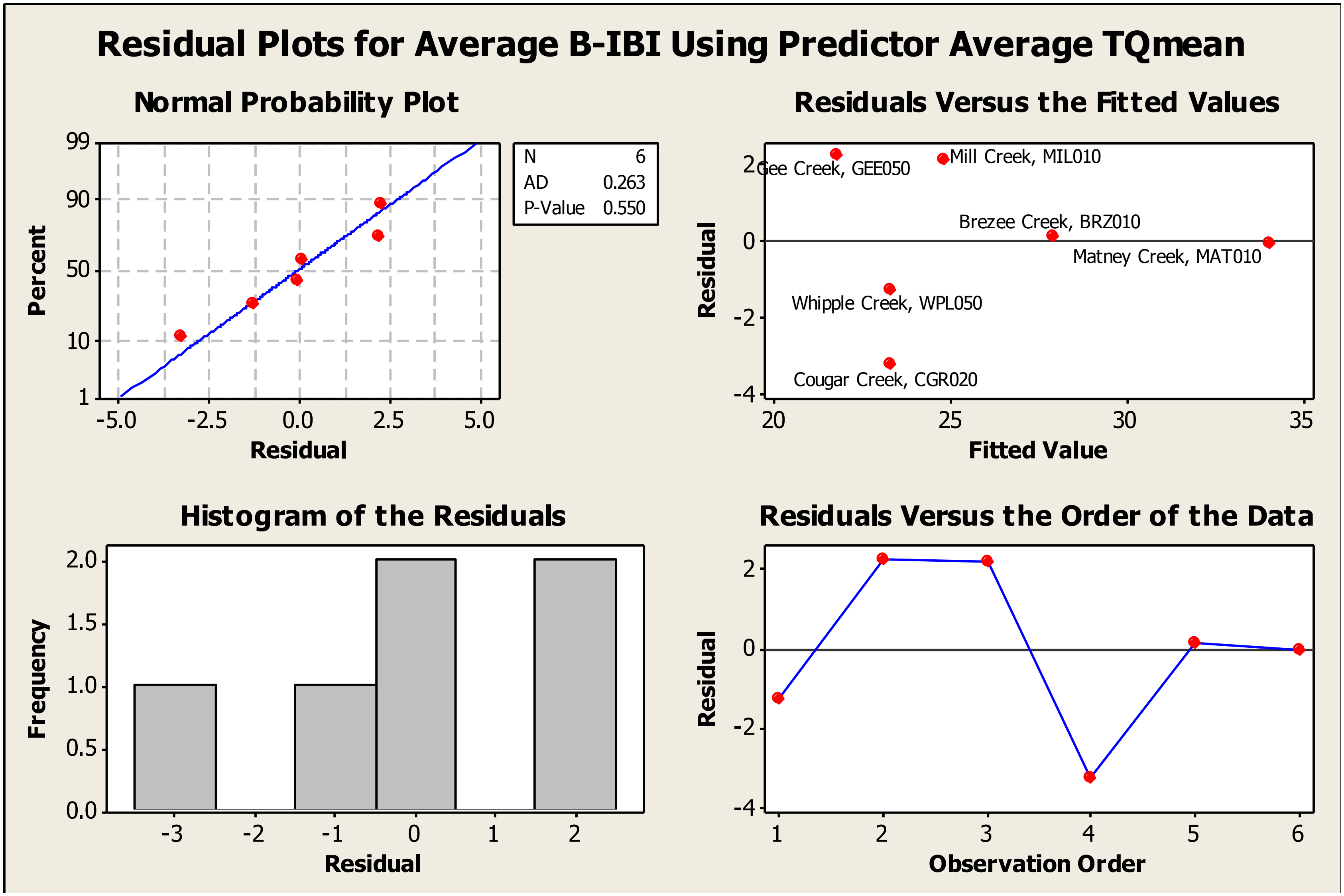
Regression models' appropriateness: average B-IBI regressed on average T_{Qmean} (scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



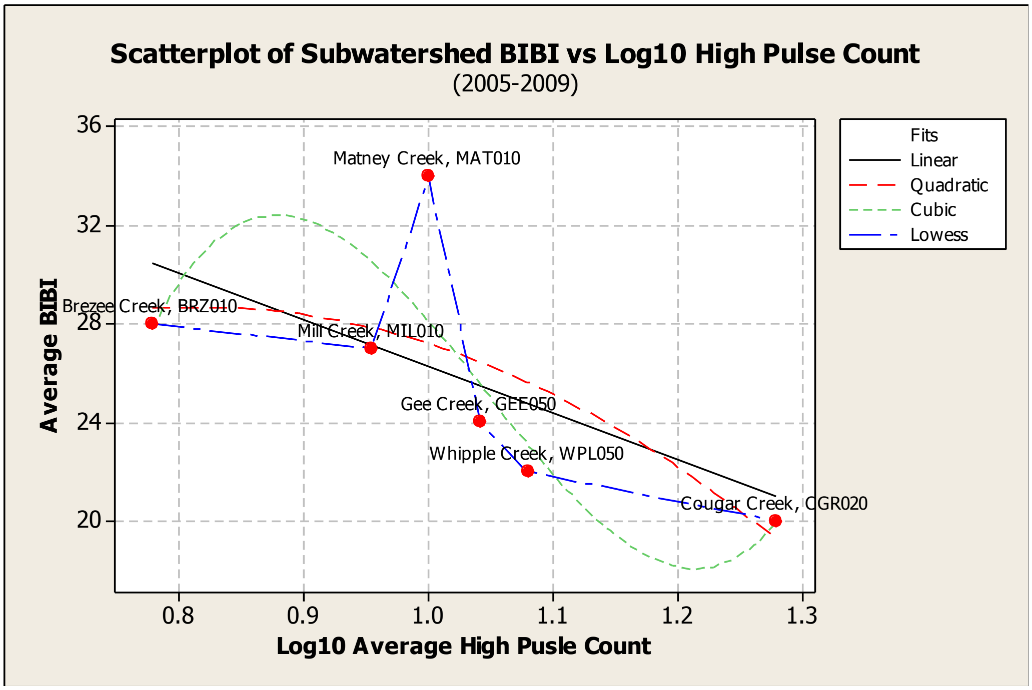
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average T_{Qmean} predictors



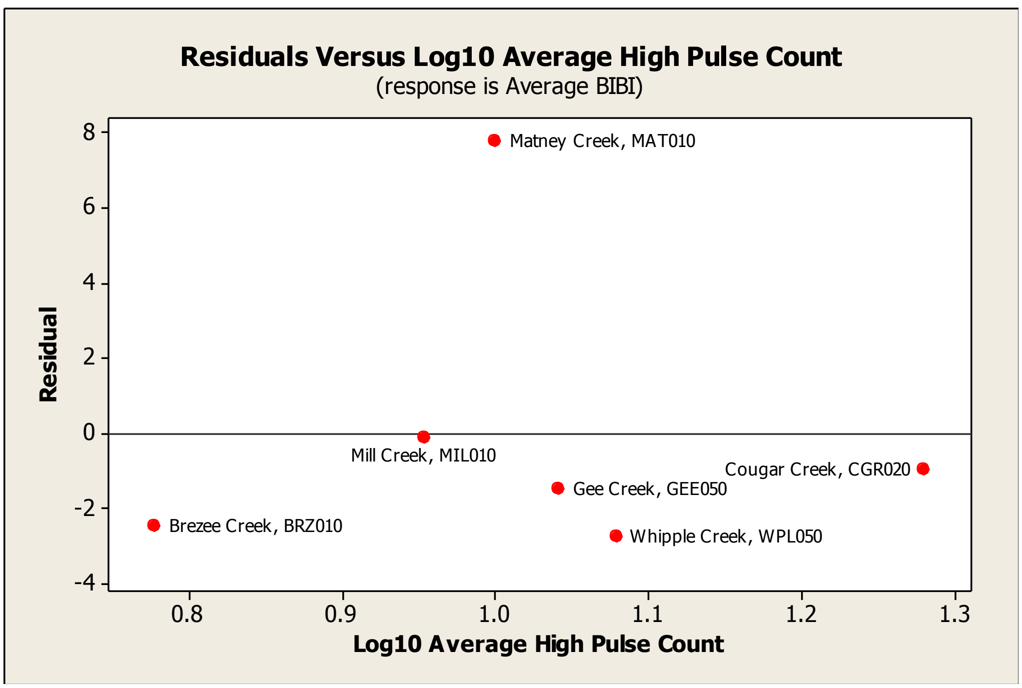
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor T_{Qmean})



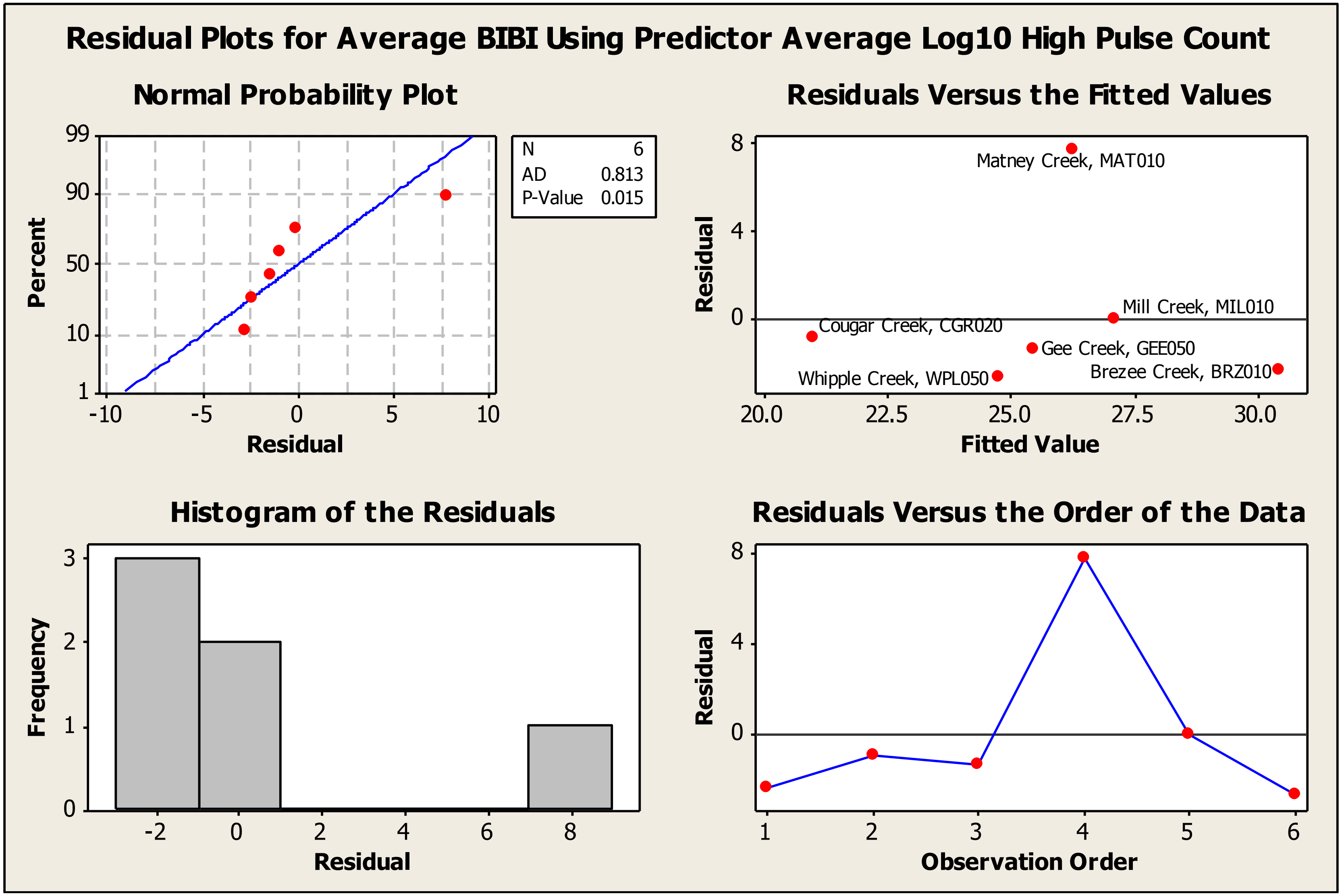
Regression models' appropriateness: average B-IBI regressed on average Log10 High Pulse Count (scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



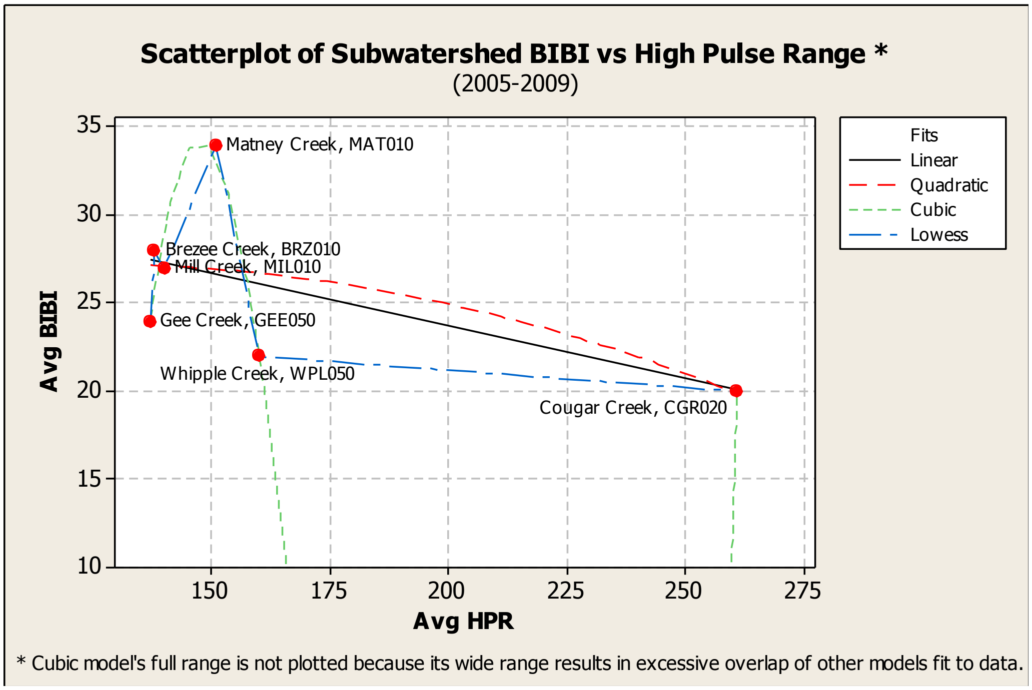
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average High Pulse Count predictors



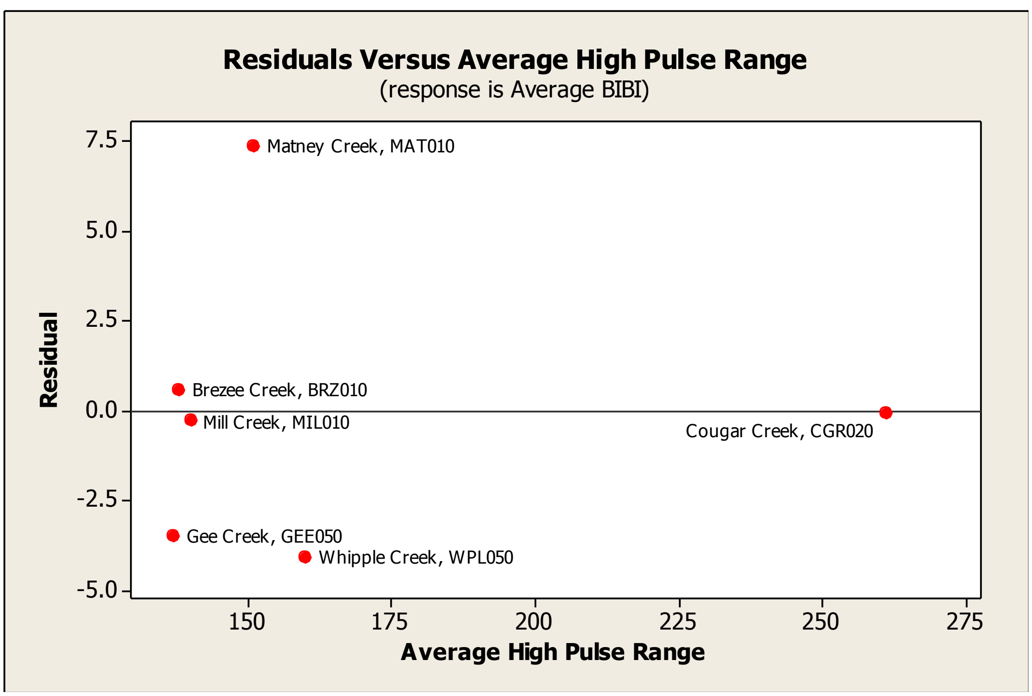
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor Log10 High Pulse Count)



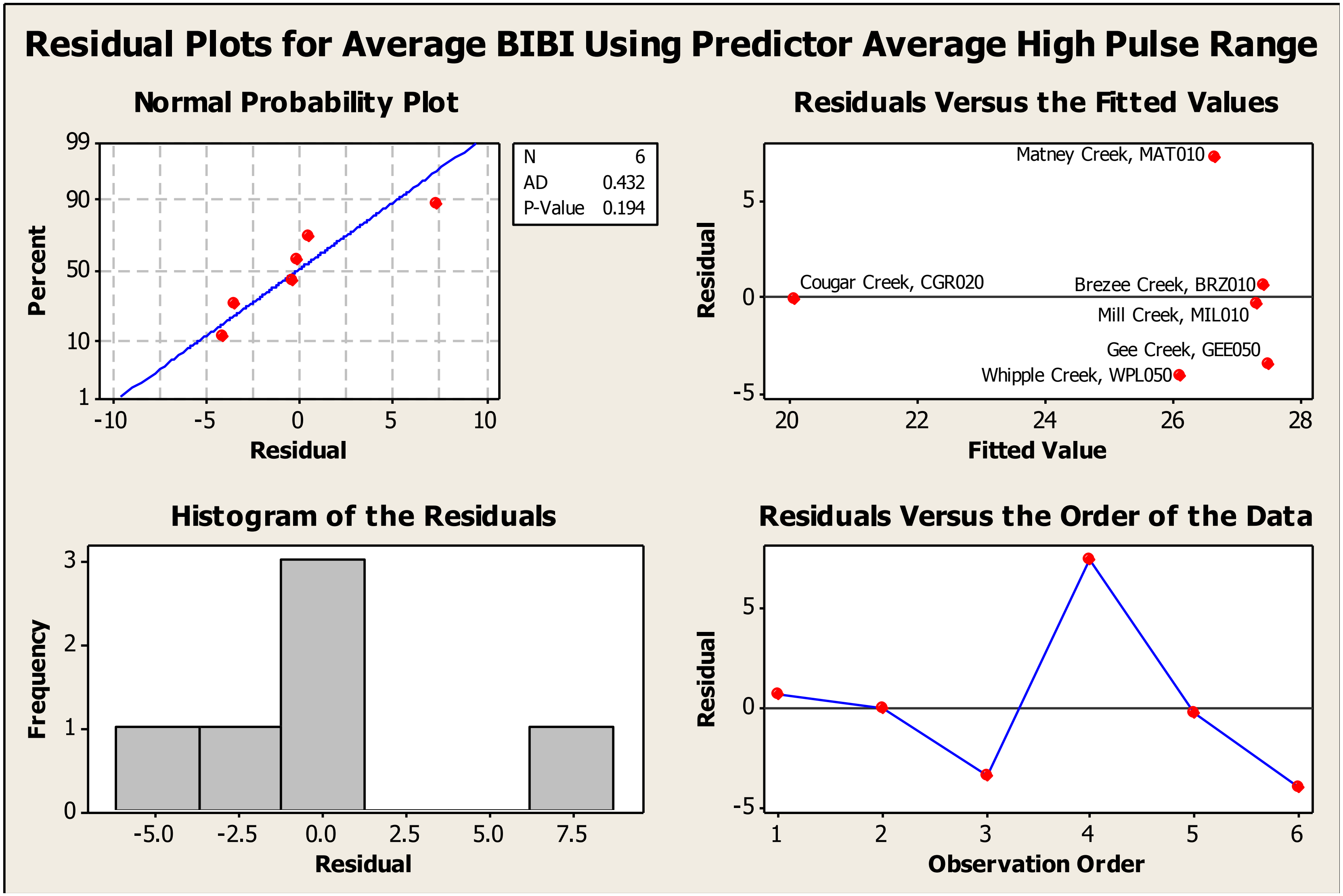
Regression models' appropriateness: average B-IBI regressed on average High Pulse Range (scatterplot with Lowess smoothing connector line and linear, quadratic, and cubic models fit)



B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted values on linear regression) across range of Average High Pulse Range predictors

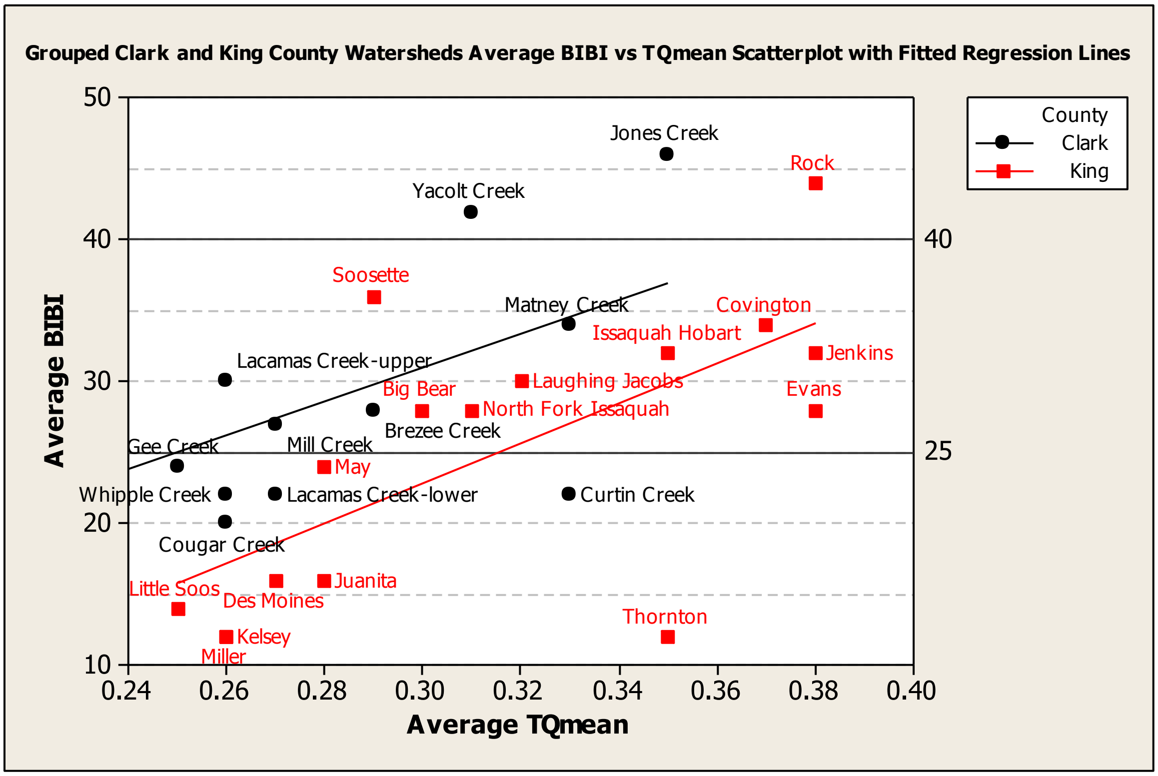


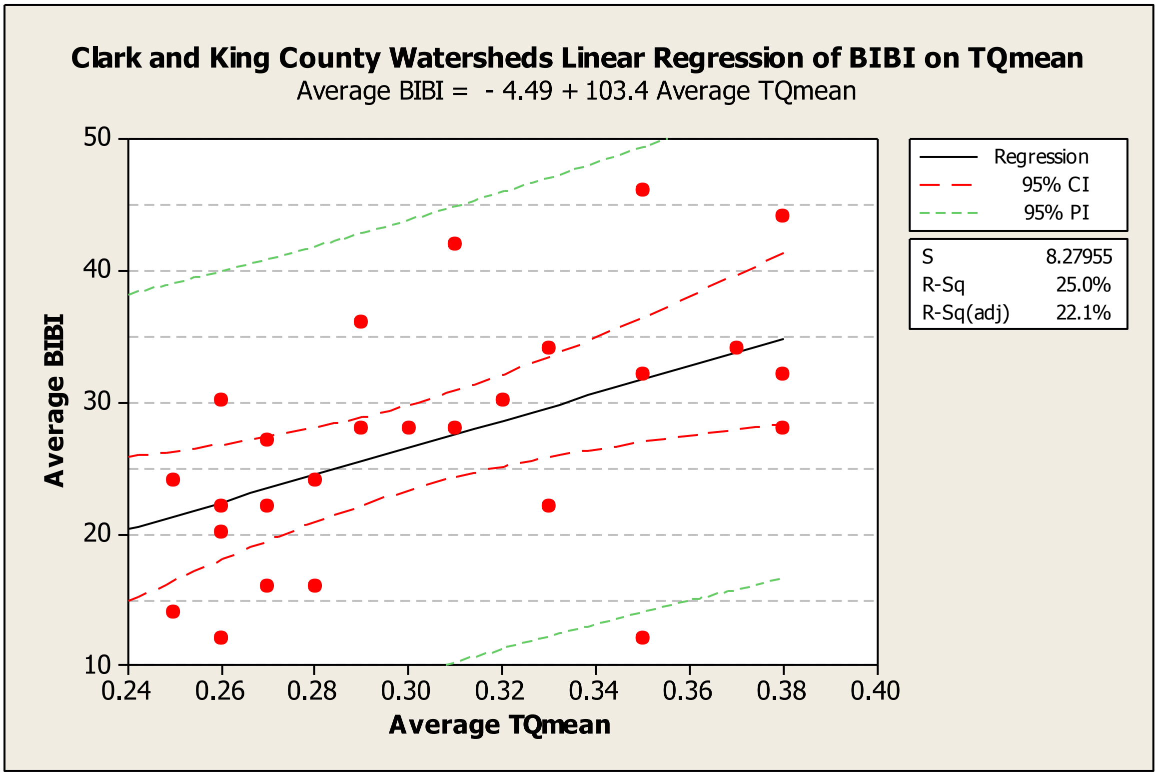
B-IBI residuals (differences between subwatersheds' observed B-IBI and their fitted linear regression on predictor High Pulse Range)

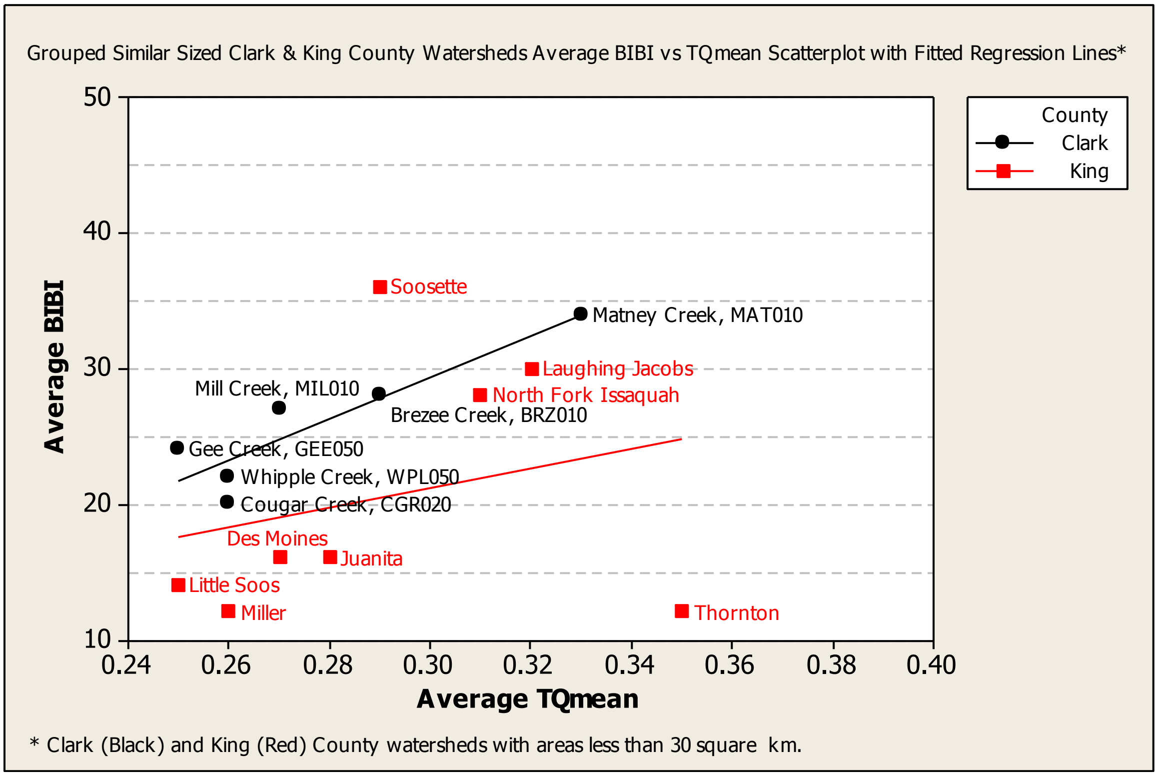


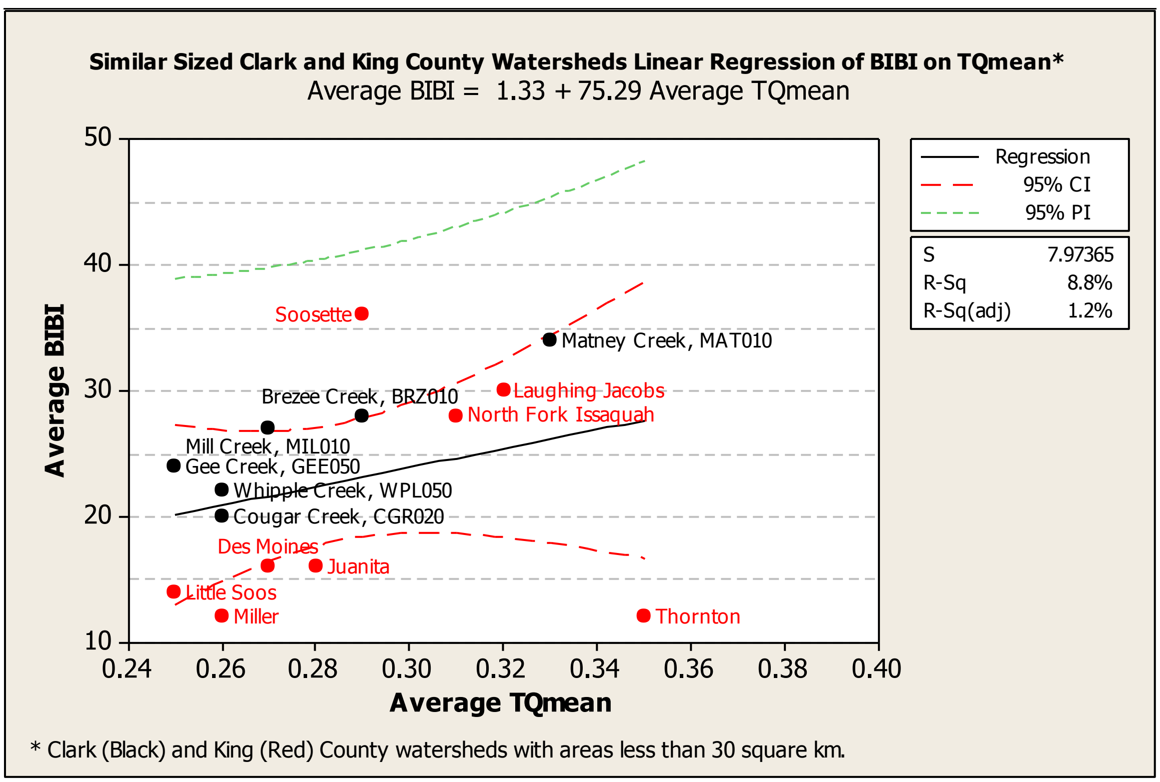
Exploratory Data Analyses:

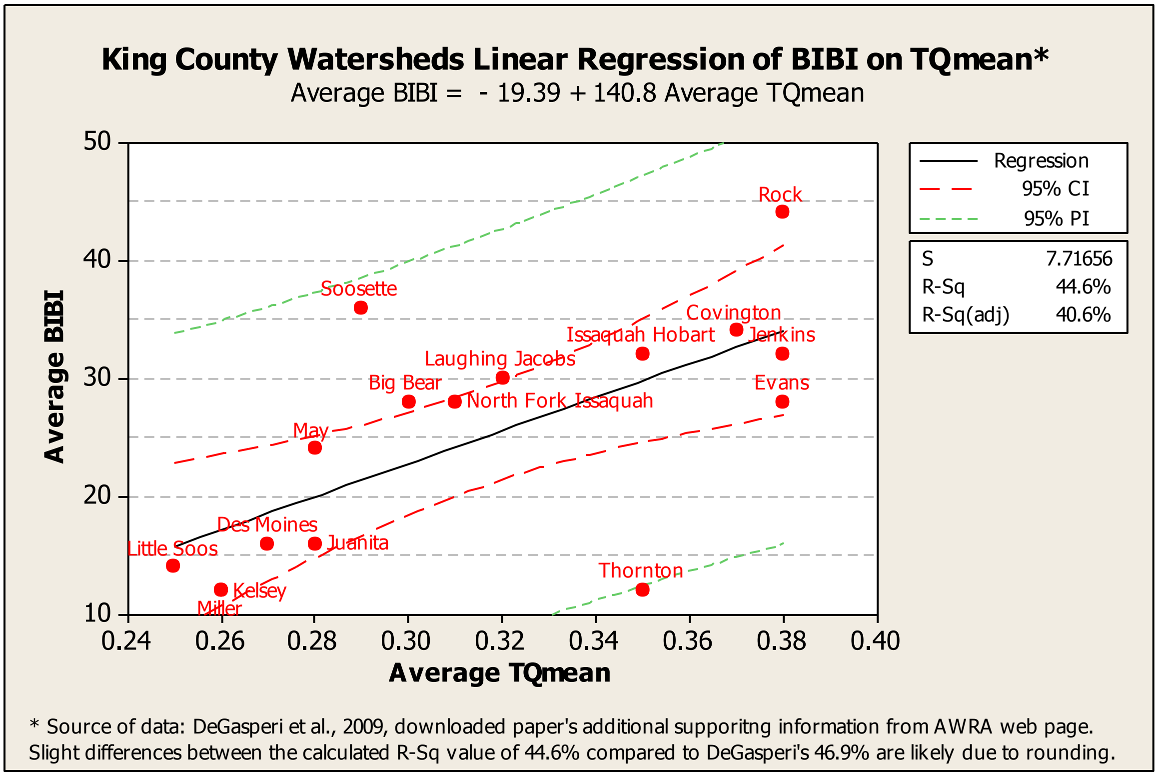
Clark and King County Subwatersheds B-IBI versus T_{Qmean} Scatterplots and Linear Relationships

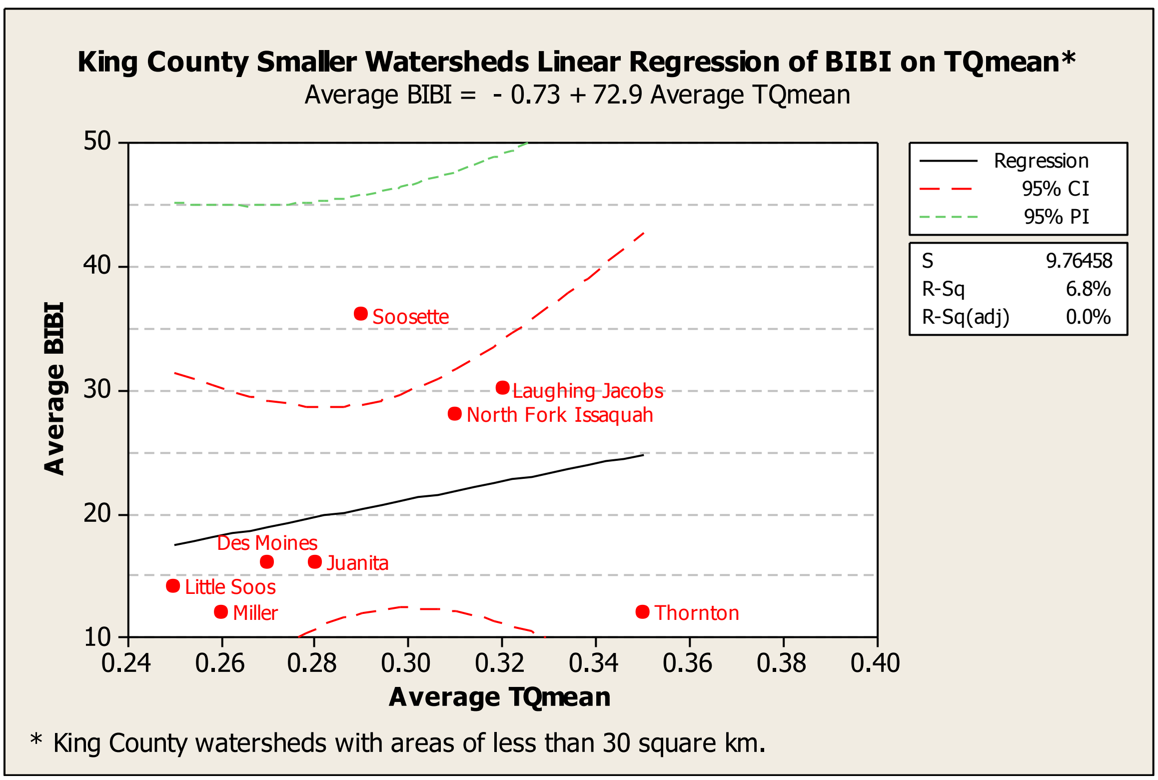





Grouped Similar Sized Clark & King County Watersheds Average BIBI vs TQmean Scatterplot with Fitted Regression Lines*
Average BIBI
Average TQmean
County
Clark
King
Soosette
Matney Creek, MAT010
Laughing Jacobs
Mill Creek, MIL010
North Fork Issaquah
Brezee Creek, BRZ010
Gee Creek, GEE050
Whipple Creek, WPL050
Cougar Creek, CGR020
Des Moines
Juanita
Little Soos
Miller
Thornton
* Clark (Black) and King (Red) County watersheds with areas less than 30 square km.


Similar Sized Clark and King County Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = 1.33 + 75.29 Average TQmean
Regression
95% CI
95% PI
S 7.97365
R-Sq 8.8%
R-Sq(adj) 1.2%
Average BIBI
Average TQmean
Soosette
Matney Creek, MAT010
Brezee Creek, BRZ010
Laughing Jacobs
North Fork Issaquah
Mill Creek, MIL010
Gee Creek, GEE050
Whipple Creek, WPL050
Cougar Creek, CGR020
Des Moines
Juanita
Little Soos
Miller
Thornton
* Clark (Black) and King (Red) County watersheds with areas less than 30 square km.


King County Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = - 19.39 + 140.8 Average TQmean
Average BIBI
Average TQmean
Regression
95% CI
95% PI
S 7.71656
R-Sq 44.6%
R-Sq(adj) 40.6%
Rock
Soosette
Covington
Issaquah Hobart
Jenkins
Laughing Jacobs
Big Bear
North Fork Issaquah
Evans
May
Des Moines
Juanita
Little Soos
Thornton
Kelsey
Miller
* Source of data: DeGasperi et al., 2009, downloaded paper's additional supporitng information from AWRA web page.
Slight differences between the calculated R-Sq value of 44.6% compared to DeGasperi's 46.9% are likely due to rounding.


King County Smaller Watersheds Linear Regression of BIBI on TQmean*
Average BIBI = - 0.73 + 72.9 Average TQmean
Average BIBI
Average TQmean
Regression
95% CI
95% PI
S 9.76458
R-Sq 6.8%
R-Sq(adj) 0.0%
Soosette
Laughing Jacobs
North Fork Issaquah
Des Moines
Juanita
Little Soos
Miller
Thornton
* King County watersheds with areas of less than 30 square km.

Appendix I

Whipple Creek Watershed-Scale Stormwater Plan Report

Use of Hydrologic Metrics as Designated Use Targets

Prepared by

Rod Swanson, NPDES Compliance Program Manager

Clark County Department of Public Works

Clean Water Division

April 2017

Contents

Background

The concept of using hydrologic metrics to estimate a biologic indicator provides an appealing option to describe whether a watershed will support salmon populations. Considering this, the Permit requires model calibration to reflect current hydrologic and biologic (B-IBI scores) conditions. The Permit further requires the use of a calibrated hydrologic model to calculate B-IBI scores for various future scenarios. However, the hydrologic model is calibrated to hydrologic metrics, not B-IBI scores.

The requirement to use hydrologic metrics to estimate biologic conditions poses a problem for modelers because there are stream and watershed conditions other than hydrologic regime influencing B-IBI scores. The main ones are channel substrate quality, elevated temperature and the presence of toxic pollutants in urban stormwater runoff. Also, subwatershed-scale pool-riffle sites having both flow data and B-IBI scores are extremely rare, making statistical analysis weak.

Simply put, streams with forested hydrology have higher B-IBI scores not only because of the channel hydrology, but also because stressors such as pollutants in urban runoff and lack of stream channel shade are less prevalent than in rural or urban streams.

If the watershed plan objective is to restore watershed hydrologic function to that of a forest as a prerequisite for supporting salmon habitat (B-IBI above high 30s), hydrologic metrics may be an appropriate tool for presenting model results.

Purpose

King County completed an analysis of flow and water quality targets for their WRIA 9 planning project (Horner, March 2013) summarizing available science on target metrics or indicators. The results of Horner's report for King County are summarized and discussed to lead to recommendations for hydrologic metric targets for Whipple Creek. Along with an evaluation of the King County work, there is an analysis of the complete set of Clark County sites for the purpose of finding reasonable hydrologic metrics to measure degree of designated use attainment for salmon habitat.

Indicator Ranges for Use Attainment

Generally, B-IBI scores are broken into five categories describing very poor, poor, fair, good and excellent conditions. For Whipple Creek, the goal is to fully support designated uses, which implies a specific B-IBI score somewhere in the upper 30s or higher (of 50). Generally, a B-IBI score below about 25 to 28 is considered non-supporting.

In 2014, Ecology used B-IBI scores to list streams as not meeting narrative standards. The criteria were greater than 37 for fully supporting beneficial uses and less than 28 for non-supporting. Waters of concern were designated for scores of 28 to 37.

For purposes of a watershed plan with a very long implementation period due to the ultimate goal of restoring watershed conditions to fully support salmon use, indicator ranges can be simplified to:

Not supporting	303(d) listing criteria with hydrologic metrics associated with a B-IBI of approximately < 25 -27
Partly supporting	303(d) water body of concern criteria with hydrologic metrics associated with B-IBI of approximately 26 -37
Fully supporting	303(d) fully supporting criteria with hydrologic metrics associated with B-IBI of approximately > 38

Possible Hydrologic Metrics for Whipple Creek Use Attainment

Three hydrologic metrics emerge as likely candidates for assessing strategy success at restoring the beneficial use of salmon habitat.

- High Pulse Count
- High Pulse Range
- TQmean

Each is briefly discussed.

High Pulse Count

King County recognized high pulse count as one of the more useful metrics for calculating the B-IBI indicator. Horner found that sites having HPCs between 3 and 7 generally supported salmon use (B-IBI greater than 35). The report also found that very low B-IBI scores (< 16) were associated with HPCs above 15. B-IBI scores above 25 were associated with HPCs less than 11.

King County published a regression equation for HPC and BIBI on page 17 in the stormwater retrofit analysis for Juanita Creek report (August 2012).

Clark County data showed increasing B-IBI with lower HPC, making it a viable indicator based on local data and the Puget Sound results.

Non supporting	Partially supporting	Fully Supporting
>11	8-11	<7

High Pulse Range

High pulse range was the second metric used by King County to estimate B-IBI. A high pulse range of 90 to 110 was associated with B-IBI scores greater than 35. B-IBI scores less than 16 were associated with HPRs greater than 200. While B-IBI scores between 25 and 38 were associated with HPRs between 175 and 100.

King County published a regression equation for HPR and B-IBI on page 17 in the stormwater retrofit analysis for Juanita Creek report (August 2012).

Clark County data for HPR showed a very poor correlation between B-IBI and the metric, suggesting it not be used for real world B-IBI estimation. However, it could be useful for presenting model results.

Non supporting	Partially supporting	Fully Supporting
>150	100-150	<100

TQmean

The Puget Sound analysis identified TQmean as a useful metric for calculating the B-IBI indicator. Evaluation of Clark County data for basins similar to Whipple Creek found a strong correlation.

King County published a regression equation for TQmean and B-IBI on page 17 in the stormwater retrofit analysis for Juanita Creek report (August 2012).

Clark County data suggest that a TQmean of about 0.25 to 0.27 is equivalent to the threshold for non-supporting streams and that about 0.37 is the lower threshold for fully supporting.

Non supporting	Partially supporting	Fully Supporting
10-27 percent	28-37 percent	>37 percent

Recommendations

The lack of precision in calculating B-IBI scores from hydrologic metrics suggests the approach is flawed and can introduce error. However, the Permit does require the use of B-IBI to demonstrate designated use attainment. The model output should be converted to B-IBI scores for TQmean, HPC and perhaps HPR. This is required to satisfy the Permit need for the biological indicator and to present hydrologic metrics in a common language for biological integrity. Use King County's Juanita Creek work (August 2012) for to calculate HPC and HPR.

The Whipple Creek report should also show model output as the actual hydrologic metrics because the analytical tool is a hydrologic model and the targeted stressor is excess flows. Horner (2013) provides a good basis for directly using hydrologic metrics and use attainment indicators.

The significant hydrologic modification of Whipple Creek watershed compared to a forested watershed suggest that the goal of fully supported salmon habitat is unattainable within any realistic time frame. The lack of precision in modeling introduces additional difficulties in accurately predicting use attainment. Because of this discrepancy between the reality of Whipple Creek watershed conditions and the NPDES Permit plan objectives, the model results should be described as fully supporting, partly supporting and not supporting.

Furthermore, the variability in hydrologic model metric and B-IBI regressions suggest presenting a gradational change between salmon habitat support categories; not supporting shades into partially supporting and partly supporting shades into fully supporting as a means to present relative strategy effectiveness in the context of making the best use of limited restoration resources.

References

Horner, Richard R, March 2013, Development of a Stormwater Retrofit Plan for WRIA 9: Flow and Water Quality Indicators and Targets; King County Department of Water Resources and Parks, Seattle Washington. http://your.kingcounty.gov/dnrp/library/water-and-land/watersheds/green-duwamish/stormwater-retrofit-project/final-report-indicators-targets-0413.pdf

King County, August 2012, Stormwater Retrofit Analysis and Recommendations for Juanita Creek Basin in the Lake Washington Watershed, Department of Natural Resources and Parks, Water and Land Resources Division, Seattle, WA. http://your.kingcounty.gov/dnrp/library/water-and-land/stormwater/juanita-retrofit/main-document.pdf

Washington Department of Ecology, 2014, Establishing Benthic Index of Biotic Integrity (B-IBI) Thresholds for Use in Water Quality Assessments. http://www.ecy.wa.gov/programs/wq/303d/2014/WQAB-IBIrationale.pdf

Appendix J

Whipple Creek Watershed-Scale Stormwater Plan Report

Whipple Creek Watershed Existing and Future Land Cover Data

Prepared by

Clark County Department of Public Works

Clean Water Division

January 2017

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APPENDICIES:

Introduction

Clark County is conducting a watershed level study of Whipple Creek watershed as mandated under NPDES permit requirements. The project includes development of HSPF model to represent the hydrologic and stream flow conditions of the watershed under both existing and future land use conditions. An existing HSPF model developed by Otak (2006) was used as a starting point and was updated to represent the current and future land cover conditions. The entire watershed is divided into 27 sub-basins based on the topography and or hydrologic control points. The sub-basin boundaries are shown in Figure 1. The existing land cover is based on the current development conditions throughout the watershed while the future land covers are based on the future buildout conditions as defined in the County's comprehensive growth management plan. The general procedures used to calculate the land cover types under both conditions are presented in the subsequent paragraphs.

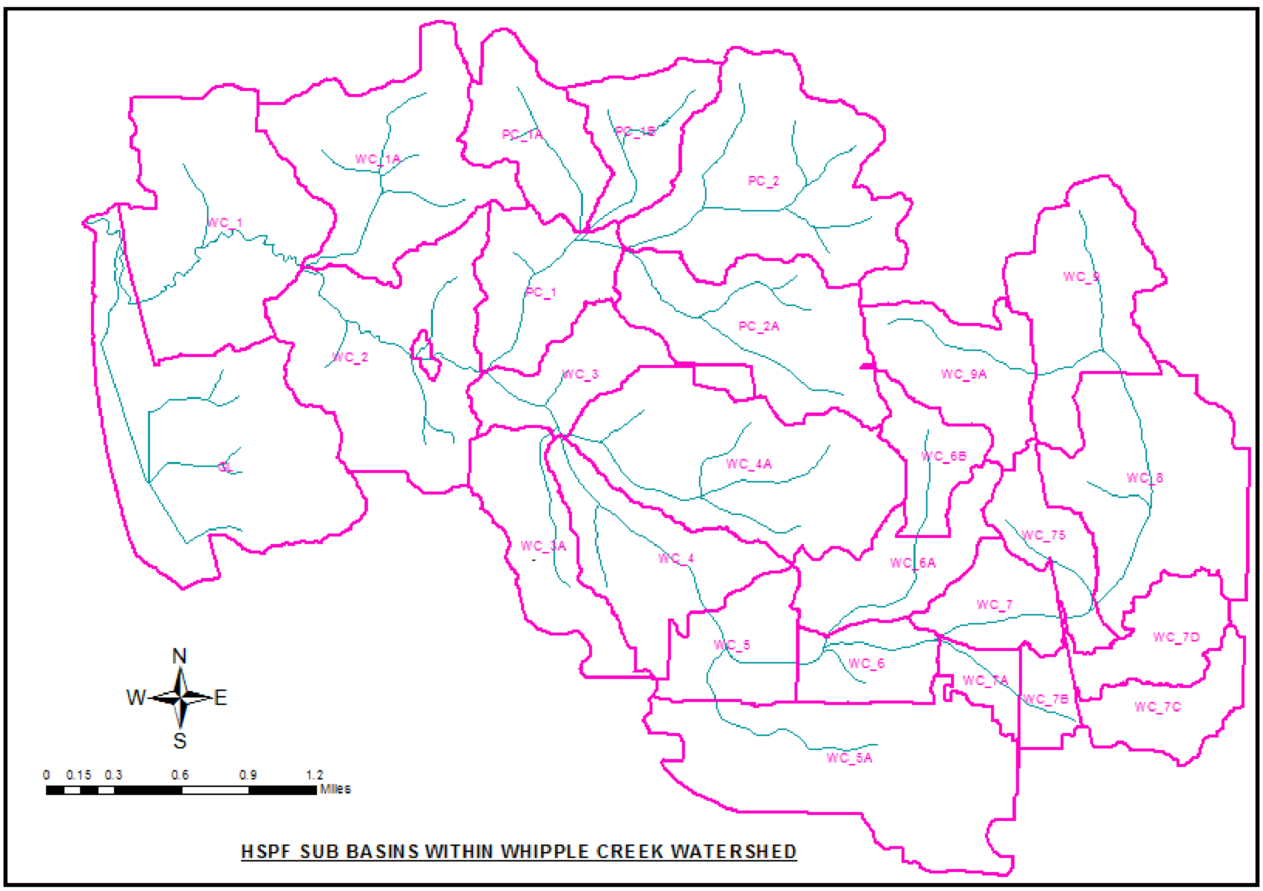

Figure-1. Whipple Creek Watershed HSPF Sub-basins.

Existing Land Cover

The original HSPF model developed in 2006 had used land covers as reflected in the County's aerial imagery 2002. While some areas have seen significant development since 2002, the land use conditions from that year provided a good "base" condition from which future development impacts were measured. The most recent available aerial imagery (2014) in County's GIS section was used to update land cover for the calibrated existing condition. ArcGIS tool was used to measure and update the land cover types within the identified areas of change.

The entire impervious area within each sub-basin was further broken down into four different categories as listed below.

- Residential Roof
- Residential Pavement
- Non-Residential Roof
- Non-Residential Pavement

The main objective of this break down is to effectively estimate the impact of certain BMPs such as street sweeping and downspout disconnection that only apply to certain types of impervious surface.

A 'roof to pavement' ratio was established for various land use types and was applied throughout the watershed in order to break down the total impervious area into roof and pavement. Three representative areas were used to represent one each of high density residential, low density residential, and non-residential land use types. The land cover type GIS layer created by Clark County in 2002 using LiDAR, Orthophoto, and Infra-Red data differentiated roofs and pavement for the calculation. Table 1 below shows the ratios calculated for representative areas.

Table 1: Roof/Pavement Ratio for Various Land Use Types			
Land Use Type	Impervious Area Type		Roof to Pavement Ratio
	Roof (acres)	Pavement (acres)	
High density residential (Figure-2)	60.40	462.84	0.13
Low density residential (Figure-3)	15.23	32.99	0.46
Non-residential (Figure-4)	17.90	314.45	0.06

A fully developed residential area located to the east of interstate I-5 was picked to represent a high density residential site. An area located along NW 149th corridor on the west side and just outside of urban growth boundary was chosen to represent a low density residential site. An area along NE 139th street on the west side of interstate I-5 was selected to represent a non-residential site. The representative areas for each land use type are shown in Figures 2 through 4.

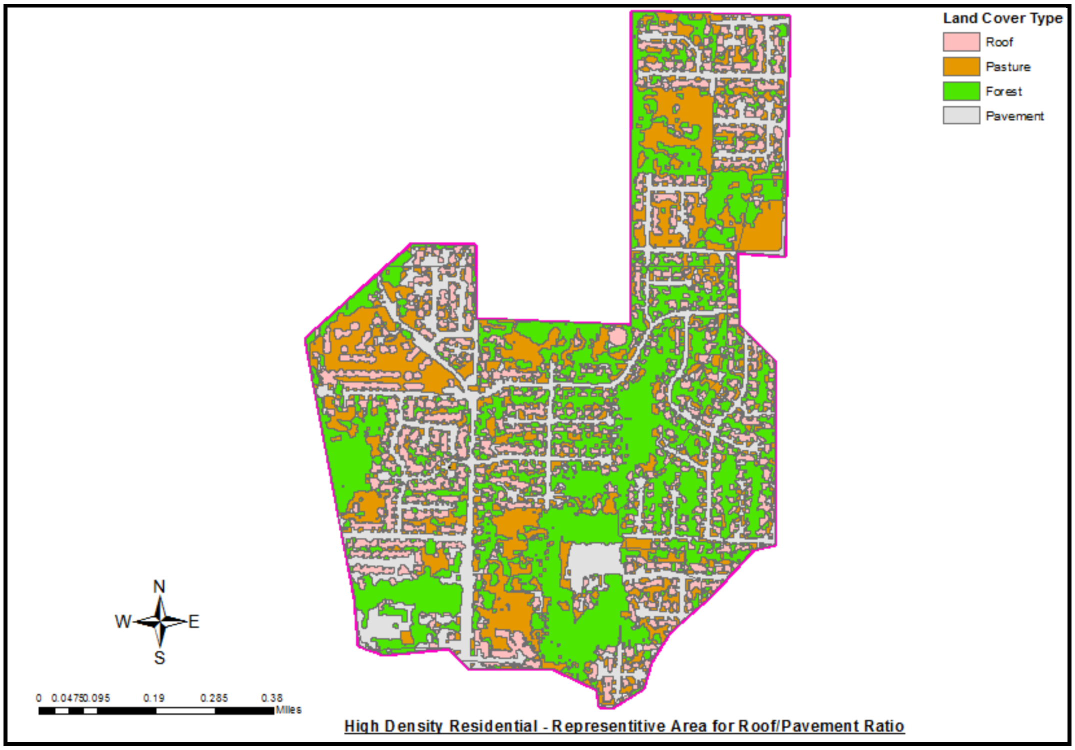

Figure-2. High Density Residential Land Use- Representative Area

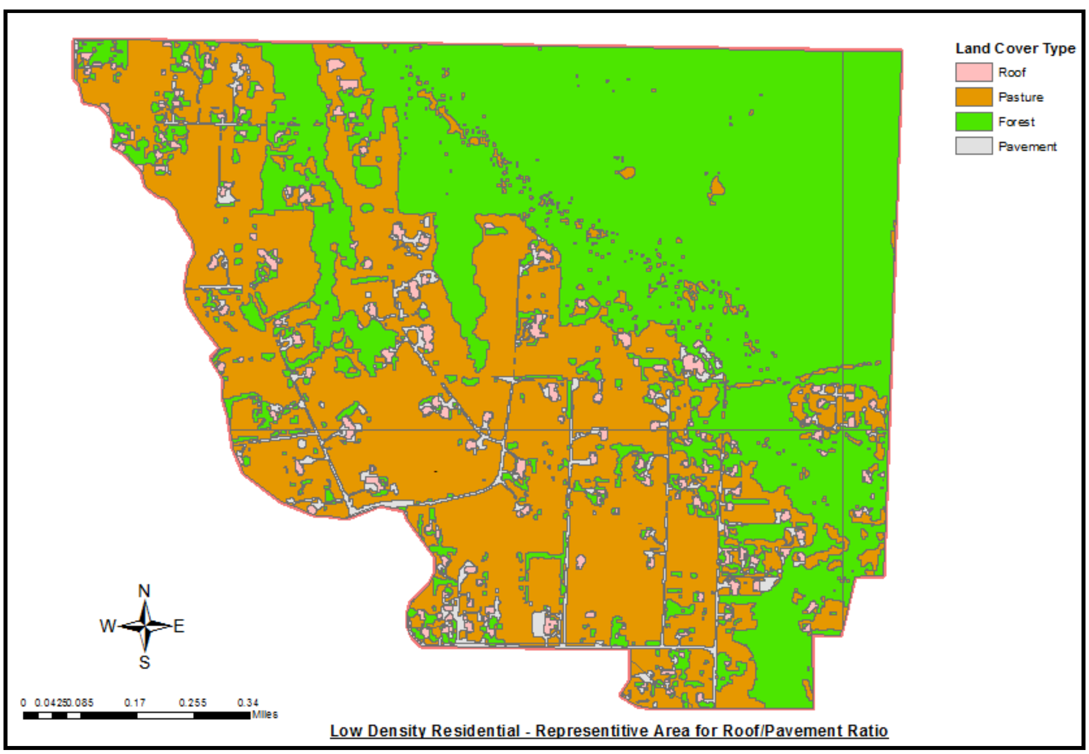

Figure-3. Low Density Residential Land Use- Representative Area

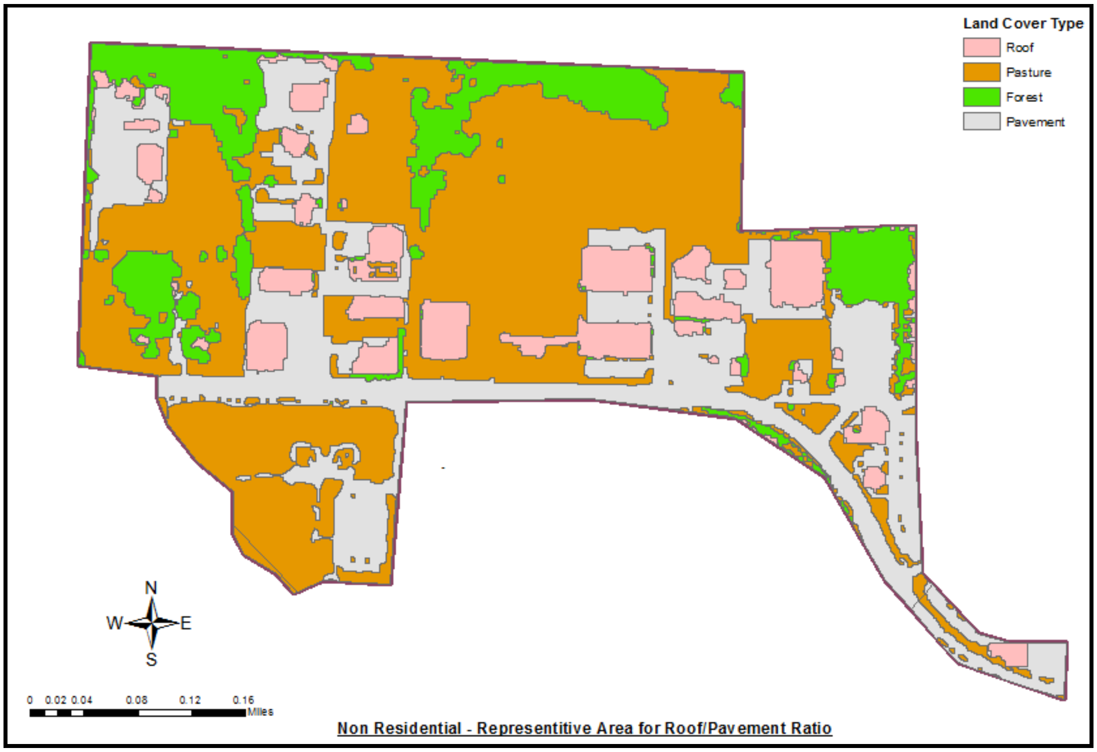

Figure-4. Non Residential Land Use- Representative Area

Future Land Cover

The future conditions land use assumptions were based on the County's comprehensive growth management plan for the area outside of urban growth boundary. The future land use assumptions were based on Predictive Land Use Model for Sewers (PLUMS) developed by Clark Regional Wastewater District (CRWWD) for the area inside the urban growth boundary. A list of HSPF sub-basins with a breakdown based on their location inside or outside of UGA boundaries is presented in Table 2.

Table 2: HSPF Sub-basins

Within UGA Boundary	Outside of UGA Boundary
WC_9	GL
WC_9A	WC_1
WC_8	WC_1A
WC_75	WC_2
WC_7D	WC_3
WC_7C	WC_3A
WC_7B	WC_4
WC_7A	PC_1
WC_7	PC_1A
WC_6B	PC_1B
WC_6A	PC_2
WC_6	PC_2A
WC_5A	
WC_5	
WC_4A	

GIS information for zoning from Clark County's comprehensive plan (2016) was applied for the sub-basins located outside of UGA, intending to represent full buildout of the basins. In general, it is assumed that the parcels will be developed to the maximum extent allowed by the proposed zoning. Exception was the 100-foot priority habitat buffer located on both sides of Whipple Creek, Packard Creek, and major tributaries. These areas will be modeled as forest, consistent with the County's Critical Areas Ordinance. All the areas encompassed between the buffers on either side of the stream will be modeled as forest. As the future land cover calculation was solely based on the book values from the comprehensive plan, the resulting impervious areas for some of the sub-basins were less than in the existing condition. In such instances, the impervious area from the existing condition was matched for the future condition. That means it was assumed that the already developed area will continue to hold in the future condition.

For the sub-basins located inside the UGA, PLUMS model was used to identify the future land use types. PLUMS model was created by CRWWD as a planning tool to represent how areas inside the urban growth boundary are expected to develop and it more accurately represents the lot by lot potential to develop in the area. Roof to Pavement ratio from Table 1 above was used to break down the total impervious areas within each sub-basin into roofs and pavements. Break down of land cover types for various land use/zoning categories for future conditions are shown in Table 3.

Table 3: Future Land Use and HSPF Land Cover Percentages					
Description	EIA %	Forest %	Pasture %	Lawn %	Wetlands
Urban Low Density Res	23			77	
Urban Medium Density Res	23			77	
Community Commercial	85			15	
General Commercial	85			15	
Light Industrial	85			15	
Mixed Use	48			52	
Public Facility	23			77	
Parks/Open Space	0	25	25	50	
Urban Reserve	23			77	
Rural 5	6		75	19	
Agriculture			100		
Agri-Wildlife		50	50		
Water					100
Employment Center	85			15	
Rural 10	4		77	19	
Rural 20	4		77	19	
Forest		100			

The resulting land cover types within each sub-basin for both existing and future land use conditions are shown in Appendix A. Sub-basins located within the Urban Growth Boundary generally show an increase in impervious area along with a decrease in forested or pasture areas. In more rural areas, the existing land use is largely unchanged in the future land use scenario. Table 4 shows the change in impervious area for several key sub-basins.

Table 4: Land Use Change in Key Sub-basins					
Sub-basin	Location	Total Sub-basin Area (acres)	Exiting Impervious Percentage	Future Impervious Percentage	Change
WC_8	Major sub-basin east of I-5	459.83	15%	26%	11%
WC_5A	Southern sub-basin south of 149th	561.43	27%	28%	1%
WC_4A	Central Sub-basin near Whipple Creek Park	522.31	3%	9%	6%
PC_2	Northern sub-basin of Packard Creek	518.05	4%	5%	1%
WC_2	Main stem sub-basin downstream of 41st	496.78	5%	5%	0%

Appendix A

(Table Summary of Existing and Future Land Cover Data)

Whipple Creek Watershed Existing Land Cover in acres

Sub-basins	Impervious Land (IMPLND 100)				Pervious Land (PERLND)									Water (500)
	Residential		Non-residential		SG3			SG4			SG5			
	Roof	Pavement	Roof	Pavement	Forest (200)	Pasture (210)	Lawn (220)	Forest (260)	Pasture (270)	Lawn (280)	Forest (300)	Pasture (310)	Lawn (320)	
GL	6.78	14.73	-	-	140.74	271.28	32.27	-	-	-	-	-	-	184.85
WC_1	9.02	19.60	-	-	146.62	234.87	95.33	-	-	-	-	-	-	1.78
WC_1A	6.84	14.87	-	-	-	-	-	145.38	190.22	82.40	-	-	-	-
WC_2	7.40	16.10	-	-	127.58	253.21	92.49	-	-	-	-	-	-	-
WC_3	1.61	3.50	-	-	63.38	82.42	17.81	-	-	-	-	-	-	0.44
WC_3A	3.45	7.51	-	-	43.70	140.85	35.14	-	-	-	-	-	-	-
WC_4	2.79	6.05	-	-	167.20	77.35	29.33	-	-	-	-	-	-	-
WC_4A	1.85	14.19	-	-	221.70	-	-	37.19	168.15	79.22	-	-	-	-
WC_5	6.23	13.54	-	-	77.47	35.97	44.48	-	-	-	-	-	-	-
WC_5A	8.30	63.90	2.37	41.70	83.06	60.81	293.01	-	-	-	-	-	5.76	2.53
WC_6	4.27	32.81	-	-	49.31	6.91	42.24	-	-	-	-	-	-	-
WC_6A	1.51	11.58	1.56	18.10	35.80	80.82	52.69	-	-	-	-	-	-	0.50
WC_6B	0.13	1.02	2.02	35.35	-	-	-	19.15	21.28	40.51	-	-	-	-
WC_7	0.35	2.69	1.38	5.71	52.61	50.90	25.97	-	-	-	-	-	-	0.22
WC_7A	0.90	6.94	-	-	24.42	14.93	16.91	-	-	-	-	-	-	-
WC_7B	0.20	1.52	0.84	14.67	12.17	18.93	18.53	-	-	-	-	-	-	-
WC_7C	3.44	26.49	-	-	-	-	-	28.13	9.19	74.21	-	-	-	-
WC_7D	4.13	31.73	-	-	-	-	-	23.44	3.09	90.50	-	-	-	1.30
WC_75	2.97	22.87	0.35	6.07	-	-	-	14.31	35.22	57.27	-	-	-	-
WC_8	7.74	59.56	-	-	-	-	-	179.85	68.29	144.39	-	-	-	-
WC_9	2.27	17.43	0.84	14.66	-	-	-	99.05	107.10	77.69	-	-	-	-
WC_9A	1.27	9.90	2.4	42.30	-	-	-	44.34	47.41	76.89	-	-	-	-
PC_1	2.81	6.12	-	-	-	-	-	109.20	84.36	17.27	-	-	-	-
PC_1A	2.16	4.71	-	-	-	-	-	74.26	92.84	35.88	-	-	-	-
PC_1B	2.20	4.78	-	-	-	-	-	63.73	79.12	27.53	-	-	-	-
PC_2	6.70	14.58	-	-	-	-	-	196.59	212.73	87.46	-	-	-	-
PC_2A	4.72	10.26	-	-	-	-	-	116.76	191.94	68.60	-	-	-	-

Whipple Creek Watershed Future (Build-out) Land Cover in acres

Sub-basins	Impervious Land (IMPLND 100)				Pervious Land (PERLND)									Water (500)
	Residential		Non-residential		SG3			SG4			SG5			
	Roof	Pavement	Roof	Pavement	Forest (200)	Pasture (210)	Lawn (220)	Forest (260)	Pasture (270)	Lawn (280)	Forest (300)	Pasture (310)	Lawn (320)	
GL	6.78	14.73	-	-	35.60	359.11	49.58	-	-	-	-	-	-	184.85
WC_1	9.02	19.60	-	-	135.20	248.07	95.33	-	-	-	-	-	-	-
WC_1A	6.84	14.87	-	-	-	-	-	137.30	198.30	82.40	-	-	-	-
WC_2	7.40	16.10	-	-	109.10	271.69	92.49	-	-	-	-	-	-	-
WC_3	1.61	3.50	-	-	63.38	82.86	17.81	-	-	-	-	-	-	-
WC_3A	3.45	7.51	-	-	41.40	143.15	35.14	-	-	-	-	-	-	-
WC_4	2.86	6.23	-	-	167.20	77.10	29.33	-	-	-	-	-	-	-
WC_4A	3.39	23.01	1.07	18.80	221.70	-	-	10.28	87.47	156.58	-	-	-	-
WC_5	6.23	13.54	-	-	60.90	32.09	64.93	-	-	-	-	-	-	-
WC_5A	12.46	95.84	2.68	47.05	66.20	8.06	323.39	-	-	-	-	-	5.76	-
WC_6	4.27	32.81	-	-	36.00	6.73	55.73	-	-	-	-	-	-	-
WC_6A	2.55	19.60	3.46	60.66	31.86	1.77	82.66	-	-	-	-	-	-	-
WC_6B	0.13	1.02	2.02	35.35	-	-	-	19.15	1.59	60.20	-	-	-	-
WC_7	0.55	4.26	3.52	62.32	41.20	-	27.98	-	-	-	-	-	-	-
WC_7A	1.45	11.13	0.43	7.58	14.83	-	28.68	-	-	-	-	-	-	-
WC_7B	0.48	3.66	1.93	34.09	6.50	-	20.20	-	-	-	-	-	-	-
WC_7C	3.82	29.36	-	-	-	-	-	8.07	1.67	98.54	-	-	-	-
WC_7D	4.13	31.73	-	-	-	-	-	15.13	3.30	99.90	-	-	-	-
WC_75	2.97	22.87	1.06	37.74	-	-	-	14.31	1.70	58.41	-	-	-	-
WC_8	13.22	101.68	0.19	3.37	-	-	-	138.85	15.17	187.35	-	-	-	-
WC_9	3.22	24.73	25.18	142.72	-	-	-	28.63	-	94.56	-	-	-	-
WC_9A	2.20	16.93	5.82	102.14	-	-	-	15.32	-	82.10	-	-	-	-
PC_1	2.81	6.12	-	-	-	-	-	109.20	84.33	17.30	-	-	-	-
PC_1A	2.92	6.34	-	-	-	-	-	55.50	109.21	35.88	-	-	-	-
PC_1B	2.79	6.08	-	-	-	-	-	29.50	110.90	28.09	-	-	-	-
PC_2	7.63	16.58	-	-	-	-	-	114.50	291.89	87.46	-	-	-	-
PC_2A	5.26	25.14	0.19	3.36	-	-	-	96.70	147.64	113.99	-	-	-	-

Appendix K

Whipple Creek Watershed-Scale Stormwater Plan Report

Using WWHM to Model Strategies for Full Build-Out Scenario Inside Whipple Creek UGA

Prepared by

Clark County Department of Public Works

Clean Water Division

and

Otak, Inc.

August 2017

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Introduction

Clark County is conducting a watershed scale study of Whipple Creek watershed as mandated under NPDES permit requirements. The project includes development of an HSPF model to represent the hydrologic and stream flow conditions of the watershed under both existing and future land use conditions. The permit also requires identification of stormwater management strategies that can result in hydrologic and water quality conditions to fully support the future build-out conditions. The Western Washington Hydrology Model (WWHM) has been used to model the conditions represented by the application of some of the BMPs identified in these strategies. The hydraulic function tables (FTABLEs) generated by WWHM are used in the HSPF model to reflect these strategic scenarios. The entire watershed is divided into 27 subbasins based on the topography and or hydrologic control points. The subbasin boundaries are shown in Figure 1. The general procedures used to run the model and all the assumptions made are presented in the remainder of this appendix.

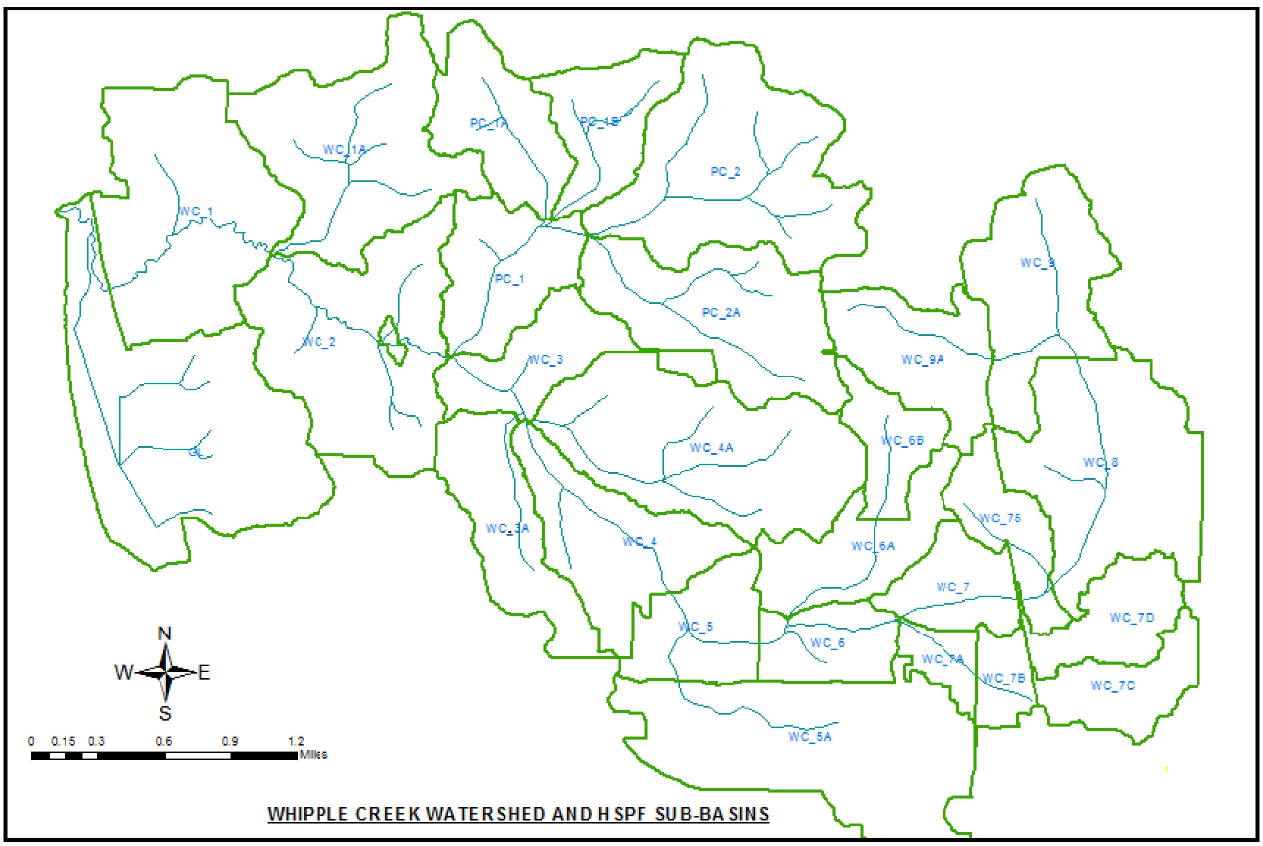


Figure-1. Whipple Creek Watershed HSPF Sub-basins.

Future Development and Minimum Requirements (MR #5, #6, and #7)

There are 27 subbasins that are modeled for future build-out scenario. These 27 subbasins are located in the area where the predominant soil types are either category SG3 or SG4. Table 1 shows the list of these subbasins identified with their predominant soil type. The subbasins with SG3 soil type are considered suitable for low impact development (LID) BMPs that infiltrate while the subbasins with SG4 soil type are considered infeasible for infiltrating LID BMPs. Based on these considerations, applicability of the minimum requirements for modeling purpose has been assumed as follows:

Subbasins with predominantly SG3 soil type trigger:

- LID performance standard (MR#5)
- Water quality standard (MR#6)
- Stream protection standard (flow duration, MR#7)

Sub-basins with predominantly SG4 soil type trigger:

- Water quality standard (MR#6)
- Stream protection standard (flow duration, MR#7)

Table 1: Sub-basins and Soil Types

SG3 Soil Type	SG4 Soil Type
WC_7B	WC_9
WC_7A	WC_9A
WC_7	WC_8
WC_6A	WC_75
WC_6	WC_7D
WC_5A	WC_7C
WC_5	WC_6B
GL	WC_4A
WC_1	WC_1A
WC_2	PC_1
WC_3	PC_1A
WC_3A	PC_1B
WC_4	PC_2
	PC_2A

It is assumed that all the acreages to be developed in the future are subject to both MR#6 and MR#7. Additionally, all the acreages to be developed within the SG3 soil are assumed to be subject to MR#5.

The future development acreages within each subbasin have been calculated as the difference between the existing and future (build-out) land cover data.

WWHM Model Set up and Assumptions

The WWHM2012 bioretention element has been used to represent LID BMPs in each sub-basin in the HSPF model; the WWHM2012 trapezoidal pond element represents the sub-basins' detention ponds. Even for the subbasins with SG4 soil where LIDs are considered infeasible, the bioretention element has been used to achieve the water quality standard (MR #6). Each individual subbasin has been considered a single large drainage basin for the modeling purpose. When future developments occur within these subbasins, there will be multiple bioretention facilities and detention ponds installed throughout each individual sub-basin. However, for modeling purposes, multiple bioretention facilities are represented by a single large bioretention facility inside an individual subbasin. Similarly, a large single detention pond is assumed to represent multiple smaller ponds within the same subbasin.

There is very limited documentation of soil infiltration tests available for the area. The few available tests have revealed infiltration rates ranging from 0 to 2 inches per hour depending on the location and depth of the test. For the modeling of subbasins with SG4 soils, the native soil infiltration rate was assumed to be 0 (zero) inches per hour (in/hr). For the modeling of subbasins with SG3 soils, a long-term soil infiltration rate of 0.50 in/hr has been used. This is calculated based on an assumption of 2 in/hr as the initial infiltration rate, and a correction factor of 0.25 (2 * 0.25 = 0.50).

The general approach used to run each WWHM sub-basin model was as follows:

<u>Subbasins with SG4 soil:</u>

- Runoff is routed into a bioretention facility that is sized using the WWHM2012 'Size Water Quality' feature. To achieve the water quality standard (MR #6), more than 91 percent of the inflow must pass through the bioretention soil layers and discharge through the underdrain.
- Overflow from the bioretention facility riser and flow through the underdrain are routed to a downstream trapezoidal pond. The WWHM0212 'Auto Pond' feature is used to size the pond and to analyze and verify if the pond passes the flow duration standard (MR #7).

<u>Subbasins with SG3 soil:</u>

- The WWHM2012 Predeveloped scenario is run to find the 2-year peak flow.
- 8% and 50% of 2-yr flow are calculated and the Point of Compliance (POC) duration criteria are changed with these values to represent the LID duration criteria.
- Runoff is passed through the bioretention facility and the facility is sized for the stream protection standard (MR #7) using the WWHM2012 'Size Facility' feature. In this case, the stream protection standard is actually the LID performance standard as the duration criteria have been changed to represent the LID duration criteria. The sized bioretention facility must

also be able to filter more than 91 percent of inflow to achieve the water quality standard (MR #6). This includes the portion of runoff that is infiltrated to the native soil and the flow that discharges downstream to the pond via the underdrain.

- The duration criteria are then changed back to the default values (50% of the 2-year peak flow to the 10-year peak flow) based on the predeveloped flow frequency.
- Overflow from the bioretention facility and flow through the underdrain are routed to a downstream trapezoidal pond. The WWHM2012 'Auto Pond' feature is used to size the pond and to analyze and verify if the pond passes the flow duration standard (MR #7).

The WWHM model set-ups for all the subbasins are shown in the following schematics:

<u>Used acronyms/abbreviations</u>:

Res: Residential

NR: Non-residential

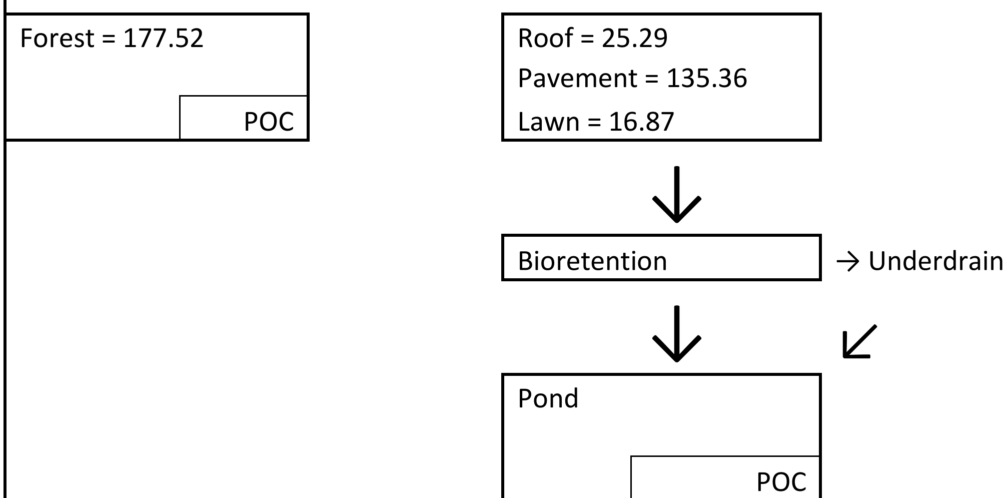
POC: Point of Compliance

<u>(All the numbers shown represent areas in acres)</u>

WC_9

	Res Roof	Res Pavement	NR Roof	NR Pavement	SG4*			
					Forest	Pasture	Lawn	Water
Future	3.22	24.73	25.18	142.72	28.63	0	94.56	0
Existing	2.27	17.43	0.84	14.66	99.05	107.1	77.69	0
Net Increase	0.95	7.3	24.34	128.06	0	0	16.87	0

Pre-developed **Mitigated**



*No native infiltration.

WC_9A

					SG4*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	2.2	16.93	5.82	102.14	15.32	0	82.1	0
Existing	1.27	9.9	2.4	42.3	44.34	47.41	76.89	0
Net Increase	0.93	7.03	3.42	59.84	0	0	5.21	0

Pre-developed

Forest = 76.43

POC

Mitigated

Roof = 4.35

Pavement = 66.87

Lawn = 5.21

↓

Bioretention → Underdrain

↓ ↙

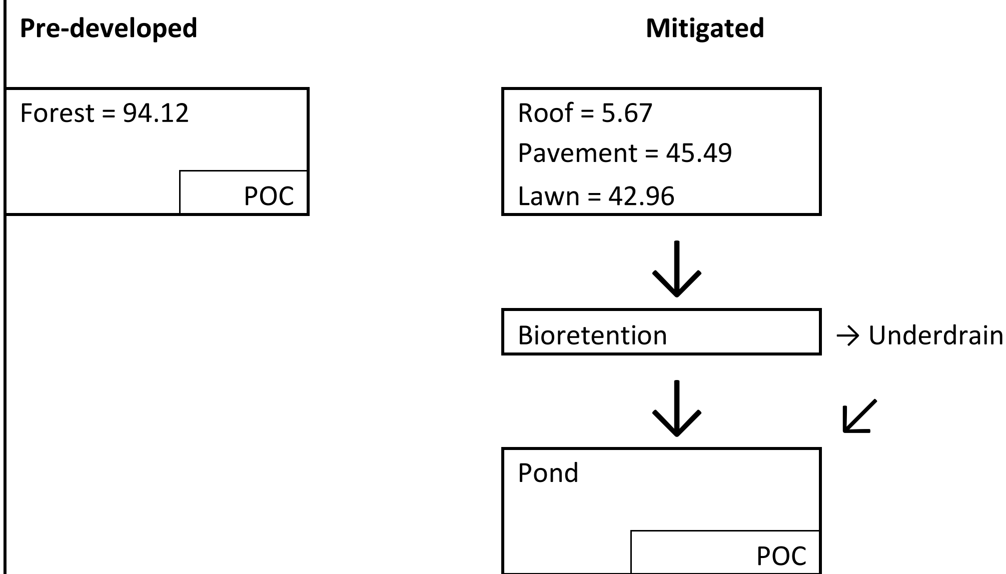
Pond

POC

*No native infiltration.

WC_8

					SG4*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	13.22	101.68	0.19	3.37	138.85	15.17	187.35	0
Existing	7.74	59.56	0	0	179.85	68.29	144.39	0
Net Increase	5.48	42.12	0.19	3.37	0	0	42.96	0



*No native infiltration.

WC_75

					SG4*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	2.97	22.87	1.06	37.74	14.31	1.7	58.41	0
Existing	2.97	22.87	0.35	6.07	14.31	35.22	57.27	0
Net Increase	0	0	0.71	31.67	0	0	1.14	0

Pre-developed

Forest = 33.52

POC

Mitigated

Roof = 0.71
Pavement = 31.67
Lawn = 1.14

↓

Bioretention → Underdrain

↓ ↙

Pond

POC

*No native infiltration.

WC_7C

	Res Roof	Res Pavement	NR Roof	NR Pavement	SG4* Forest	SG4* Pasture	SG4* Lawn	Water
Future	3.82	29.36	0	0	8.07	1.67	98.54	0
Existing	3.44	26.49	0	0	28.13	9.19	74.21	0
Net Increase	0.38	2.87	0	0	0	0	24.33	0

Pre-developed

Forest = 27.58

POC

Mitigated

Roof = 0.38
Pavement = 2.87
Lawn = 24.33

↓

Bioretention → Underdrain

↓ ↙

Pond

POC

*No native infiltration.

WC_7B

					SG3*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	0.48	3.66	1.93	34.09	6.5	0	20.2	0
Existing	0.2	1.52	0.84	14.67	12.17	18.93	18.53	0
Net Increase	0.28	2.14	1.09	19.42	0	0	1.67	0

Pre-developed

Forest = 24.60

POC

Mitigated

Roof = 1.37

Pavement = 21.56

Lawn = 1.67

↓

Bioretention

Native infiltration = 2 in/hr

→ Underdrain

↓ ↙

Pond

POC

*native infiltration.

WC_7A

					SG3*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	1.45	11.13	0.43	7.58	14.83	0	28.68	0
Existing	0.9	6.94	0	0	24.42	14.93	16.91	0
Net Increase	0.55	4.19	0.43	7.58	0	0	11.77	0

Pre-developed

Forest = 24.52

POC

Mitigated

Roof = 0.98
Pavement = 11.77
Lawn = 11.77

↓

Bioretention

Native infiltration = 2 in/hr
→ Underdrain

↓ ↙

Pond

POC

*native infiltration.

WC_7

	Res Roof	Res Pavement	NR Roof	NR Pavement	SG3* Forest	SG3* Pasture	SG3* Lawn	Water
Future	0.55	4.26	3.52	62.32	41.2	0	27.98	0
Existing	0.35	2.69	1.38	5.71	52.61	50.9	25.97	0.22
Net Increase	0.2	1.57	2.14	56.61	0	0	2.01	0

Pre-developed

Forest = 62.53

POC

Mitigated

Roof = 2.34

Pavement = 58.18

Lawn = 2.01

↓

Bioretention

Native infiltration = 2 in/hr

→ Underdrain

↓ ↙

Pond

POC

*native infiltration.

WC_6A

					SG3*			
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	2.55	19.6	3.46	60.66	31.86	1.77	82.66	0
Existing	1.51	11.58	1.56	18.1	35.8	80.82	52.69	0.5
Net Increase	1.04	8.02	1.9	42.56	0	0	29.97	0

Pre-developed

Forest = 83.49

POC

Mitigated

Roof = 2.94
Pavement = 50.58
Lawn = 29.97

↓

Bioretention

Native infiltration = 2 in/hr
→ Underdrain

↓ ↙

Pond

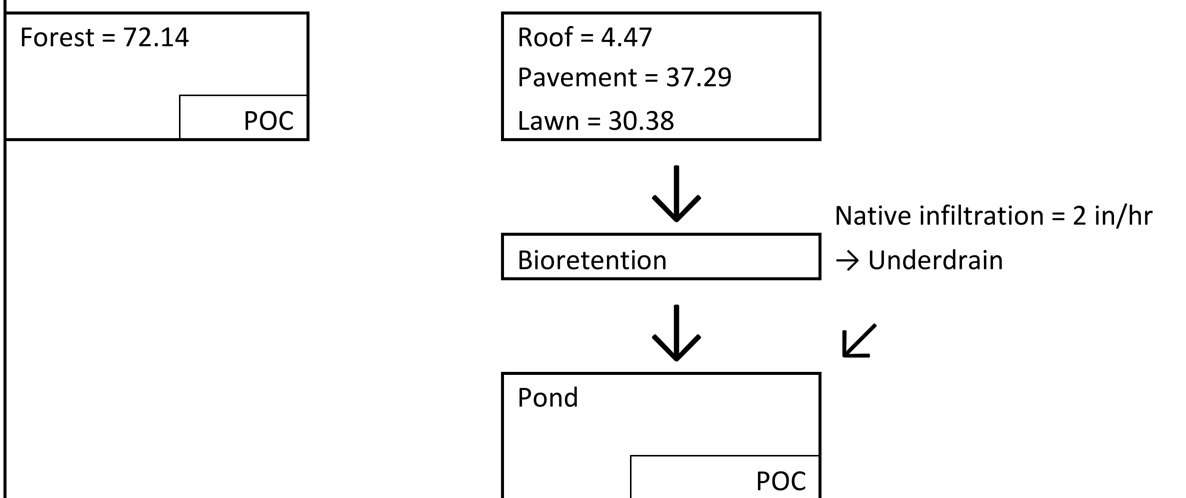
POC

*native infiltration.

WC_5A

					SG3*			**
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	12.46	95.84	2.68	47.05	66.2	8.06	323.39	0
Existing	8.3	63.9	2.37	41.7	83.06	60.81	293.01	2.53
Net Increase	4.16	31.94	0.31	5.35	0	0	30.38	0

Pre-developed **Mitigated**



*native infiltration. **Additional **5.76** SG5 Lawn for both future and existing.

WC_4A

					SG4*			**
	Res Roof	Res Pavement	NR Roof	NR Pavement	Forest	Pasture	Lawn	Water
Future	3.39	23.01	1.07	18.8	10.28	87.47	156.58	0
Existing	1.85	14.19	0	0	37.19	168.15	79.22	0
Net Increase	1.54	8.82	1.07	18.8	0	0	77.36	0

Pre-developed

Forest = 107.59

POC

Mitigated

Roof = 2.61
Pavement = 27.62
Lawn = 77.36

↓

Bioretention → Underdrain

↓ ↙

Pond

POC

*No native infiltration. **Additional **221.70** SG3 Forest for both future and existing.

Appendix L

Whipple Creek Watershed-Scale Stormwater Plan Report

Whipple Creek Channel Restoration Analysis

Prepared by

Clark County Department of Public Works

Clean Water Division

January 2017

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Background and Purpose

Flood plain reconnection using channel spanning log jams and any other needed method are is not simulated directly in the HSPF model for Whipple Creek. Instead, this strategy is modeled as a detention facility located on the flood plain. There may be places where this strategy is most and least effective due to channel gradient, position in the watershed, and flood plan features.

The purpose of this short paper is to organize several thoughts for implementing flood plain detention as a channel restoration and flood plain reconnection strategy. The main consideration is hydrologic modeling to demonstrate future conditions that fully support the beneficial use of salmon spawning, rearing and migration.

Limitations

This cursory analysis is intended to be a beginning step to place flood plain reconnection projects aimed at modeling an historic forest hydrology in Whipple Creek. It does not consider feasibility issues and access issues other than to note areas where county land is present or a private critical area parcel is present in the upper watershed.

Packard Creek was not considered at this point but should be evaluated as hydrologic modification impairing the beneficial use of salmon habitat is considered.

Process/Factors for Siting Flood Plain Detention

Flood Plain Conditions and Potential for Projects

At some point, the flood plain is either too flat or too steep to be an effective detention site.

Below about RM 2.0, the valley flattens to near zero gradient, making such facilities undesirable due to low stream power and no downstream benefit.

Above RM 8 and the recent channel restoration project, the channel has a higher gradient and is confined without much of a flood plain.

One potential site above RM 8 exists immediately above the county channel project. Parcel 182063000 includes this flood plain area and is essentially undevelopable open space with a tax value of nearly $1,000,000.

A site at about RM 7.8 is between I-5 and Union Rd may be good for a project. This property is owned in part by Public Works and two private persons. The larger piece in private ownership is untaxed open space associated with Whipple Creek Meadows. WSDOT ROW is at the lowermost end of this reach.

Between I-5 and RM 6, the river gradient is roughly 0.5 percent. At this gradient, a 2.5 feet of vertical (Milne said the most we could get permitted would be 3 feet) lift above the flood plain would backwater approximately 500 feet. Assuming the reach is fully utilized, there could be a dozen or so structures between RM 6 and I-5.

Between RM 3 and RM 6 the gradient is about 0.3 percent, here a 2.5 foot lift would backwater about 700 feet. This reach is characterized by a channel that is not incised to the point that it is disconnected from the flood plain according to InterFluve's 2006 report. InterFluve also notes that it is likely that a 2-year event would remain in the current channel and that the flood plain was likely created under the historic channel. Such conditions make this reach ideal for log jam detention where the channel is not incised.

Below RM 6, to about RM 4, the flood plain is fully to partly forested, perhaps limiting the ability to create frequent flood events that might harm forest by flooding tree roots.

At about RM 5, Whipple Creek enters Whipple Creek Park where the channel is incised and separated from the flood plain in places where I have observed it. It is not apparent that InterFluve surveyed this reach from the descriptions in the report because they did not note the incision Clark County has observed in the park. The park property is an obvious place to scope channel and flood plain restoration projects.

The stream exits the park a little bit above RM 4 which is at the mouth of a fairly large tributary on the left bank. Field observations from this area have identified both natural channel and deeply incised banks, my recall is that the incised banks tended to be on the outside of bends.

River Mile 3.2 to 2.4 is described by InterFluve as having essentially natural channel migration, wood debris and a gravel substrate derived from the Troutdale gravel. Presumably, flood plain reconnection or detention would not be appropriate here where natural channel migration dominates.

Below RM 2.4, to RM 2.0, InterFluve notes a dramatic change to an incised channel in mud bank through pasture. Here, there would be little value in flood plain detention but riparian restoration would provide shade and, in the long term, wood debris to create a more natural channel configuration. Below RM 2.0 the incised channel is visible using the Lidar topography.

Columbia River Backwater

Below approximately 15 to 20 feet altitude, the flood plain valley is below the typical Columbia flood elevation and subject to spring flooding. There is no point in placing detention in this area; it should be flow exempted under the Clark County Stormwater Manual because detaining stormwater runoff would have no effect on hydrology here.

W:\PROJECT\012159 Watershed Plan\Modeling\Strategies development\5.X Flood Plain Detention Thoughts.docx

Appendix M

Whipple Creek Watershed Plan

Whipple Creek Use Attainability Initial Discussion

Prepared by

Clark County Department of Public Works

Clean Water Division

March 2017

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Background

The permit requirement to create a plan that restores designated uses does not consider whether those uses are attainable using AKART. Designated uses for Whipple Creek are specified in Chapter 173-201A using no basin-specific data; instead, the designated uses are generic to the waters of the state where salmon are present. That is salmon spawning, rearing and migration. Along with salmon habitat, the standards call for bacteria levels that allow full contact recreation.

Basically, a designated use can be removed if conditions causing its loss are irreversible. However, irreversible is a relative term. Federal law lays out conditions whereby an unattained designated use is irreversible.

It is apparent that the Whipple Creek designated uses once existed and they are either not being met or are severely degraded due to over 100 years of mechanized reconfiguration of the basin land cover and hydrology. As we develop our plan, we should consider the extent to which our remedies are attempting to reverse the irreversible.

While a use attainability analysis is beyond the scope of this project, adaptive management restoration goals should consider attainability as proposed management actions are prioritized for implementation.

Regulatory Framework

Federal

Under **40 CFR 131.10(g),** federal law allows states to remove a designated use which is not an existing use, as defined in § 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentrations prevent the attainment of the use; or
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or
3. Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or
4. Dams, diversions or other types of *hydrologic modifications* preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses; or
6. Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.

State

The state or Washington (section 173-201A.440 WAC) allows the alteration of a designated use through a use attainability analysis meeting the standards of federal law.

Hydrologic modifications in Whipple Creek

Clark County MS4 as a hydrologic Modification to Waters of the State

By their very nature, stormwater facilities are hydrologic modifications. These include everything from roadside ditches and driveways to regional stormwater facilities that replace natural elements of the watershed hydrology.

Many hydrologic modifications were built before municipal stormwater permits were in effect and therefore were legally built before water quality standards of state or federal law regulating storm sewer construction.

In Whipple Creek Watershed, hydrologic modifications are extensive, altering watershed hydrology since settlement and forest clearing over 100 years ago.

Restoring stream hydrology to that assumed to fully support the designated use of salmon habitat requires that hydrologic modifications created since settlement and before the first NPDES stormwater permits be removed or somehow mitigated to the point where their effect is removed. To do so will cost huge sums of money beyond the realm of reason. These numbers are in the $100,000,000 and up range in a basin where the current total stormwater utility fee is less than $400,000 per year.

Manmade barriers to fish migration exist in Whipple Creek. The most notable is the full barrier created by box culverts under Interstate Freeway 5. As long as the I-5 barrier exists, all use by salmon above I-5 is lost.

Removing hydrologic modifications within the MS4 regulated by the permit is a legitimate requirement for restoring designated uses under an NPDES permit. This includes retrofitting the MS4 to reduce hydrologic modifications.

Fish Barriers

Fish barriers such as the I-5 culvert are not part of the permitted MS4 and eliminate a designated use not possible to mitigate by an action on the MS4.

Physical conditions related to the natural features of the water body

These conditions include lack of a proper stream substrate, which is a gravel substrate to support salmon spawning and healthy macroinvertebrate populations. Ecology's use of relationships between BIBI scores, (which are dependent on gravel substrate sample collection sites) highlights the critical importance of gravel substrate for the beneficial use of salmon spawning, rearing and migration.

Gravel substrate exists naturally in very limited areas of Whipple Creek watershed: main stem below Union Road, lower Packard Creek and Miners Creek near the mouth of Whipple Creek. In these areas, salmon spawning is possible, but not in other areas of Whipple Creek watershed.

Human Caused Pollution and the MS4

The MS4 contains many areas where Clark County cannot fully control pollutant sources. Simple examples are roof and pavement runoff from residences. These areas must be treated by stormwater BMPs in the MS4 to approach the water quality standards for fecal coliform bacteria.

Treatment to remove bacteria from runoff is by one method: infiltration to ground water or deeper interflow. There are no other treatment BMPs available in the SWMMWW.

Many parts of Whipple Creek are underlain by clayey soil and weathered sediment that do not allow infiltration. In these sub-basins, no bacteria treatment is possible using standard BMPs. In these areas, it is not possible to remove bacteria from the MS4 discharges using known technology under AKART.

Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact

Assuming we apply AKART at the state level and MEP at the federal level, it becomes clear that the implementation of a plan to restore the current designated uses would not only place substantial economic and social impact on the residents of Whipple Creek watershed but also on the entire area of the MS4 permit.

Appendix N

Whipple Creek Watershed-Scale Stormwater Plan Report

Clark County Stormwater Regulatory History

Prepared by

Clark County Department of Public Works

Clean Water Division

January 2017

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Background

Several regulatory programs have significantly influenced the use of stormwater controls and habitat preservation as Whipple Creek developed. While there are additional plans such as the WRIA plan and salmon recovery plan, the principal regulatory protections in Whipple Creek are stormwater design requirements, the water quality ordinance, and the Growth Management Act zoning and habitat protections.

Stormwater Manual Regulatory Landmarks

Stormwater controls required for development projects have changed considerably over the last 30 years. In Whipple Creek watershed, most of the urban development includes some level of treatment and flow control. The key milestones occurred as Whipple Creek was being developed:

1981 – Clark County adopts a drainage manual that includes the requirement to include a flow control requirement not to exceed the predevelopment 10 year event flow rate.

1990 – Clark County added treatment requirements based on the King County manual.

1994 - 1995 – Adoption of the Ecology 1992 Stormwater Management Manual for Puget Sound as the county manual. Flow control standard was implemented to not exceed the predevelopment rate for 2-year, 10-year and 100-year flows. In 1995, the flow rate was reduced to limiting the 2-year release rate to ½ of the predevelopment 2-year rate. This manual used a smaller treatment design storm than the 2/3 of the two year included in the manual. The county adopted a standard similar to the Portland, Oregon standard of treating 90 percent of the storms rather than 91 percent of all rainfall.

1999 – Clark County adoption the treatment standard of the 1992 Puget Sound Stormwater Management Manual.

2009 – Adoption of the 2005 Stormwater Management Manual for Western Washington. Projects having approved engineering plans before December 28, 2011 were built using the existing land cover as the predevelopment condition for flow control. The manual included LID BMPs for the first time.

December 2011 – Projects approved after December 28, 2011 are required to use the forested condition as the predevelopment land cover.

January 2016 – Clark County adopted its Stormwater Management Manual (2015) containing standards equivalent to the 2012 SWMMWW which included mandatory LID.

Water Quality Ordinance

In 1998, Clark County added a code chapter prohibiting the discharge of pollutants to storm drains, surface water and ground water. This chapter also required businesses to use source control BMPs to prevent pollutant discharges. The chapter was later amended in 2000 to require all stormwater facilities to follow maintenance standards of the county stormwater manual.

Growth Management Act (GMA) Protections

Clark County is a state GMA county along with the other phase I counties. Along with setting the urban growth area boundary separating rural land uses from urban, the GMA required critical habitat areas such as flood plains, wetlands, riparian areas and landslide prone areas be set aside from development or fully mitigated if developed. The critical areas protections put in place during the mid-1990s play a large part in retaining forested riparian areas and wetlands.

Recommendations

As a practical matter, projects built before the mid-1990s have little or no flow control and treatment, projects built between the late 1990s and 2012 are built to the standards of the Puget Sound manual, and projects built after 2012 are built designed to the standards of the 2005 SWMWW.

The plan should consider including a map of the facility catchments with a date of installation in categories:

- Before 1982
- 1983 – 1996
- 1997 to 2012
- after 2012

Appendix O

Whipple Creek Watershed-Scale Stormwater Plan Report

Cost Estimates

Prepared by

Chuck Green, Senior Project Manager, Otak, Inc.

Trista Kobluskie, Stormwater Planner, Otak, Inc.

Jeff Schnabel, Stormwater Infrastructure Manager, Clark County Public Works

Rod Swanson, NPDES Permit Manager, Clark County Public Works

August 2017

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Introduction

Conceptual-level cost estimates were prepared for the Whipple Creek Watershed-scale Stormwater Plan Report.

Costs for stormwater facilities were based on model outputs of hypothetical facilities, which likely would not be feasible as modeled. The cost estimates are therefore used primarily to estimate the relative magnitude of costs for different strategies contemplated by the report.

Capital cost estimates rely on the county's recent historical costs for land, engineering design, construction, and operation & maintenance. Costs are estimated independently for each strategy. Costs for each future scenario would include the costs of each component strategy.

The sum of one-time capital costs for all strategies is $347 million. Operation and maintenance of structural facilities is estimated at $4 million annually at full implementation. All costs are in 2017 dollars.

Cost Estimate Assumptions

Property Acquisition Assumptions

Model output for stormwater facilities – bioretention and detention ponds – included pond surface area. Land needs were estimated for bioretention facilities and detention ponds. Land needs were not estimated for easements relating to riparian restoration.

Land Costs

Land costs were provided by Clark County and were divided into urban land costs within the Vancouver Urban Growth Area and rural land costs outside of it. Based on Clark County Assessor data, urban land cost was assumed to be $2,308,680/acre, and rural land cost was assumed to be $430,000/acre.

Bioretention Land Needs and Costs

Bioretention land needs were estimated to be 1.1 times the pond surface to account for side slopes, curbs/walls, and setbacks. Bioretention was assumed to occur in county-owned rights-of-way and thus land costs were assumed to be zero.

Detention Ponds Land Needs and Costs

Detention pond land needs were estimated to be 1.8 times the pond surface to account for side slopes, grading, buffers, setbacks, access roads, and fencing. These factors were provided by Clark County based on engineering experience and judgement.

Condemnation Costs

Detention pond land costs were assumed to include both the cost of purchasing private property for all ponds and the costs of condemnation. Based on a report by the Center for Transportation Research at The University of Texas at Austin, using a sample of public works projects from around the country, on average 15% of acquired parcels go through condemnation.

Based on the County's real property acquisitions for the NE 10th Avenue road project and research into common legal costs of condemnation, condemnation costs were assumed to increase land costs by 33% and to incur legal costs of $30,000 per condemned parcel.

To estimate the number of parcels needed for detention ponds by sub-basin, the minimum number of parcels was assumed to be the minimum of either two per sub-basin or the total modeled detention pond surface area divided by 0.75 acres per pond. Number of condemned parcels was assumed to be the greater of one parcel per sub-basin or 15% of needed parcels.

Condemnation costs were only calculated based on pond surface area, not the entire amount of property acquired.

Riparian Restoration (Shade Strategy)

Riparian restoration was assumed to be 75 feet on each side of the channel to be shaded. Land was assumed to be privately owned and restored under an easement or to be publicly owned. Costs of easements were rolled up into the county's estimation of capital costs and were not estimated separately.

Channel Restoration

Costs of easement or land acquisition for channel restoration were rolled up into the county's estimation of capital costs and were not estimated separately.

Capital Cost Assumptions

Capital costs were estimated as the one-time costs for engineering design and construction. Capital construction costs were provided by Clark County based on recent projects and engineering judgement.

Bioretention

Capital costs for hypothetical bioretention were estimated at $2,178,000 per acre of modeled pond surface area.

Detention Ponds

Capital costs for hypothetical detention ponds were estimated at $300,000 per acre of modeled pond surface area.

Riparian Restoration (Shade Strategy)

Riparian restoration costs were estimated at $700,000 per mile of stream based on costs of the county's Capital Construction Program. For riparian restoration to add shade, estimates of one-time capital costs included land acquisition (easements), outreach, and a four-year maintenance program for plant establishment.

Channel Restoration

Channel restoration costs were estimated at $3,300,000 per stream mile based on costs of the county's Upper Whipple Creek Restoration project. Estimates of one-time capital costs included land acquisition (easements).

Operating Costs

Ongoing operating costs were estimated for bioretention and detention ponds. Annual operating costs were provided by Clark County based on recent budgets and assumed a facility lifecycle of 30 years.

Annual operating costs for bioretention were estimated at $82,764 per acre. Annual operating costs for detention ponds were estimated at $8,712 per acre.

No ongoing operating costs were estimated for riparian restoration (beyond the initial four-year plan establishment period included as a one-time capital cost) or for channel restoration.

For the financial model, operating costs were assumed to be zero from years one through five and to accrue equally each year thereafter for 25 years.

Revenue Basis Assumptions

This memo briefly summarizes the assumptions and methodology used for estimating the increase in equivalent residential units (ERUs) in the Whipple Creek watershed.

In Clark County, ERUs are the basis for calculating stormwater fees. As Whipple Creek develops in accordance with assumptions in the watershed-scale stormwater plan, ERUs will increase and stormwater fee revenue generated in the watershed will consequently increase over time.

One ERU is 3,500 square feet (SF) of hard surface (roof, driveway, roadway, etc.). To estimate the maximum possible increase in ERUs at full build-out under the current county Comprehensive Plan, the estimated increase in impervious/hard surfaces which was input into the hydrology model for full build-out of the Vancouver UGA in the Whipple Creek watershed was divided by 3,500 SF.

Maximum potential increases in ERUs were used in the financial analysis, in which is Appendix P of the watershed-scale plan.

Cost Estimates

Costs for each strategy are presented for each modeling sub-basins established for the Whipple Creek hydrology model.

Costs of Full Build-out Baseline Model (Future Scenario 1)

Future Scenario 1, the full build-out baseline, is implemented by private developers and has no new costs for the County.

Costs of Urban Structural Retrofits in UGA (Future Scenario 2)

Urban Structural Retrofits were modeled in Future Scenario 2 (FS2) of the plan.

The retrofits resulted in 29 acres of bioretention (at pond surface) and 38 acres of detention pond (at pond surface).

A conceptual-level cost estimate of FS2, below, does not include capital planning to identify and study feasibility of individual projects, nor does it attempt to anticipate a realistic number of facilities that would provide the modeled treatment and hydrology benefits.

Table 1: Conceptual Cost Estimate for Urban Structural Retrofits (FS2)

			Capital Costs ($Millions)				O&M Costs ($Millions)
Sub-basin	**Bioretention Surface (ac)**	**Detention Pond Surface (ac)**	**Bio-retention**	**Detention**	**Land Acquisition**	**Total One-Time Capital Costs**	**Annual**
WC 5	1.43	3.14	$3.12	$0.94	$15.47	$19.53	$0.15
WC 5A	9.7	12.23	$21.13	$3.67	$60.21	$85.01	$0.91
WC 6	2.07	3.86	$4.51	$1.16	$19.01	$24.68	$0.21
WC 6A	2.07	3.4	$4.51	$1.02	$16.75	$22.28	$0.20
WC 6B	1.16	1.53	$2.53	$0.46	$7.55	$10.54	$0.11
WC 7	0.7	1.5	$1.53	$0.45	$7.41	$9.38	$0.07
WC 7A	0.52	1.11	$1.13	$0.33	$5.49	$6.96	$0.05
WC 7B	1.16	1.61	$2.53	$0.48	$7.95	$10.96	$0.11
WC 7C	1.43	1.26	$3.12	$0.38	$6.23	$9.72	$0.13
WC 7D	1.55	1.6	$3.38	$0.48	$7.90	$11.75	$0.14
WC 75	1.16	1.31	$2.53	$0.39	$6.47	$9.39	$0.11
WC 8	2.81	2.35	$6.12	$0.71	$11.59	$18.41	$0.25
WC 9	1.32	1.57	$2.88	$0.47	$7.75	$11.10	$0.12
WC 9A	1.49	2.01	$3.25	$0.60	$9.91	$13.76	$0.14
Total	**29**	**38**	**$62.23**	**$11.54**	**$189.69**	**$263.46**	**$2.70**

Riparian Restoration for Full Shade (Future Scenario 3)

Riparian restoration to achieve full shade was modeled in Future Scenario 3 (FS3). It assumed riparian restoration would span 75 feet on each side of an unshaded stream channel. 3.79 miles of channel were estimated to be eligible for riparian restoration.

A conceptual-level cost estimate did not include capital planning to identify and study feasibility of individual projects. Four years of anticipated maintenance for plant establishment were incorporated into a one-time capital cost.

Table 2: Conceptual Cost Estimate for Riparian Restoration for Full Shade (FS3)

Sub-basin	Stream Length (mi)	Percent Shaded - Existing Conditions	Stream Length with Shade BMP Applied in Scenario 3 (mi)	Total Cost (Millions) (1)
GL	0.773	99.9%	0.000	$0.00
WC 1	1.264	50.0%	0.632	$0.44
WC 1A	0.977	99.9%	0.000	$0.00
WC 2	1.095	50.0%	0.548	$0.38
WC 3	1.045	50.0%	0.523	$0.37
WC 3A	0.786	99.9%	0.000	$0.00
WC 4	1.080	50.0%	0.540	$0.38
WC 4A	2.118	99.9%	0.000	$0.00
WC 5	0.608	50.0%	0.304	$0.21
WC 5A	0.703	99.9%	0.000	$0.00
WC 6	0.733	50.0%	0.367	$0.26
WC 6A	0.752	99.9%	0.000	$0.00
WC 6B	0.100	99.9%	0.000	$0.00
WC 7	0.578	50.0%	0.289	$0.20
WC 7A	0.481	99.9%	0.000	$0.00
WC 7B	0.142	99.9%	0.000	$0.00
WC 7C	0.085	99.9%	0.000	$0.00
WC 7D	0.100	99.9%	0.000	$0.00
WC 75	0.194	99.9%	0.000	$0.00
WC 8	1.167	50.0%	0.584	$0.41
WC 9	0.832	99.9%	0.000	$0.00
WC 9A	0.283	99.9%	0.000	$0.00
PC 1	1.030	99.9%	0.000	$0.00
PC 1A	0.507	99.9%	0.000	$0.00
PC 1B	0.548	99.9%	0.000	$0.00
PC 2	0.208	90.0%	0.000	$0.00
PC 2A	1.266	90.0%	0.000	$0.00
Total			**3.79**	**$2.65**

Costs of Rural Structural Retrofits (Future Scenario 4)

Rural Structural Retrofits were modeled outside of the UGA in Future Scenario 4 (FS4).

Retrofits resulted in 14 acres of bioretention (at pond surface) and 21 acres of detention pond (at pond surface).

A conceptual-level cost estimate, below, did not include capital planning to identify and study feasibility of individual projects, nor did it attempt to anticipate a realistic number of facilities that would provide the modeled treatment and hydrology benefits.

Table 3: Conceptual Cost Estimate for Rural Structural Retrofits (FS4)

			Capital Costs ($Millions)				O&M Costs ($Millions)
Sub-basin	Bioretention Surface Area (ac)	Detention Pond Surface Area (ac)	Bio-retention	Detention	Land Acquisition	Total One-Time Capital Costs	Annual
GL	1.38	2.71	$3.01	$0.81	$2.51	$6.33	$0.14
WC 1	2.07	4.5	$4.51	$1.35	$4.15	$10.01	$0.21
WC 1A	1.06	1.33	$2.31	$0.40	$1.25	$3.96	$0.10
WC 2	2	2.74	$4.36	$0.82	$2.54	$7.72	$0.19
WC 3	0.39	0.85	$0.85	$0.26	$0.81	$1.91	$0.04
WC 3A	0.83	1.48	$1.81	$0.44	$1.39	$3.64	$0.08
WC 4	0.7	1.28	$1.53	$0.38	$1.20	$3.11	$0.07
WC 4A	1.16	1.08	$2.53	$0.32	$1.02	$3.87	$0.11
PC 1	0.29	0.46	$0.63	$0.14	$0.45	$1.22	$0.03
PC 1A	0.52	0.59	$1.13	$0.18	$0.57	$1.88	$0.05
PC 1B	0.39	0.3	$0.85	$0.09	$0.31	$1.24	$0.04
PC 2	1.43	1.32	$3.12	$0.40	$1.24	$4.75	$0.13
PC 2A	1.74	2.07	$3.79	$0.62	$1.93	$6.34	$0.16
Total	**14**	**21**	**$30.41**	**$6.21**	**$19.36**	**$55.98**	**$1.34**

Channel Restoration Program

The Channel Restoration Program could consider channel restoration on up to eight miles of main stem Whipple Creek. Only stream miles on the main stem were considered eligible.

The conceptual-level cost estimate did not include capital planning to identify and study benefits and feasibility of individual projects.

Table 4: Conceptual Cost Estimate for Channel Restoration Program

Sub-basin	Stream Reach No.	Stream Length (mi)	Channel Restoration Stream Length (mi)	Channel Restoration Capital Cost
GL	100	0.773	0.773	$2.55
WC 1	110	1.264	1.264	$4.17
WC 2	120	1.095	1.095	$3.61
WC 3	130	1.045	1.045	$3.45
WC 4	140	1.080	1.080	$3.56
WC 5	150	0.608	0.608	$2.01
WC 6	160	0.733	0.733	$2.42
WC 7	170	0.578	0.578	$1.91
Total			**7.176**	**$23.68**

Appendix P

Whipple Creek Watershed-Scale Stormwater Plan Report

Financial Analysis Technical Memorandum

Prepared by

John Ghilarducci, Principal

Wyatt Zimbleman, Financial Analyst

August 2017

FCS GROUP
Solutions-Oriented Consulting

| Memorandum

To: Tim Kraft, Otak
Trista Kobluskie, Otak

Date: August 18, 2017

From: John Ghilarducci
Wyatt Zimbleman

RE: Whipple Creek Basin Stormwater Funding

INTRODUCTION

This high level financial feasibility analysis incorporates the cost of capital projects and associated O&M defined in the Whipple Creek (Clark County) Basin Stormwater Plan. This analysis considers the current and projected future customer base in the Whipple Creek Basin, and assesses the financial impacts of Plan implementation on those customers.

ASSUMPTIONS

The analysis reflects the assumption that all three future scenarios and the channel restoration projects identified in the Stormwater Plan, totaling $345.77 million in capital costs and $4.04 million in annual O&M costs, will be implemented in the Basin over time.

With input from Otak and County staff, a number of assumptions were made to forecast customer growth, cost inflation, and implementation timelines.

- **General Cost Inflation** is based on average historical values from the Consumer Price Index (CPI) and is applied to O&M costs. This analysis assumes 1.77 percent cost escalation per year, based on the 10-year average increase in CPI.
- **Construction Cost Inflation** is based on average historical values from the Engineering News Records (ENR) Construction Cost Index (CCI) and is applied to capital project costs. This analysis assumes 2.92 percent cost escalation per year, based on the 10-year average increase in CCI.
- **Customer Growth** is based on Basin buildout projections and measured in Equivalent Residential Units (ERUs). This analysis assumes annual growth of 1.53 percent for thirty years (to Basin buildout), with zero growth after year thirty.
- **Baseline ERU and Revenue** numbers are based on county data.
- **O&M Implementation** is assumed to occur over a thirty year period, with no additional O&M assumed for the first five years of the analysis. Each subsequent year, O&M costs increase by 1/25th of the proposed annual O&M cost (plus general cost inflation) until reaching full implementation in year thirty of the plan, assumed to be 2047.
- **Capital Implementation** is assumed to occur over a thirty year period on a straight-line basis: each year, 1/30th of the proposed total capital cost is implemented (plus construction cost inflation).

Firm Headquarters
Redmond Town Center
7525 166th Ave NE, Ste D-215
Redmond, Washington 98052

Locations
Washington | 425.867.1802
Oregon | 503.841.6543

RESULTS

Using current reported revenue for the Basin and assumed customer growth, we project total rate revenue of $534,844 in year one of implementation, assumed to be 2018. With the addition of planned capital projects, the revenue requirement would increase to $12,397,435. Results are summarized in the following table:

Table 1. Total Cost Summary

	2018	2019	2020	2021	2022	2027	2037	2047
Base Revenue	$534,844	$543,035	$551,352	$559,797	$568,370	$613,249	$713,916	$831,109
Additional O&M Cost	0	0	0	0	0	962,962	3,442,929	6,838,717
Additional Capital Cost	11,862,591	12,209,400	12,566,348	12,933,731	13,311,856	15,374,903	20,509,732	27,359,464
Adjusted Revenue	12,397,435	12,752,435	13,117,700	13,493,528	13,880,226	16,951,114	24,666,578	35,029,289
Percentage Increase	2218%	2248%	2279%	2310%	2342%	2664%	3355%	4115%

Using the current ERU count and reported revenue for the Basin, we project an annual bill per ERU of $49.83 (estimated) in year one of implementation, assumed to be 2018. With the addition of planned capital projects, the annual rate would increase to $1,155.04. Rate results are summarized in the following table:

Table 2. Total Annual Bill Impact per ERU

	2018	2019	2020	2021	2022	2027	2037	2047
Base Bill	$49.83	$50.08	$50.34	$50.59	$50.84	$52.08	$54.39	$56.56
Additional O&M Cost	$0.00	$0.00	$0.00	$0.00	$0.00	$81.77	$262.31	$465.40
Additional Capital Cost	$1,105	$1,126	$1,147	$1,168	$1,190	$1,305	$1,562	$1,861
Adjusted Bill	$1,155	$1,176	$1,197	$1,219	$1,241	$1,439	$1,879	$2,383
Percentage Increase	2218%	2248%	2279%	2310%	2342%	2664%	3355%	4115%

Appendix Q

Whipple Creek Watershed-Scale Stormwater Plan Report

Analysis of Watershed Prioritization for Stormwater Retrofits

Prepared by

Rod Swanson, NPDES Compliance Program Manager

Clark County Department of Public Works

Clean Water Division

January 2017

Background

Recently, the Washington Department of Commerce released a guidance document titled *Building Cities in the Rain – Watershed Prioritization for Stormwater Retrofits*. The aim is to most effectively deploy scarce resources to protect and restore receiving waters for stormwater runoff by prioritizing areas for stormwater retrofitting. The guidance relies heavily on companion guidance by Ecology for elaborate GIS-based watershed characterization and the newer stormwater control transfer program that promotes placing restorative stormwater controls where there is the greatest benefit.

Purpose

This analysis will prioritize Whipple Creek subareas for protection, restoration or development based on hydrologic modeling, water quality modeling and areas of special interest such as salmon bearing stream reaches. The hope is that this analysis will supplement the permit-driven goal of a long-term plan to restore designated uses by identifying areas where restoration should be a near-term priority.

Methodology

This project and analysis is based on the approach presented in the Washington Department of Commerce *Building Cities in the Rain – Watershed Prioritization for Stormwater Retrofits* (September 2016).

The prioritization uses two factors, importance of the subarea resource and level of resource degradation to assign management strategies. Management strategies or approaches are Protection (keep it good), Restoration (make it better) and Development (keeping it from getting worse as development occurs). The procedure allows for more than one management strategy in an area, for example development and restoration in a developing urban area.

Under the NPDES permit stormwater planning requirement to restore designated uses, the goal is clearly restoration and protection, leaving development as an interim watershed state that will someday require restoration.

The calibrated HSPF hydrology model for current conditions in Whipple creek integrates many of the watershed characteristics defined in the GIS-based analysis of the Building Cities in the Rain guidance. The use of a calibrated model removes the need to estimate past hydrology using GIS data.

Hydrologic data can indicate importance by simply noting the discharge rates at base flow conditions. Higher base flow provides better salmon habitat. The flashiness metric TQmean correlates very well with the BIBI score in Clark County streams similar to Whipple Creek. The TQmean therefore provides a good indicator of stream habitat quality based on hydrology.

Along with the calibrated hydrology model, the project uses a calibrated water quality model to estimate historical water quality conditions for five key indicators: temperature, total suspended solids

(TSS), dissolved copper (Cu), dissolved zinc (Zn) and fecal coliform (bacteria). Use of the calibrated water quality model also negates the need for an elaborate GIS model to estimate water quality conditions.

Areas of special concern are considered outside of the modeling analysis. The most significant areas for special concern are those stream reaches that have known or potential salmon presence, and those areas where gravel substrate is present. These factors describing potential salmon habitat will tend to correlate with the hydrologic metrics indicating higher historic importance.

Presenting Results

Results can be presented in absolute terms such as BIBI based on modeled TQmean, or can be ranked and split into groups such as high, medium and low. The figure below is from Ecology watershed guidance and describes the process of binning and displaying results. Once subareas are assigned a metric or a category for protection, restoration or development, these features can be easily mapped using GIS and subbasin or reach maps.

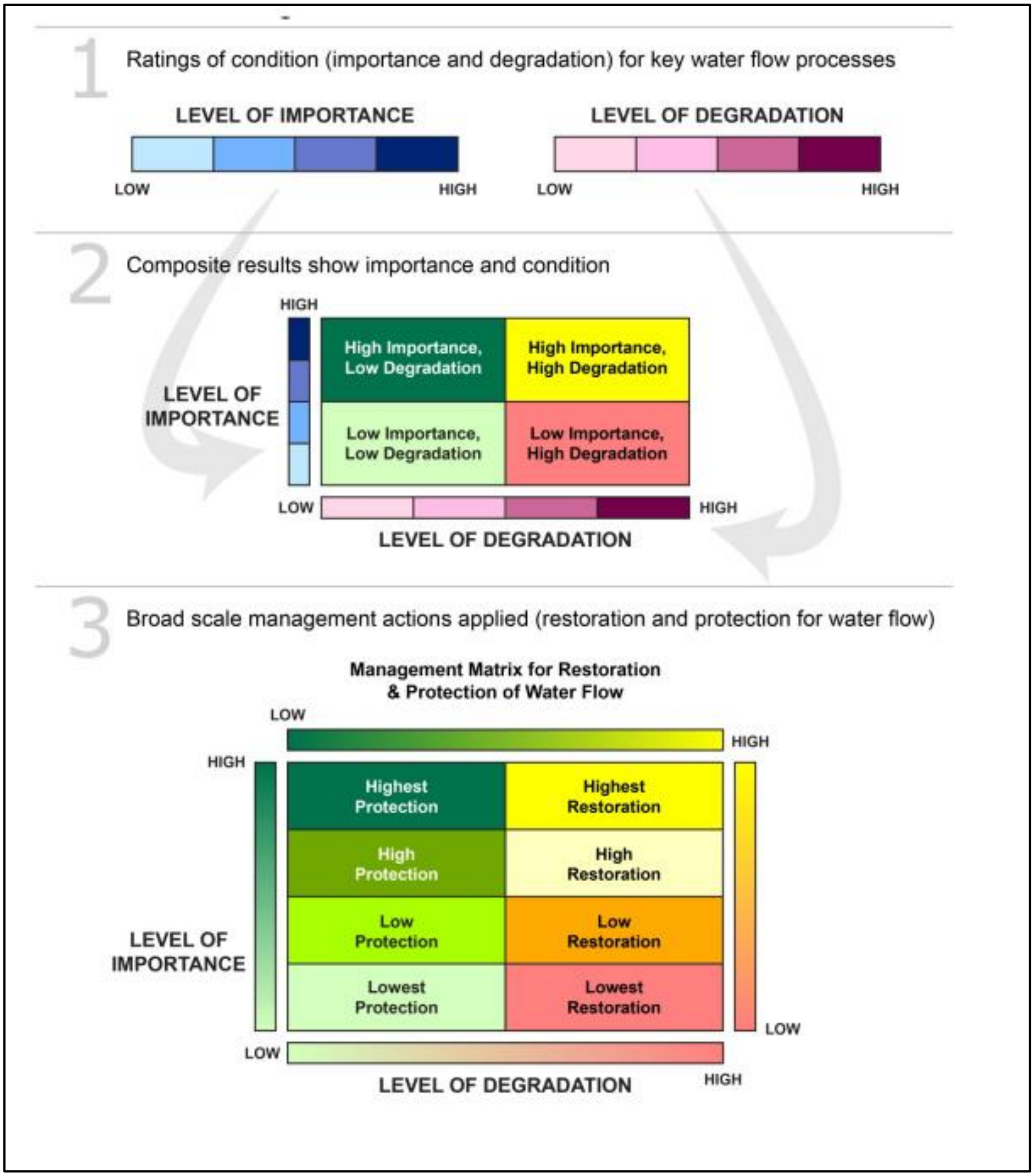

Figure 1: Figure from Ecology Watershed Characterization Guidance

Hydrologic Importance and Degradation by Subarea

The Hydrologic Importance and Degradation of a subarea is determined by how much influence it has on watershed processes. For Whipple Creek, there are two conditions to consider in a simple analysis:

- Hydrologic Importance of a subarea based on historic flows

- Hydrologic Degradation of a subarea based on current hydrology compared to historic.

Hydrologic Importance

Metrics describing **Hydrologic Importance** of historic forested land cover are modeled using the historic predeveloped model which could include metrics such as:

- Base flow (wet and dry season) per unit area to compare to other subareas
- Base flow (wet and dry season) in absolute terms to compare too current conditions
- TQmean to rank importance of subareas historically

Current hydrologic conditions could also be used to establish hydrologic importance considering the reality of watershed conditions.

Hydrologic Degradation (Current Condition)

Metrics describing **Hydrologic Degradation at current conditions** of a subarea are modeled using calibrated HSPF existing conditions model. The integrates a wide array of watershed processes not readily described by a GIS analysis. Hydrologic degradation should be quantified as a deviation from the historical hydrologic condition. For example, the difference in TQmean between historic forest and the current condition would be greatest where streams are most degraded.

Hydrologic Degradation (Comprehensive Plan Condition)

Hydrologic Degradation due to future development of a subarea is modeled using calibrated HSPF model and model inputs that simulate added urbanization built to stormwater standards of the 2015 Clark County Stormwater Manual. The results could be used to show areas where restoration projects are needed to simply maintain the current hydrology.

Water Quality Baseline and Degradation

Water Quality Baseline and Degradation analysis can use the HSPF water quality model to define historic and current water quality, and therefore the amount of degradation from historic conditions. Water quality is somewhat different from hydrology in that there are clear state criteria for water quality based on concentrations of Zn, Cu, and bacteria. Temperature has a more complex standard based on daily maximum temperatures. Total suspended solids do not have criteria in state standards but are a widely used surrogate for pollutants in runoff, as a simple way to measure pollutant impacts due to human activities.

Baseline Historic Water Quality

Modeling water quality for the historic forest condition creates a model-derived baseline defining water quality conditions before settlers arrived. Whether such conditions existed in the area is an open question. The modeled historic water quality may, or may not pass state water quality criteria, but are the best estimate for historic water quality using the calibrated water quality model.

Water Quality Degraded Conditions

The calibrated existing condition model defines current water quality metrics to describe the degree of degradation compared to historic forested condition. Modeled water quality data is used for the comparison instead of actual field data. The difference between current conditions and historic conditions show the level of degradation. The comparison will be for simple metrics such as annual load/unit area or mean concentrations.

Special Areas of Protection and Restoration

Whipple Creek plan scope Task 2 describes areas of special concern. Areas inhabited by salmon and areas contributing flow to salmon-bearing reaches are the highest priority. Areas where gravel stream bed may support salmon spawning are limited to parts of the main channel and Tributary. These areas may be identified as priorities for restoration and/or preservation using specific projects such as channel restoration or flood plain reconnection.

Priority stream reaches could also indicate the greatest need for upstream water quality projects in degraded areas. Whipple Creek is unusual in that the most degraded areas are headwaters along the I-5 corridor and the most important habitat will likely be downstream rural reaches. This means that to protect or restore higher priority reaches, hydrology and water quality restoration may be required up stream in lower priority subareas.

Appendix R

Whipple Creek Watershed-Scale Stormwater Plan Report

Whipple Creek Watershed-Scale Stormwater Planning Scope of Work and Schedule

Prepared by

Clark County Department of Public Works

Clean Water Division

June 2014

Clark County

Whipple Creek Watershed-Scale Stormwater Planning

Scope of Work and Schedule

June 2014

Contents

INTRODUCTION

The Washington State Department of Ecology issued a 2013-2018 Phase I Municipal Stormwater Permit (Permit) on August 1, 2012 that requires Clark County (County) to select a watershed and perform watershed-scale stormwater planning as outlined in section S5.C.5.c. This section states that “the objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support ’existing uses‘ and ‘designated uses’, as those terms are defined in WAC 173-201A-020, throughout the stream system.” The submittal of this scope of work and schedule addresses the permit requirement that “No later than April 1, 2014, the Permittee shall submit a scope of work and schedule to Ecology for the complete watershed planning process.” Of the two watersheds listed in the permit as options for watershed-scale stormwater planning, Clark County has selected Whipple Creek.

WHIPPLE CREEK WATERSHED

Whipple Creek watershed is located in southwest Clark County, draining west from low hills to the Columbia River flood plain (Figure 1). Whipple Creek watershed was once dominated by rural and agricultural land uses. It is currently moderately developed with a mix of rural, urban and urbanizing areas at the northern edge of the Vancouver Urban Growth Area (Figure 1). The 8.8 square mile upper sub-watershed (including Packard Creek) includes approximately 4.4 square miles inside the Vancouver urban growth area, while the 3.3 square-mile lower watershed is entirely outside the urban growth area. Historic clearing and development impacts have degraded stream habitat and caused areas of severe channel instability and erosion. Impacts from these land use changes are consistent with those documented elsewhere around Washington State and the country for channel stability, water quality, and overall ecological function.

Whipple Creek is not specifically listed in WAC 173-201A-602. The designated uses for streams not specifically listed are: salmonid spawning, rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; shellfish harvesting; commerce and navigation; boating; and aesthetic values. Among these, the salmonid uses are the most challenging to maintain and restore, typically requiring habitat conditions equivalent to those found in a predominantly forested watershed.

The 2010 Clark County Stream Health Report rated Whipple Creek as poor for flow, water quality, and biological health. Ecology includes Whipple Creek in its 303(d) Category 5 list (polluted waters requiring a TMDL) for fecal coliform bacteria and Category 2 list (waters of concern) for temperature. In addition to the 303(d) listings, high nutrient concentrations, low Benthic Macroinvertebrate Index of Biological Integrity (BIBI) and Oregon Water Quality Index (OWQI) scores, and elevated turbidity levels are commonly observed (Clark County, 2006). There is currently only limited fish distribution data, but anecdotal information indicates that Whipple Creek may be used by anadromous fish including cutthroat trout, steelhead, and Coho salmon. The most suitable habitat has been identified in the lower Whipple Creek Basin (Clark County, 2006).

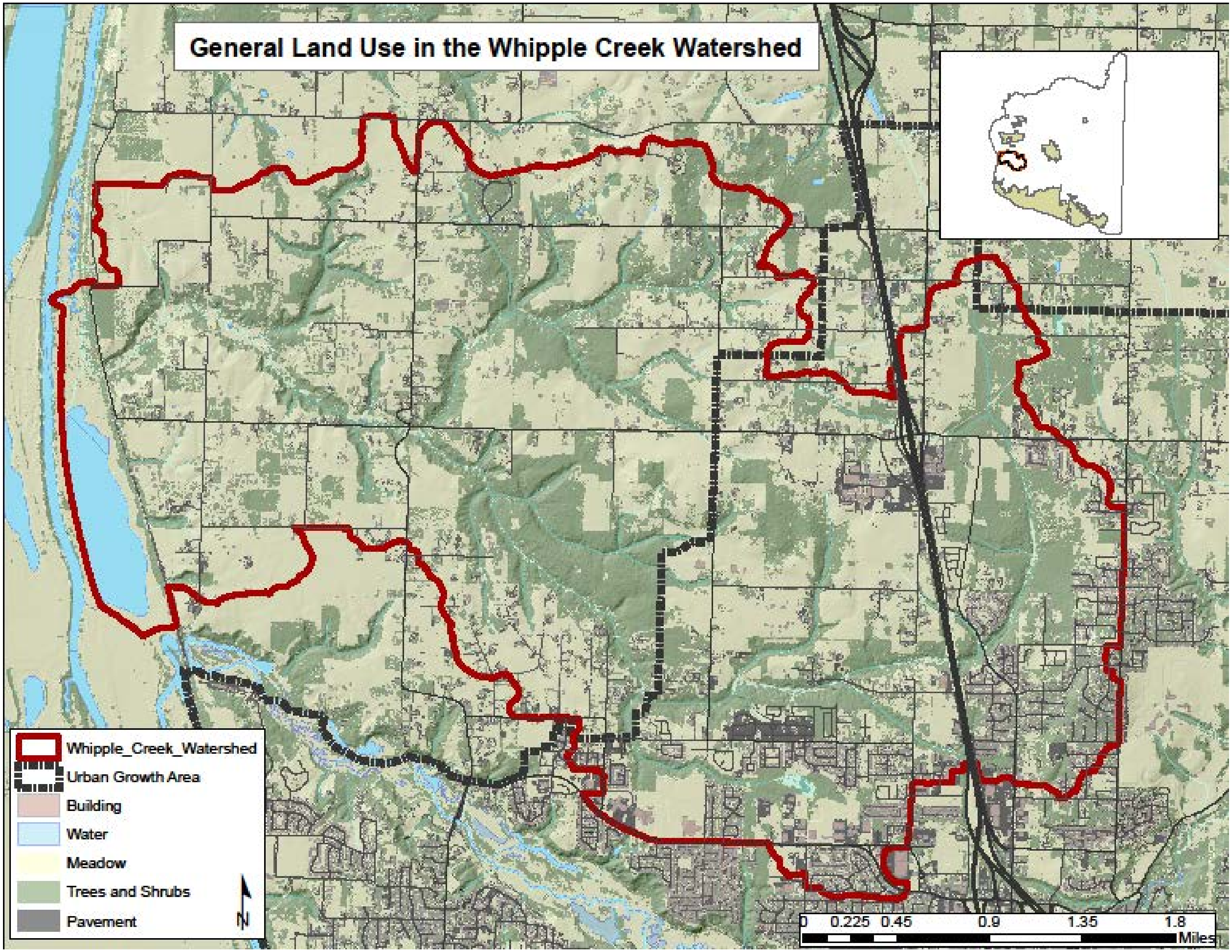

Figure 1 Whipple Creek watershed, general land use

SCOPE OF WORK

Section S5.C.5.c. of the Phase I permit describes required work products and the types of stormwater planning activities required for each. This scope of work describes the proposed watershed-scale stormwater planning for Whipple Creek to be accomplished through the following tasks:

- Task 1. Data Collection and Assessment of Existing Conditions
- Task 2. Environmental Mapping Dataset Development and Assessment
- Task 3. Develop and Calibrate Existing Conditions Runoff and Water Quality Models
- Task 4. Model Baseline Scenarios
- Task 5. Evaluate Watershed-Scale Stormwater Planning Scenarios
- Task 6. Develop Draft and Final Implementation Plan
- Task 7. Public Review and Comment Process
- Task 8. Project Management

TASK 1. Data Collection and Assessment of Existing Conditions

An assessment of existing hydrologic, biological, and water quality conditions will be performed using existing and newly collected environmental monitoring data. Water quality data will be compared, as applicable, to state water quality standards and accepted metrics. The data will also serve as input datasets for hydrologic model and water quality model development and calibration described in Task 3.

The assessment will include a variety of data including water chemistry, continuous temperature, macroinvertebrates base flow and storm event samples, continuous stream flow, and precipitation. Project sampling sites are described in the following sections and shown in Figures 2-4 and Tables 1-3.

The existing data review will include a description of data suitability for use in this project. Clark County will develop a QAPP to guide each data gathering task.

Due to the important role sediment has in the ecological health of Whipple Creek, the County has added total suspended solids (TSS) to the list of parameters to be evaluated as part of this project. Suspended sediment (as TSS) is also the constituent simulated by most common continuous runoff models. Strategies identified to address suspended sediment may also have secondary benefits on nutrient concentrations in Whipple Creek, although nutrients will not be directly investigated as part of this project.

The monitoring and mapping data reviewed and collected in Tasks 1 and 2 will be used to calculate and compile metrics characterizing hydrology and water quality in up to 10 subareas based on land use and hydrologic setting. A narrative description of each subarea will include analysis of map information compiled for Task 2.

Task Outcomes/Deliverables:

- **A report characterizing existing conditions in Whipple Creek**
- **Datasets for calibration of continuous hydrologic and water quality models**

TASK 1.a.i. Water Quality Assessment – Existing Site Data

Long-term Index Site Project (LISP) Site – The only existing long-term monitoring site in the Whipple Creek basin is WPL050, located just downstream of the confluence with Packard Creek at 179th Street, which has been operated since water year 2002. Water quality monitoring at this site allows calculation of the regionally-appropriate Oregon Water Quality Index and comparisons with state water quality standards. Monitoring at WPL050 also includes annual macroinvertebrate sampling, year-round continuous stream flow measurements, and summer continuous temperature measurements. Starting in WY2013, monitoring of dissolved copper and dissolved zinc was added. In addition to the existing parameters being collected at WPL050, continuous recording of water temperature will be performed year-round, and the collection of air temperature data may also be added.

Stormwater Needs Assessment Program Sites (3 total) – During WY 2012, the County performed monitoring to calculate the OWQI and BIBI at WPL010, WPL080, and PCK010 (See Table 1 and Figure 2). These sites will be included in proposed base flow, storm flow and continuous temperature monitoring.

Stormwater Outfall Characterization at LDR010 – From 2010 to 2013, approximately 33 composite stormwater samples, continuous stream flow and continuous precipitation data were collected at this site. These data provide detailed information about stormwater runoff from a small rural headwater basin.

Table 1. Existing Data

Station	Station Location Description	Water Quality	Stormwater Discharge	Macroinvertebrate	Temperature
WPL010	Whipple Cr upstream of Kreiger Rd	WY2012	----	WY2012	----
WPL050	Whipple Cr upstream of NW 179th St	WY2002 - Current	----	WY 2001 Current	WY2002 - Current
WPL080	Whipple Cr Downstream of Union Rd	WY2012	----	WY2012	----
PCK010	Packard Cr downstream of NW 179th St	WY2012	----	WY2012	----
LDR010	Packard Cr west of NW 184th St	----	WY2010 - WY2013	----	----

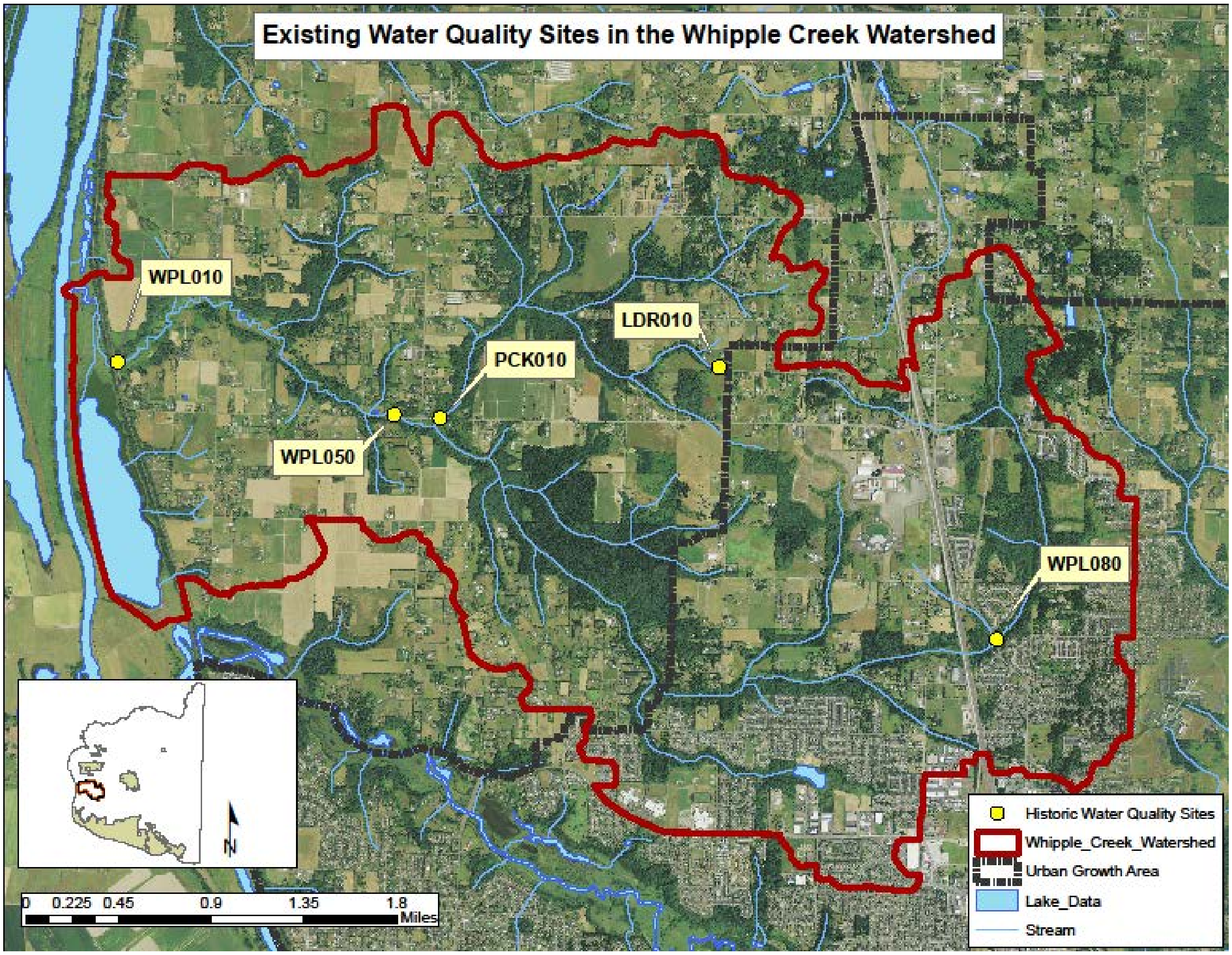

Figure 2. Sites with existing data

TASK 1.a.ii. Water Quality Assessment – Base Flow and Storm Grab Samples

Along with data collected by the County since 2002, additional water quality samples are needed to characterize existing conditions and calibrate water quality models. The Permit requires that sampling be performed "*at locations up-gradient and down-gradient of stream sections influenced by MS4 discharges*". In Whipple Creek watershed, the headwaters of both Packard Creek and Whipple Creek already receive water from the County's MS4, making it impossible to locate monitoring sites upstream of MS4 discharges. Instead, the intent of this permit requirement was interpreted to require a characterization of the gradient of water quality and stream flow within the system. Parameters will include, at a minimum:

- Dissolved copper (Cu)
- Dissolved zinc (Zn)
- Temperature
- Turbidity
- pH
- Fecal coliform
- Total Suspended Solids
- Hardness

Monitoring for base flow and storm events is planned to occur at nine sites (Figure 3). Base flow water quality will be assessed by collecting samples twice a day (morning and afternoon) at each site during each event. A total of six base flow sampling events will be performed; three in the wet season (October – April) and three in the dry season (May – September).

To the extent allowed by hydrologic conditions and logistical constraints, storm sampling will collect three samples per event, distributed to capture a range of conditions during the storm (one sample each on the rising, peak, and falling limb of the hydrograph). The project goal is six storm-flow sampling events with four wet season and two dry season events.

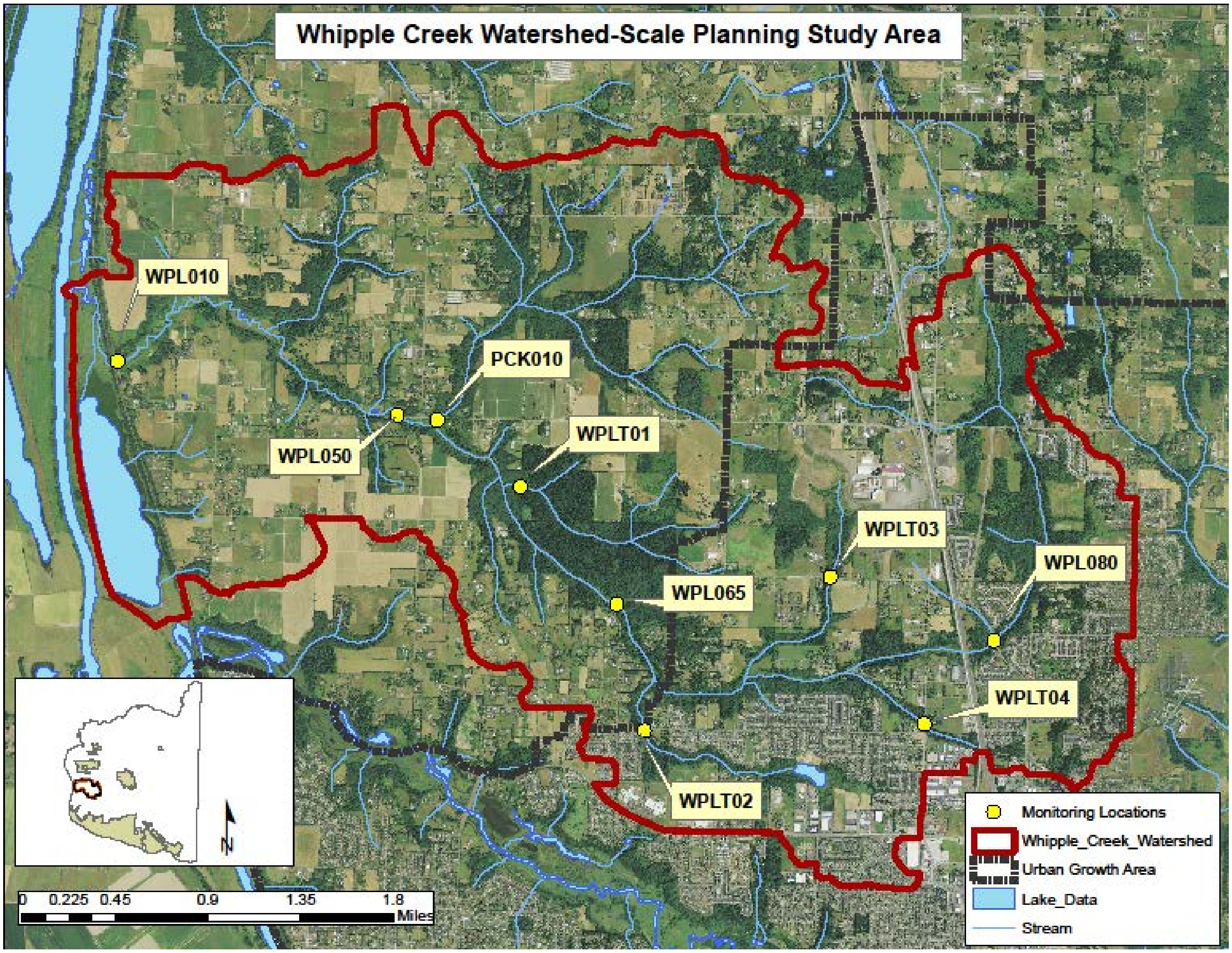

Figure 3. Water quality monitoring locations

Table 2. Project Water Quality and BIBI Monitoring Sites

Station	Description	Water Quality	BIBI	Temperature Gauge
WPL010	Whipple Creek mouth	Yes	No	Yes
WPL050	Whipple Creek at NW 179th St	Yes	Yes	Yes
WPL080	Whipple Creek at Union Rd	Yes	Yes	Yes
PCK010	Packard Creek at mouth	Yes	Yes	yes
WPL065	Whipple Creek at NW 21st Ave.	Yes	No	Yes
WPLT01	Tributary at NW 31st Ave.	Yes	No	Yes
WPLT02	Tributary at NW 149th St.	Yes	No	Yes
WPLT03	Tributary at NW 164th St.	Yes	No	Yes
WPLT04	Tributary at NE 10th Ave.	Yes	No	Yes

TASK 1.b. Hydrologic Conditions Assessment

The County will collect additional stream flow and precipitation data at multiple sites (Table 3, Figure 4). Flow monitoring will continue at WPL050 and two gauges will be added at PCK010 and WPL080. In 2012, Clark County contracted with Northwest Hydraulic Consultants to prepare a preliminary scope of work, which stated flow data is needed at PCK010 for calibration of the continuous runoff model and may be helpful at WPL080. Where the record is sufficient, flow data will also be used to calculate priority hydrologic metrics to compare to BIBI scores using DeGasperi and others (2009). Ongoing continuous rainfall monitoring includes three gauges in use since 2002 and newer gauges since 2010 as shown in Figure 4.

Table 3. Hydrologic sites

Station	Station Location Description	Stream Flow	Precipitation	Data Record
WPL050	Whipple Creek upstream of NW 179th St	Yes	No	5/15/2003 - Current
WPL080	Whipple Creek downstream of Union Rd	Yes	No	New
PCK010	Packard Cr downstream of NW 179th St	Yes	No	New
LDR010	Packard Cr west of NW 184th St	Yes	Yes	12/16/2009 - Current
RDGFLD	Ridgefield Treatment Plant	No	Yes	10/01/2003 - Current
SMCRTP	Salmon Creek Treatment Plant	No	Yes	4/05/2003 - Current
SMN045	Salmon Creek at NE 156th St	No	Yes	10/01/2003 - Current

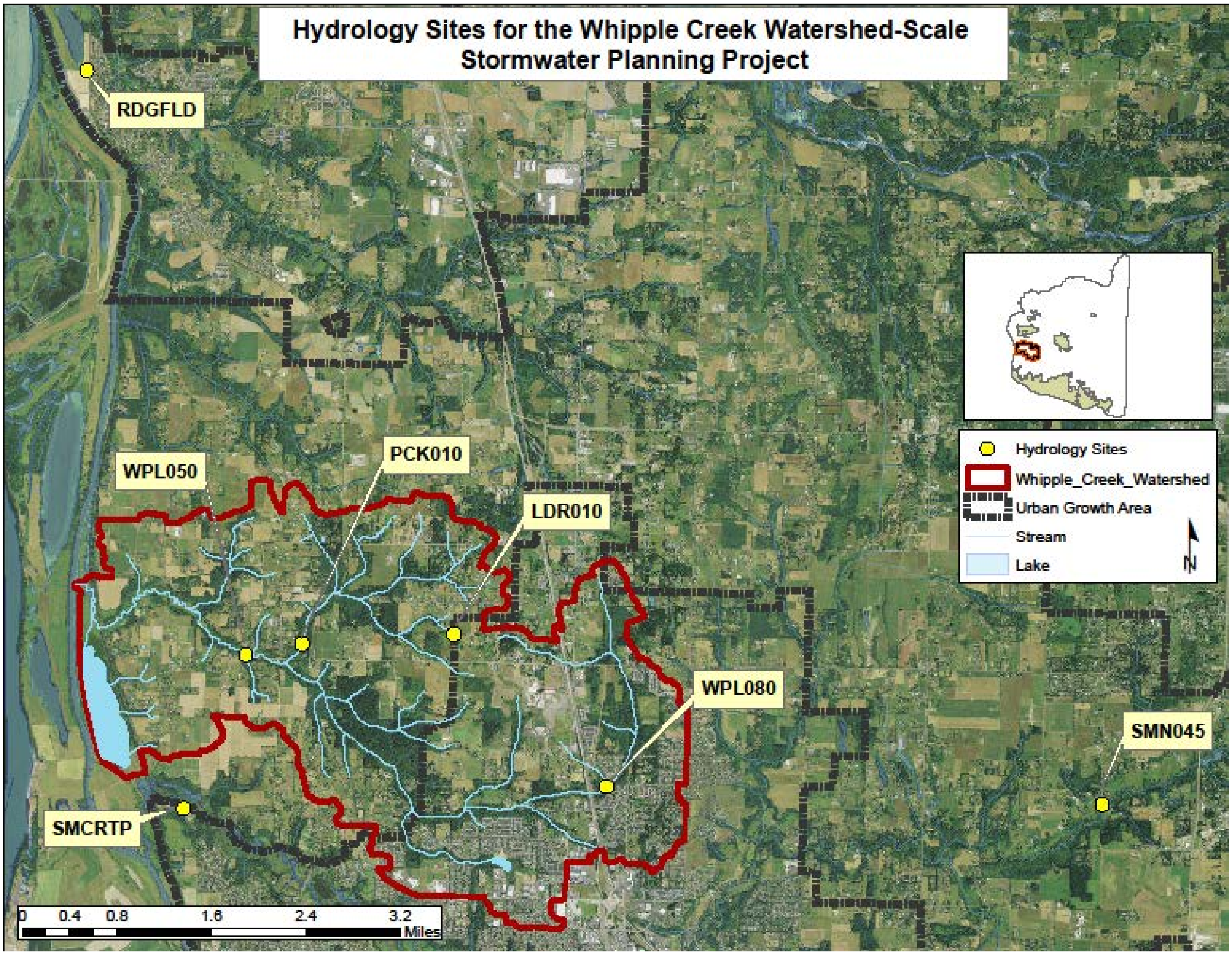

Figure 4. Hydrologic Sites

TASK 1.c. Macroinvertebrate Data

Macroinvertebrate data will be used to characterize current watershed conditions and compare to modeled flow metrics as described in the Permit. Sites are limited to stream reaches where the key assumptions of the BIBI metric are met: sample reaches consist of riffle-habitat with gravel substrate. Whipple Creek geology is predominantly fine-grained Ice Age Cataclysmic Flood deposits with limited amounts of Pliocene Troutdale Formation sand and gravel deposits. There are over 10 years of macroinvertebrate data at WPL050 and one year at WPL010, PCK010 and WPL080. Data will be collected at WPL050, WPL080, and PCK010. Additional sites where stream channel geomorphology and hydrology are appropriate for the BIBI may be sampled to increase the number of data points for comparison to hydrologic metrics.

TASK 1.d. Fish Distribution

Salmon and trout distribution will be described using available data from the Washington Department of Fish and Wildlife.

TASK 2. Environmental Mapping Dataset Development and Assessment

Environmental mapping datasets will be used to characterize the current hydrologic condition of the Whipple Creek basin and also to serve as primary data sources for hydrologic model and water quality model development. The data will also be used to identify areas where special attention should be paid for hydrologic and water quality impacts. The mapping datasets used for runoff modeling and planning may include the following:

- **Existing datasets in the Clark County GIS system (principal ones)**
    - Stream channels using standard Washington DNR data
    - Storm sewer system and treatment/flow control facilities mapped by Clark County
    - Facility and Outfall catchments mapped by Clark County
    - Drainage Catchments at the 50 to 100 acre level mapped by Clark County
    - Surficial geology mapped by the USGS and Clark County
    - Soil units mapped by the USDA NRCS
    - Detailed 2002 land cover mapped by Clark County
    - Orthophotography for various years from 1955 to 2012 owned by Clark County
    - Existing 20-year comprehensive land use plan approved by Clark County
    - Permit-regulated and non-permit regulated storm sewer system mapped by Clark County
    - LiDAR ground elevation and canopy owned by Clark County
    - Field assessment data, HPSF model output, and HEC-RAS model data from mid-2000's studies completed by Clark County
    - Critical Areas mapped by Clark County pursuant to the state Growth Management Act, such as wetlands, geologic hazard areas, and riparian habitat zones using various data sources
    - Buildable and under-utilized lands inventory maintained by Clark County for comprehensive plan development

- **Datasets to be developed under this task**
    - Land cover for model calibration (if needed)
    - Areas within the watershed appropriate for special attention in regard to hydrologic and water quality impacts, as required under S5.C.5.c.ii.(2) (e.g. headwater wetlands and critical aquifer recharge areas)

Task Outcomes/Deliverables:

- **A GIS workspace including existing and developed environmental mapping datasets**
- **Data in suitable format for use in hydrologic and water quality models**

TASK 3. Develop and Calibrate Existing Conditions Runoff and Water Quality Models

Clark County intends to use an HSPF continuous runoff model for this project. Clark County will also review proposed strategies for analysis to select an optimization model (if needed) that best accommodates the key strategies. Clark County possesses an uncalibrated HSPF model for Whipple Creek (Otak, 2007) that has sufficient detail to simulate scenarios required by the permit. The hydrologic model will be calibrated primarily using ten years of flow data collected at WPL050 and county rain gauges. Flow data from the two project sites at PCK010 and WPL080 will be used to further refine model calibration. The existing HSPF model will also be used to model water quality using data described in Task 1.

Existing flow control and treatment BMPs are not represented in the 2007 Whipple Creek hydrologic model. Approximate drainage catchments are defined for most of the facilities. The effective flow control and/or water-quality treatment capacity of these BMPs will be added to the model using available engineering plans. This may include lumping multiple smaller facilities together when modeled hydrologic response is representative of the facilities.

The model will be used to simulate stream flow and water quality for the time when data are available, referred to as the calibration period. The model parameters will be adjusted to calibrate the model to match the observed streamflow and water quality values for the calibration period.

Model performance and calibration accuracy will be described by presenting qualitative and quantitative measures, involving both graphical comparisons and statistical analysis. Calibration accuracy metrics will focus on observed flow at WPL050. Statistics characterizing model accuracy may include root-mean-square error, Pearson correlations, coefficient of determination, relative percent difference, mean errors, and absolute errors. Metrics may include mean daily stream flow volumes, mean annual flow volumes, daily mean discharge rates, and storm peak discharge rates. Calibration will also include graphical comparisons of hydrographs for simulated flows to observed flows, which will be a principal tool at the two project gauges where less than two years of data will be available. Since the frequency of channel modifying flow events is a key issue for stormwater planning, flows in those ranges should be a focus of calibration. While the objective is for the model to be as accurate as possible, there will be variability in model accuracy depending on flow rates and location. Quantification of calibration accuracy allows the user of model results to describe the degree of certainty or limitations of planning and analysis.

Model output will be used to generate hydrology metrics that will be compared to published stream flow metrics and corresponding BIBI scores in DeGasperi and others (2009) and any updates from more recent work in the Puget Sound Basin. While it is not possible to calibrate the model to BIBI scores, comparison of model flow metrics to observed BIBI scores will provide some degree of understanding of the ability of the model to correlate flow metrics with the published relationships.

Task Outcomes/Deliverables:

- **Calibrated HSPF hydrology and water quality models**
- **Memorandum documenting model calibration**
- **Memorandum comparing modeled flow metrics to observed BIBI scores**

TASK 4. Model Baseline Scenarios

The Permit requires modeling to estimate the hydrologic changes from historic conditions to the existing (calibrated) condition. It also requires the use of the model to predict future hydrologic, biological and water quality conditions based on full build-out of the current or proposed comprehensive plan.

Three mandatory scenarios prescribed under Section S5.C.5.c.ii(5) of the Phase I permit will be simulated to evaluate how Whipple Creek measures up to Washington State water-quality criteria, under current and full-buildout conditions. These include:

- Historic landcover (simulate hydrologic condition with current stream structure)
- Existing landcover/land use (simulate hydrologic condition using the calibration model) and calculate change relative to historic landcover condition
- Full-buildout land use under existing comprehensive land use plan and stormwater standards of the 2013 permit (simulate hydrologic, water-quality, and stream flow metrics to estimate BIBI scores)

If model results show Whipple Creek fails water-quality criteria under the full-buildout land use scenario, runoff model-based stormwater management strategies will be evaluated as part of Task 5.

Runoff flow rates for future development will be based on implementation of the 2012 Stormwater Management Manual for Western Washington (SWMMWW) including mandatory LID lists and the flow duration standard to predeveloped forested land cover. Infiltration feasibility based on soil and geologic factors will determine where infiltration BMPs are modeled.

Existing stormwater monitoring data collected by Clark County in rural, urban-residential and urban-commercial land uses will be used to estimate pollutant concentration in future runoff before treatment. Clark County will utilize the methodology described by the water quality model to estimate runoff temperature by land use type. The removal efficiency targets currently established by Ecology for basic and enhanced treatment in the 2012 SWMMWW will be applied to future development.

Future land use will be determined by the Comprehensive Plan for the period of the plan. For future scenarios beyond the 20-year comprehensive plan window, the county will develop a process to estimate longer-term land use changes, perhaps in collaboration with the other phase I counties. Other information such as GMA critical areas and the Clark County vacant or underutilized buildable lands model will help identify areas that develop or remain undeveloped. The amount of effective impervious area depends on several factors and will be estimated as future land development and its likely permit-required stormwater infrastructure are defined for each modeled sub-basin.

The full-buildout scenario will use existing stormwater data and standard treatment BMP effectiveness values to estimate pollutant concentrations for existing development. The full-buildout scenario will only include treatment BMPs simulated in the calibration model for existing development.

The method described in DeGasperi and others (2009) will be used to associate BIBI scores with modeled hydrologic metrics.

Task Outcomes/Deliverables:

- **Model results for the three mandatory scenarios**
- **Memorandum describing modeled hydrology changes from historical conditions to existing conditions, and estimated water quality standard attainment under full buildout scenario**

TASK 5. Evaluate Watershed Scale Stormwater Planning Scenarios

The purpose of the watershed-scale stormwater planning process is the evaluation of stormwater management strategies and other watershed-scale activities. The list of scenarios to be evaluated will be finalized in Task 5.1. Selected scenarios meeting the permit objective will be evaluated in Task 5.2 and Task 5.3. The scenario results will be compared to one another and the preferred strategies will be selected in Task 5.4.

TASK 5.1. Develop Strategy Scenarios

Runoff-model based strategies are required to come from the following list of potential stormwater strategies:

- Changes to development-related codes, rules, standards, and plans
- Potential future stormwater control projects consistent with S5.C.6.a.

The Permit does not specify which development-related codes, rules, standards and plans should be evaluated as stormwater strategies.

Task 5 may also evaluate additional stormwater strategies that include alternative stormwater standards as allowed by Appendix 1 of the Permit and regulations or programs encouraging infill and redevelopment. Evaluations of other watershed-scale strategies such as channel restoration, culvert removal and woody debris placement are considered optional under section S5.C.5.c.iii of the Permit but may be evaluated as effective measures to restore salmon habitat.

Assumptions for BMP pollutant removal will be based on the standards of the 2012 SWMMWW and influent concentrations based on past Clark County stormwater monitoring, the SWMMWW, and/or data from Puget Sound permittees.

Flow control regulation for future development will apply the current standard of Permit Appendix 1, considering the influence of soil and geologic conditions on infiltration practices. Infiltration rates will be based on soil types in published NRCS maps. Geologic mapping by Washington DNR and the USGS will augment the published soil information for description of earth materials underlying mapped topsoil.

Task 5.1 Outcomes/Deliverables:

- **List of stormwater strategies to be evaluated (will be incorporated into a later report developed under Task 5.2)**

TASK 5.2. Apply Runoff Model to Simulate Required Planning Scenarios

The hydrologic, water-quality, and biological conditions in Whipple Creek will be simulated for the Task 5.1 scenarios to define several combinations of stormwater strategies that meet the overall goal of the planning effort to restore and protect designated uses. Along with the hydrology and water quality model, an optimization model such as SUSTAIN may be used to evaluate scenarios to find the most cost-effective mix of strategies to meet the watershed scale stormwater planning objective under S5.C.5.c.

Task 5.2 Outcomes/Deliverables:

- **Memorandum documenting the analytical assumptions, methods and results for incorporation into the report produced in Task 6.**

TASK 5.3. (OPTIONAL) Apply Runoff Model to Simulate In-Channel Treatments or other Watershed-Scale Strategies

In-channel restoration projects may be the most effective tools to restore hydrology through direct intervention with the stream channel and flood plain. These strategies go beyond the structural controls required to meet Special Condition S5.C.6. Scenarios evaluated in Task 5.2 may be revised to include optional channel and flood plain restoration projects.

Task 5.3. Outcomes/Deliverables:

- **Memorandum describing optional strategy scenarios and results**
- **Model results**

TASK 6. Develop Draft and Final Implementation Plan

Task 6 will develop the implementation plan using information produced in Tasks 1 through 5. A set of preferred strategies should be selected for the implementation plan. The plan and schedule will include:

- potential future actions
- responsible parties
- estimated costs
- potential funding mechanisms

Task Outcomes/Deliverables:

- **Draft and final reports meeting the permit requirements for an implementation plan, including appendices describing the methods and results from Tasks 1-5.**

TASK 7. Public Review and Comment Process

The public involvement process will be focused on addressing key milestones. Public review and comment will target citizen education and public review of the primary documents. Clark County will establish a Whipple Creek Watershed-Scale Stormwater Planning web page with a project description and timeline. Project documents will be posted as they are completed. Internal stakeholders will be identified early in the project. These will include staff whose input is needed to complete the plan, coordinate with plan development or implement strategies of the plan. External stakeholders will be identified for targeted outreach as plan documents are completed. Other department programs that focus on outreach and education may be utilized, as appropriate, to identify stakeholders and interested citizens and direct them to available materials.

The project will have a 60-day public review and comment period for the draft implementation plan. Public input will inform the final report created under Task 6. Clark County will distribute the implementation plan review notice to stakeholders and interested parties in Whipple Creek watershed and within the region, such as the Lower Columbia Fish Recovery Board, state agencies, neighborhood associations and tribes.

Task Outcomes/Deliverables:

- **Project web page**
- **Public comment records**
- **Memorandum documenting county response to comments**

TASK 8. Project Management

The Clark County project team will meet on a routine basis to ensure efficient project communication. The project manager will track project scope, schedule, budget and quality to ensure that all permit obligations are met.

The project will involve county departments such as Public Works, Community Development and Community Planning who have a stake in the planning and implementing stormwater strategies. The Washington State Department of Transportation will also be engaged and invited to participate.

Task Outcomes/Deliverables:

- **Meeting notes, project schedule, project review notes, financial records**

SCHEDULE

Task	2014		2015				2016		
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1. Data Collection and Analysis for Existing Conditions	X	X	X	X	X	X			
2. Mapping Dataset Development and Assessment	X	X	X	X					
3. Calibrate Existing Conditions Runoff and Water Quality Models		X	X						
4. Complete Model Baseline Scenarios				X					
5. Evaluate Watershed-Scale Stormwater Planning Scenarios		X	X	X	X	X	X	X	
6. Develop Draft and Final Implementation Plan					X	X	X	X	X
7. Public Process	X	X	X	X	X	X	X	X	X
8. Project Management	X	X	X	X	X	X	X	X	X

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