IDENTIFICATION OF DEGRADED LOTIC FRESHWATER THAT AFFECTS SALMON HABITAT, SHELLFISH BEDS AND RECREATION IN SOUTH PUGET SOUND USING WATER QUALITY DATA AND LAND USE ANALYSIS

by
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A Thesis-Essay of Distinction
Submitted in Partial Fulfillment
of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
July 2012

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This Thesis for the Master of Environmental Studies Degree
by
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has been approved for
The Evergreen State College
by

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Date

ABSTRACT

Identification of Degraded Lotic Freshwater that Affects Salmon Habitat, Shellfish Beds and Recreation in South Puget Sound Using Water Quality Data and Land Use Analysis

Don Loft

Ecosystems are becoming degraded through human activity and neglect, resulting in the decline of productive habitats, increasing levels of toxins and a threat of species extinction. The quality of water in aquatic habitats is essential, because water is the basis for all life. To improve the health of an ecosystem, we must maintain the quality of water that sustains it. The purpose of this thesis project was to use water quality standards to identify habitats with degraded water quality for key species of salmonids, shellfish beds, as well as human recreation.

This research will answer the following questions: 1) Which water quality parameters define healthy and sustainable salmon habitats in lotic freshwater systems? 2) By using water quality standards as criteria, which freshwater lotic systems are degraded in two South Puget Sound watersheds? 3) What are the degrading effects of different types of land use and impervious surfaces having on water discharging from drainage systems into creeks, streams and wetlands?

This study focused on two watersheds in Western Washington's South Puget Sound, WRIA 11 (Nisqually) and WRIA 13 (Deschutes), and utilized water quality data analysis and geographic information system (GIS) to map the analysis results. The next level of analysis used the GIS hydrology tools to define the flow basins and identify land use features within those flow basins. This was performed on those sites considered to have highly degraded water quality. The selected flow basins were used to identify land use that could potentially affect water quality and degrade habitat.

The analysis compared existing water quality data against the Washington State Department of Ecology water quality standards to develop a color coded tier ranking system based on how often the data failed to meet the criteria standards. The ranking system resulted in an enhanced method for the identification of degraded and healthy lotic freshwater systems. The methods used in this thesis project produced a valuable tool, graphically representing potential target areas for salmon recovery and habitat restoration and enhancement.

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Acknowledgements

The first person I would like to acknowledge is Randy Lehr, Ph.D. for first guiding me on the path of identifying degraded freshwater systems through the analysis of water quality data. My work on the Chehalis River Basin Water Quality Project with Mr. Lehr provided the rudimentary foundation for my thesis project. My second partner in the Chehalis River Basin Water Quality Project was Joel Green, Ph.D. His expertise in fish biology helped me to refine my focus on the fundamental water quality parameters that support seasonal use by a variety salmonid species in aquatic habitats. Green played an important role in proofing the data for outliers and statistical analysis. He also performed the major role in the State-of-the-River report we co-authored.

The next acknowledgements go to people who supported my original water quality project for the Chehalis Basin. My thanks and admiration goes to the following people: Mike Kelly (Grays Harbor College) for his friendship and facilitating my contract to study the water quality in the Chehalis Basin. Janel Spaulding (Chehalis Basin Partnership) for her support and networking which supported my project. David Rountry (Department of Ecology) for his guidance on water quality issues and standards. Harry Pickernell (Water Resources Specialist The Chehalis Tribes) for the water quality data supplied for my project and his expertise as field research and lab methods.

I would now like to acknowledge those people who were instrumental in the creation and support of my thesis project. When I entered the MES program, I had a fairly good idea where I wanted to take it. Through the support of many professors and fellow students in my undergrad and graduate programs helped me clarify my thesis objectives. Special thanks to: Dylan Fischer, Ph.D., Rob Knapp, Ph.D., Rob Cole, Ph.D., Martha Henderson, Ph.D., Ralph Murphy, Ph.D., Timothy Quinn, Ph.D., Alison Styring, Ph.D., Anna Wederspahn, MES, Tim Benedict, MES, Noel Ferguson, MES, Chris Holcomb, MES, Nahal Ghoghaie, MES, Scott Morgan (Office of Sustainability), Gavin Glore (Mason Conservation District), and Jerilyn Walley, MES for support and proof reading my thesis.

For help in GIS spatial analysis for hydrology, I would like to give my thanks to Greg Stewart, Ph.D. for all his help and guidance. Thanks to Gerardo Chin-Leo, Ph.D. for his help in crafting and organizing my thesis from prospectus to thesis project. Special thanks goes to Gail Wootan (Assistant Director to the MES Program) for her gentle and caring support to get my thesis to the goal line.

My utmost gratitude goes to my esteemed thesis reader Judith Cushing, Ph.D. whose help and guidance got me to the finish line. Her input was invaluable, her support unwavering. When I got off track, she nudged me back on path. Judith's support and suggestions on methods and refinements has made the crafting of my thesis a pleasure to accomplish. I could not have picked a better person to be my thesis reader. I am a better graduate student for having known her.

Chapter One:

Water Quality Standards, Criteria and Methods of Analysis for Two Watersheds in South Puget Sound

Introduction:

The key element to assessing the health of salmon habitat is the collection of reliable data on that habitat. If there are no existing data for a habitat sustainability study, then field work is needed to obtain samples to analyze. When data are available on the study area's lotic freshwater salmon habitat, it is often obtained from many of the stakeholders in the area, and that can range from state and federal environmental agencies as well and local tribes and conservation districts. For this study data were acquired from The Washington State Department of Ecology, which maintains a large database collected from stakeholders from all regions in the state. The data used in this study were downloaded from their Environmental Information Management System (EIM) for two watersheds in the South Puget Sound area. Watersheds in Washington State are referred to as Water Resource Inventory Areas (WRIA) which defines the flow direction of runoff water from rainfall and snow melt. The salmon habitats in lotic freshwater systems in this study are WRIA 11 (Nisqually) and WRIA 13 (Deschutes).

Water quality data are used to determine if any salmon habitats or recreational streams have become degraded and for potential impact on shellfish. The water quality parameters used in this study are dissolved oxygen, fecal coliform, turbidity, pH and temperature. These data will undergo analysis that compares the data against the water quality standards outlined in the Clean Water Act and by The Washington State Department of Ecology. The criteria for high water quality standards will be used to compare samples taken at specific monitoring sites and then ranked by percentage of time the samples do not meet the criteria. A second level of criteria for low water quality standards will be used for some of the parameters, as this is needed for some species habitat requirements. This ranking will be graphically represented in a geographic information system (GIS) format. Monitoring sites showing the highest percentage of times not meeting the criteria will be given further analysis of the flow basins to those sites and the land use within those flow basins.

This thesis project produced enhanced methods for identifying degraded lotic streams, creeks and drainage of freshwater systems. This was accomplished through the use of water quality data analysis and applying those findings to GIS maps. GIS hydrology tools were used to identify land use features within flow basins that could potentially affect the water quality results found at specific monitoring sites. This information could be used to target potential habitat restoration and mitigation projects. The defined flow basins for these sites could also assist in assembling strategies for a more in-depth research within troubled habitats.

Area of Study:

This study took place in the Pacific Northwest and focused on two watersheds that discharge runoff water into Puget Sound. The Puget Sound, in the western part of Washington State, is a large estuarine system carved out by the advancement and receding of the last glacial age over 13,000 years ago. The approximate mile thick glacial ice stretched down from Canada to what is now near the State Capitol of Washington, with the Olympic Mountains to the west and the Cascades to the east. The retreating glacier scoured the landscape leaving behind many lakes, rivers and streams that now shed runoff water, melting ice and snow from the mountains and hills surrounding Puget Sound on the east, west and south. The north end of the Puget Sound opens to oceanic saltwater of the Pacific through the Strait of Juan de Fuca (Ecy, 2011).

The two watersheds in this study are located at the south end of Puget Sound; the Nisqually (WRIA 11) and the Deschutes (WRIA 13). The Washington State map shown in Figure 1.1 defines the location of WRIA 11 and WRIA 13 in relation to South Puget Sound and respectively to each other. These watersheds were chosen because of the different land uses respective to each.

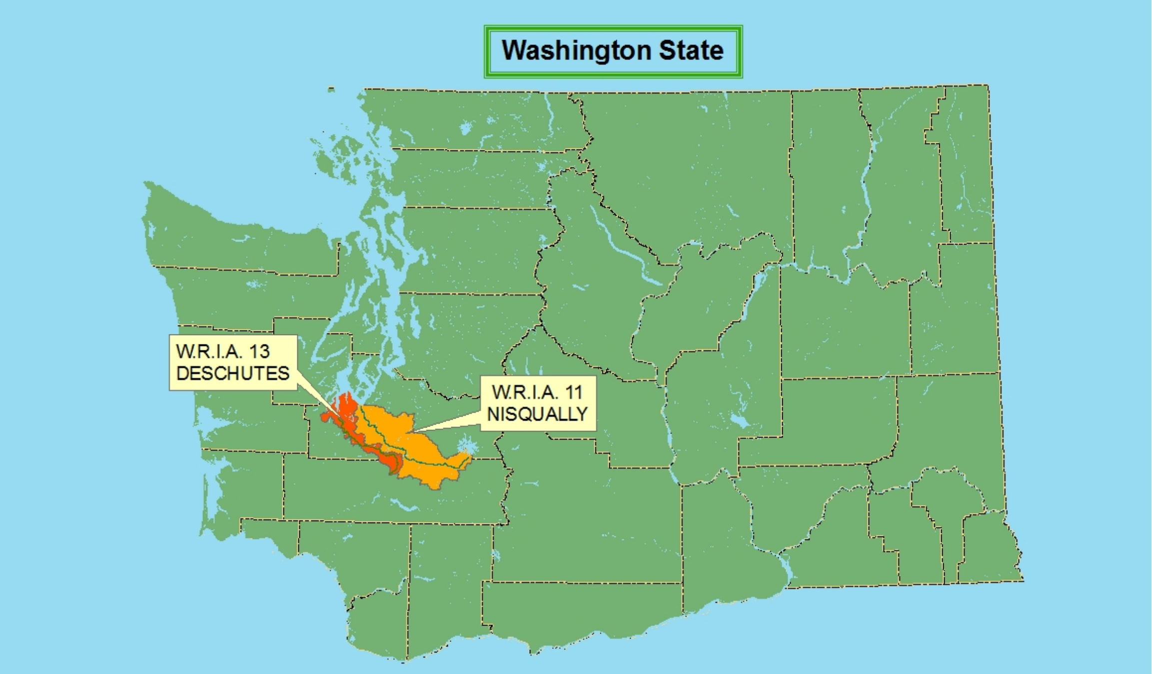


Figure 1.1: Washington State map showing location of watersheds in this study. Locations: The Nisqually River Basin (WRIA11) and the Deschutes River Basin (WRIA 13).

Nisqually River Basin (WRIA 11): The Nisqually River headwaters begin on the south face of Mt. Rainer, traveling southwest, then west through the upper basin, and northwest through the mid to lower basin. From headwater to the Nisqually Refuge Estuary, the Nisqually River flows approximately 78 miles and drains roughly 760 square miles. The elevation from headwater to estuary ranges from over 14,000 feet to sea level, although most of this watershed lies below 1,000 feet (PCPWU, 2011).

Fish Species and Habitat (WRIA 11): Anadromous fish species that migrate and inhabit the Nisqually basin are chum, coho, chinook and pink salmon, steelhead, rainbow and cutthroat trout. Also a non-anadromous species of sockeye salmon called kokanee was introduced to Alder Lake. The anadromous sockeye have been seen occasionally in the basin and are believed to be strays or kokanee that have left the reservoir. Although there is little evidence of the presence of bull trout, they are believed to live within the basin. Listed as threatened under the Endangered Species Act are the Nisqually fall chinook and Nisqually bull trout. A candidate for listing is the Nisqually coho salmon. Numerous warm water species have been introduced to low-land lakes; including bluegill, bullheads, pumpkinseed, yellow perch and largemouth bass. The primary salmon habitat is found in the subbasins Mashel, Muck/Murry, and the Tanwax/Kreger/Ohop. Salmonids also utilize the main channel of the Nisqually River. Access to other subbasins is limited because of natural and manmade barriers (WPN, 2002).

Deschutes River Basin (WRIA 13): The headwaters of the Deschutes River begin in Cougar Mountain at an elevation of 3,870 feet above sea-level, and flows through steep terrain in Lewis County to the rolling topography of the mid-waters in Thurston County and to the relatively flat grassy prairies and urban areas. The Deschutes River discharges about 60% of WRIA 13, approximately 270 square miles. The remainder of WRIA 13 discharges directly into Puget Sound. The Deschutes River discharges into Capitol Lake impoundment in downtown Olympia before entering Budd Inlet of South Puget Sound (WA Ecology, 2005). Percival Creek also discharges into Capitol Lake and not the main stem of the Deschutes River. WRIA 13 also contains two large flow basins that do not discharge directly into the main channel of the Deschutes River, Capitol Lake or Budd Inlet. To the west of Budd Inlet is Eld Inlet, and to the east, Henderson Inlet. Eld Inlet receives runoff water from McLane, and Swift Creeks at the southernmost tip, and Green Cove Creek which drains runoff from Cooper Point. Henderson Inlet receives runoff discharge from two main channels, the Woodland and Woodard Creeks, which both originate in dense urban areas of Olympia and Lacey. Dobbs, Meyer, Myer and Goose Creeks are several smaller creeks that discharge from less dense urban and more rural areas into Henderson Inlet.

Fish Species and Habitat (WRIA 13): With assistance from Native Tribes and tribal organizations, the Washington State Department of Fish and Wildlife (WDFW) publishes the State Salmon and Steelhead Stock Inventory (SASSI) report on the condition of local and introduced fish species. The information used here is from the *Deschutes River Watershed Initial Assessment (Draft May 1995)*. The SASSI states that the Deschutes River watershed supports three salmon species, the chum, chinook, and coho in addition to the winter steelhead. Also utilizing WRIA 13 are the Henderson Inlet fall chum, McLane Creek steelhead and a variety of other fish including Dolly Varden, sea-run cutthroat trout, pygmy whitefish and Olympic mudminnow (Ecy-2, 2011).

WDFW Salmonid Stock Inventory: WDFW's Salmonid Stock Inventory (SaSI) issues reports on the health of salmonids species throughout Washington State. The SaSI is a tool developed by Native Tribes and WDFW to inventory and monitor Washington's salmonids species, because of their cultural and commercial importance to the state's ecosystems and its people. The inventory data is compiled on all wild salmonid species and is assessed to determine if the stock is healthy, depressed, critical, extinct, or unknown. This results in a recovery action plan to prioritize restoration. Anthropogenic activities have placed heavy pressures on salmonid stocks through urban development, industry, forestry, agriculture, overfishing and hydropower dams to name a few. Many of Washington's species have become imperiled over time. As of 2002, out of the 598 species that have been identified, 180 are rated as healthy, 132 as depressed, 26 as critical, 9 as extinct and 251 were given a status of unknown. Table 1.1 shows the SaSI inventory status for species in WRIAs 11 and 13 (WDFW, 2011).

Table 1.1: WDFW's Salmonid Stock Inventory (SaSI) Stock Status WRIA 11 and 13.
Source: Washington Department of Fish and Wildlife (WDFW) Salmonid Stock Inventory (SaSI) Stock Status for species (WDFW, 2011).

Species	Stock Name	WRIA	1992 Status	2002 Status
Chinook	Nisqually Chinook	11	Healthy	Depressed
Chum	Nisqually Winter Chum	11	Healthy	Healthy
Coho	Nisqually Coho	11	Healthy	Healthy
Pink	Nisqually Pink	11	Healthy	Unknown
Steelhead	Nisqually Winter Steelhead	11	Healthy	Depressed
Chum	Eld Inlet Fall Chum	13	Healthy	Healthy
Chum	Henderson Inlet Fall Chum	13	Unknown	Unknown
Coho	Deschutes Coho	13	Healthy	Critical
Steelhead	Deschutes Winter Steelhead	13	Healthy	Not Rated

Water Quality Standards:

The dependent variable is water quality in streams, creeks and drainage systems that support salmonid rearing and spawning habitats as well as a healthy water quality fecal coliform standard for shellfish and recreational purposes. The measure of water quality in lotic systems was determined by freshwater parameters for sustainable salmonid spawning and rearing habitats, as outlined by the Department of Ecology's Water Quality Standards for Surface Water of the State of Washington, Chapter 173-201A WAC (WA Ecology, 2006). Water quality parameters used in this Thesis (with corresponding tables referenced in the above mentioned publication) are: dissolved oxygen (Table 200 (1)(d)), bacteria levels (Table 200 (2)(b)), turbidity (Table 200 (1)(e)), temperature (Table 200 (1)(c)) and pH (Table 200 (1)(g)). The criteria used for analysis are those defined in Washington State water quality standards 173-201A WAC, and are outlined below:

Dissolved Oxygen: Dissolved oxygen levels can be influenced by water temperature and the large die-off and decay of organic plant material and algae. Stagnant water or stream water flow that lacks a rough substrate for mixing can also be the cause of low dissolved oxygen levels. The water quality standards for dissolved oxygen levels are: 8 mg/L (Low Standard) or above in streams and creeks are necessary to support salmon spawning and rearing, and 9.5 mg/L (High Standard) or above are needed to support char and trout (WA Ecology, 2006).

Bacteria Levels: Elevated bacterial levels in stream water can cause problems such as eutrophication from the growth and decay of plants and algae which depletes dissolved oxygen. Also, higher bacteria levels can increase stream turbidity as well as bacterial diseases. Water quality data collected for fecal coliform (FC) was from Ecology's EIM database. The standard of measurement is colony forming units (cfu). The standards used for analysis were the high standard of 50 cfu/100 ml for exceptional water quality to protect stream water discharge over shellfish beds, and the lower standard of 100 cfu/100 ml to protect recreational primary contact (Green, et al., 2009). Long-term testing at a sampling site that receives a geometric mean over 100 cfu/100 ml with at least

10% of the sample data above 100 cfu/100 ml gets placed on the 303(d) listing. This is used for a Total Maximum Daily Load (TMDL) study to find and correct point source(s) of bacteria in fresh surface water (WA Ecology, 2006).

Turbidity: High water quality standards for streams and creeks measure for 5 Nephelometric Turbidity Units (NTU) above background turbidity for individual rivers, streams and creeks. When water gets to elevated levels of suspended solids, it can have several adverse effects on fish in spawning and rearing habitats. Turbid water dissuades fish from taking advantage of habitats because of irritation caused to their gills. Also, suspended solids settle out over stream beds, covering suitable substrate for laying eggs. Turbidity decreases the amount of light that is received by benthic plants and algae, thus decreasing productivity that supports invertebrate habitat and food supply (WA Ecology, 2006).

pH: The high and low standards for pH are between 6.5 and 8.5. Water quality standards for pH are a factor in the health of lotic systems, but will not be the primary focus of this research. In future work pH may be utilized if needed for a more in depth analysis.

The Washington State standards for surface water quality parameters for dissolved oxygen, fecal coliform, turbidity and pH, have been summarized in Table 1.2 below. For this study the numerical values of these standards were used as the criteria for analysis. These standards have two levels of protection. The high standards are adopted for high or extraordinary fresh surface water quality to protect char and salmon habitats for spawning, rearing, migration and to protect shellfish from stream water discharge over shellfish beds. The low standards are adopted to protect dissolved oxygen levels for salmon spawning, bacteria levels for recreational primary contact protection and turbidity levels to protect salmon migration and rearing. The pH range is the same for both high and low standards.

Table 1.2: Washington State surface water quality standards for dissolved oxygen, fecal coliform, turbidity and pH. Source: WA Ecology, 2006 and Green, Loft and Lehr, 2009.

Parameter	High Standards	Description	Low Standards	Description
Dissolved Oxygen	9.5 mg/L	Lowest 1-Day minimum to protect Char Spawning and Rearing	8 mg/L	Lowest 1-Day minimum to protect Salmon Spawning
Fecal Coliform (Bacteria)	50 cfu/100 ml	Max. Geometric Mean for extraordinary water quality of streams flowing to shellfish beds	100 cfu/100 ml	Max. Geometric Mean to protect for recreation primary contact
Turbidity	5 NTU above background	To protect salmon spawning, rearing and migration	10 NTU above background	To protect salmon migration and rearing
pH	6.5 to 8.5	To protect salmon spawning, rearing, and migration	6.5 to 8.5	To protect salmon spawning, rearing, and migration

Temperature: This water quality parameter was analyzed differently from the analysis method employed for the other parameters. Because species utilize habitat at different times of the year and for different purposes, the temperature datasets were broken into seasonal use categories (see Table 1.3). The timeframe used for suitable habitat temperatures will be discussed in further detail in the Data Analysis section of this chapter (WA Ecology, 2006).

Table 1.3: Washington State surface water quality standards for temperature.
Source: WA Ecology, 2006 and Green, Loft and Lehr, 2009.

Category	**Temperature**	**Time Period**
Fall Char Spawning	9°C (48.2°F)	Sept. 16th – Dec. 22nd
Char Rearing	12°C (54.6°F)	All Year
Salmon & Trout Spawning (F/W/Sp)	13°C (55.4°F)	Sept. 16th – June 14th
Core Summer Salmonid Habitat	16°C (60.8°F)	June 15th – Sept. 15th

Data Analysis:

The objective of this data analysis was to identify those lotic fresh water habitats that exhibit poor standards of water quality, or had a tendency toward poor water quality. The criteria were set for pass or fail for the high and low water quality standards on the sample parameter result numbers (Summarized in Tables 1.2 and 1.3 in the previous section). The sample parameters of dissolved oxygen (DO), turbidity (TURB) and fecal coliform (FC) each have two criteria for analysis. Each of these parameters was measured for the high and low water quality, as outlined by the Washington State standards for surface water quality. The pH parameter has one measure for both high and low water quality standards. Temperature (TEMP) data were arranged by seasonal needs for salmon, char and trout. Four temperature criteria were used for specific seasonal habitat utilization during spawning, rearing and migration.

Source of Data: Washington Department of Ecology's Environmental Information Management System (EIM) Database Search was used to acquire fresh surface water quality data on the above parameters for the two watersheds in this study, the Nisqually (WRIA 11) and the Deschutes (WRIA 13). The parameter data download produced three file folders, one each for study, location and results (Ecy-3, 2011).

Data Organization: The folder containing the study data was left intact as it gives information for study ID, study name, purpose, start and end dates, grant loan numbers and Ecology's lead contact person. The location folder was used to extract data for two location tables, one tabular to provide location information data and one for spatial coordinates to use in creating features for the watershed maps in GIS. The analysis portion of this project was performed using the data contained within the results folder. The Washington Department of Ecology (WADOE) requires quality assurance levels to be included with every data upload to the EIM database. Every study must do this to enter result parameters for samples taken at a study location. This is referred to as the Study Quality Assurance (QA) Assessment Level (Ecy-3, 2011).

The Study QA Assessment is defined by five levels for reliability for the data. Level 1 is the lowest level of reliability and Level 5 is the highest. The levels are assigned as follows:

- Level 1 - Data neither Verified nor Assessed for Usability
- Level 2 - Data Verified
- Level 3 - Data Verified and Assessed for Usability
- Level 4 - Data Verified and Assessed for Usability in a Formal Study Report
- Level 5 - Data Verified and Assessed for Usability in a Peer-Reviewed Study Report

These levels of reliability are located within the EIM dataset field titled “Study QA Assessment Level” (Ecy-3, 2011). For analysis to lend credibility to this study, only the data for formal and peer-reviewed reports were used. Data for QA Levels 4 and 5 were extracted from the EIM download. Data for QA Levels 1 through 3 were discarded.

The next step in analysis was to group the data sets by WRIA and water quality result parameter. Both WRIA 11 and WRIA 13 were assigned their corresponding parameter datasets for DO, TURB, FC, pH, and TEMP. Each parameter was then further sorted alphabetically by its Location ID and Study ID. These two identifiers were made from unique combinations of letters and numbers. Then the parameters were sorted from start to end date of the study. With the exception to the TEMP datasets, the last step was alphanumeric sorting for the Sample ID from smallest to largest. The final sort for TEMP was from the time of day the sample was taken (when provided), because the time of day can have an effect on water temperature in some locations.

The analysis objective for this project was to define the water quality at specific sampling sites where ongoing and long-term monthly sample collections were taken within WRIA 11 and WRIA 13. Organizing the data as described above provided block sets of data for each sample site location. These block datasets arranged the data for useful extraction of site and study information, start and end dates, and to analyze the result parameter numbers site by site.

Methods:

Tabular Data Analysis:

Information for the site, study and result parameter number analysis was performed in Microsoft (MS) Excel. The Washington State standards for surface water quality (High and Low) were used for the criteria in the analysis formulas. Refer back to

Tables 1.2 and 1.3 in the Water Quality Standards section. Each site and parameter provided information on site location, study information and the result parameter numbers taken for each site. Formulas were created for each site location dataset to acquire the total number of records, the number of records not meeting the criteria and the percentage of those records that did not meet the criteria. Also assembled from these records were the study site's geometric mean, minimum (smallest) and maximum (largest) from the result parameter numbers. Other information assembled from each dataset was the QA assurance level, start date, end date and unique identifiers for the site location and the study. A formula bar was created for each parameter dataset to organize and assess the information described above. The algorithms were exported and aggregated for each parameter in each WRIA for this study. This created join tables for the GIS portion of this analysis, discussed later in this section. Discussion on the land use and impervious surface GIS procedures for this study are in following chapters.

The criteria functions and formulas for DO, FC, pH and TURB are summarized in Table 1.4 below. To acquire the total number of records for each site's dataset the 'count' function was used. To get the number of records within that dataset that did not meet the criteria the 'count if' function was used. To get the percentage of records that did not meet the criteria the 'count if' function result was divided by the 'count' function result.

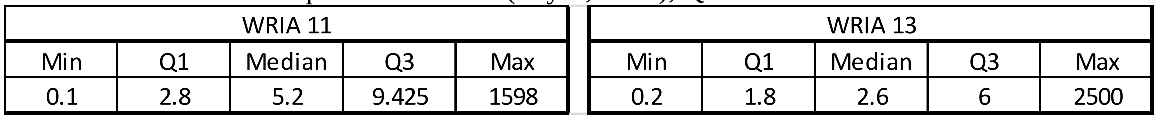
Table 1.4: Criteria, Functions and Formulas for DO, FC, pH and TURB.
Source: Washington State water quality standards 173-201A WAC (WA Ecology, 2006) and Green, Loft and Lehr, (2009). Formula functions in Microsoft Excel.

			PARAMETER FORMULAS				
	A	B	C	D	E	F	G
	Field Name	Function	DO	FC	pH	TURB (WRIA 11)	TURB (WRIA 13)
1	Records	COUNT	[Range]	[Range]	[Range]	[Range]	[Range]
2	Criteria 1 (High)*	COUNTIF	[Range] < 9.5 mg/L	[Range] > 50 CFU	[Range] < 6.5 pH or [Range] > 8.5 pH	[Range] > 7.8 NTU**	[Range] > 6.8 NTU**
3	Criteria 2 (Low)*	COUNTIF	[Range] < 8 mg/L	[Range] >100 CFU	Same	[Range] > 12.8 NTU**	[Range] > 11.8 NTU**
4	Percent Rank 1 (High)	DIVIDE	C2 / C1	D2 / D1	E2 / E1	F2 / F1	G2 / G1
5	Percent Rank 2 (Low)	DIVIDE	C3 / C1	D3 / D1	Same	F3 / F1	G3 / G1
* Actual Field Name consists of Math Function + Criteria + Measurement Units.							
** Criteria number includes the calculated background turbidity for each WRIA.							

It should be noted that the high and low water quality standard criteria were not applied across all parameters for this study. The exceptions are temperature, pH and turbidity. The temperature data were set for seasonal use by different species of salmon, char and trout spawning and rearing habitation. The pH standard for fresh surface water quality is in a range from 6.5 pH to 8.5 pH. The standard for pH is the same for high or low water quality. The turbidity high water quality standard is 5 NTU above background, and the low water quality standard is 10 NTU above background (WA Ecology, 2006). For this study only the high water quality standard was used for the turbidity analysis. The low water quality standard was used only to identify those sites of extreme turbidity. Background turbidity is somewhat unique to each lotic system. Different background levels can be influenced by soil types and streambed substrates. The typical measure for background levels is to sample the turbidity of a stream above a disturbance site to gain normal stream function turbidity levels. Examples of a disturbance include timber practices, road construction, culvert removal or replacemant and stream modification.

To establish background turdibity for this study a different metric needed to be applied. Instead of monitoring turbidity at a specific site of disturbance, the object of this study is to monitor turbidity effect from different land use types throughout the whole watershed. Data downloaded from EIM (Ecy-3, 2011) did not provide adequate results for headwaters for either Deschutes or Nisqually Rivers. The best option was to define a normal turbidity level from aggregated datasets for each watershed. To accomplish this, the results data were arranged in ascending order and calculated for the minimum (Min), 1st quartile (Q1), median, 3rd quartile (Q3), and maximum (Max). This measure of the spread is shown in Table 1.5 below.

Table 1.5: Measure of data spread for WRIAs 11 & 13 (Min, Max, Quartiles, & Median)
Source: Datasets were acquired from EIM (Ecy-3, 2011), Quartiles functions in Microsoft Excel.



WRIA 11				
Min	Q1	Median	Q3	Max
0.1	2.8	5.2	9.425	1598

WRIA 13				
Min	Q1	Median	Q3	Max
0.2	1.8	2.6	6	2500

To establish the normal NTU background levels for each of these two systems, the first quartile (Q1) was used as the standard background. The criteria analysis NTU number for high water quality standards is 5 NTU above background (Refer to Table 1.2 in the section Water Quality Standards). To create the turbidity criteria number for each watershed, the following defined formula was used: Q1 plus 5 NTU equals Criteria NTU. Q1 for WRIA 11 is 2.8 NTU and Q1 for WRIA 13 is 1.8 NTU. The formulas are:

- WRIA 11: Background of 2.8 NTU (Q1) + 5 NTU = 7.8 NTU.
- WRIA 13: Background of 1.8 NTU (Q1) + 5 NTU = 6.8 NTU.

Therefore the turbidity criteria are 7.8 NTU for WRIA 11 and 6.8 NTU for WRIA 13. These adjusted water quality standards were applied as criteria to their respective watershed turbidity datasets for analysis.

The final water quality parameter for analysis was to segregate stream (lotic) and lake (lentic) temperature data, with stream water temperature being the primary study objective and lake water temperature secondary for analysis. Lentic temperatures were included in the analysis when the lotic sample site temperatures had a high frequency of not meeting the analysis criteria. Unlike the other water quality parameters, the temperature criteria were not based on the high and low water quality standards, but rather on seasonal use by salmonid species. For a summary of seasonal use, refer to Table 1.3 in the section on Water Quality Standards. Data were sorted into four categories by seasonal use and the temperature criteria established for each of those seasonal use categories. As with the other water quality parameters, algorithms were created for each site and category to organize the information from blocks of site and the seasonal specific datasets. Three information (INFO) fields were added to the seasonal temperature algorithms before export to GIS join tables. This information was necessary to add context for each of the seasonal tables when the information was accessed in GIS. The new fields were: Category, Temp Criteria and Sample Period. The Category field holds information on species, the Temp Criteria field holds the temperature analysis criteria in degrees centigrade and the Sample Period field holds information on the month and day range of samples taken.

The summarized criteria formulas for TEMP were categorized by seasonal use and are shown in Table 1.6, below. As with the previous four parameters, to acquire the total number of records for each site's dataset the 'count' function was used. To get the number of records that did not meet the criteria the 'count if' function was used, and for the percentage of records that did not meet the criteria the 'count if' result was divided by the 'count' result.

Table 1.6: Info, Criteria, Functions and Formulas for Seasonal Use Temperature Analysis. Source: WA water quality standards 173-201A WAC (WA Ecology, 2006) and Green, Loft and Lehr, 2009. Formulas in MS Excel.

			TEMPERATURE FORMULAS			
	A	B	C	D	E	F
	Field Name	Function	Temp 1	Temp 2	Temp 3	Temp 4
INFO	Category	Text	Char Rearing	Fall/Winter/Spring Salmon & Trout	Core Summer Salmonid Habitat	Fall Char Spawning
	Temp_Criteria	Text	12 deg. C	13 deg. C	16 deg. C	9 deg. C
	Sample_Period	Text	All_Year	Sept. 16th-June 14th	June 15th-Sept. 15th	Sept. 16th-Dec. 22nd
1	Records	COUNT	[Range]	[Range]	[Range]	[Range]
2	Criteria	COUNTIF	[Range] > 12 deg. C	[Range] > 13 deg. C	[Range] > 16 deg. C	[Range] > 9 deg. C
3	Percent Rank	DIVIDE	C2 / C1	D2 / D1	E2 / E1	F2 / F1

Before data could be used in the GIS portion of this analysis, a minimum number of records (per study sample site) was needed so that the ranking of results output would not be skewed. The Percent Rank field in each join table was used for tier ranking the GIS display symbology. Tier ranking is explained in more detail in the next section. For the GIS image output, the tier ranking was divided into five tiers to display the percentage range of records not meeting the analysis criteria. For this study, sample sites containing fewer than 5 records were discarded from the analysis.

The parameter formula and functions described above in Table 1.4 for DO, FC, pH, and Turbidity (TURB), and Table 1.6 for Temperature (TEMP) yielded a list which ranked each parameter by the percentage of times that study sample sites did not meet the analysis criteria for water quality standards. Each site was given a percentile rank ranging from zero to 100%. These percentiles were divided into a five tier ranking to define the quality of water at a given site. The ranking was in percentile degrees from excellent to degraded water quality. Based on the percentage of times a study sample site did not meet the analysis criteria, the tier ranking is as follows:

- Excellent (0 to 5%),
- Good (>5 to 15%),
- Fair (>15 to 25%),
- Poor (>25 to 35%)
- Degraded (>35 to 100%).

This tier ranking method was previously used in a report to analyze the water quality in the Chehalis River Basin in Western Washington (Green et al., 2009). The procedure in this study takes the analysis process several steps further than the aforementioned report. The objective of this study was to identify the more degraded sample sites, and define possible contributing factors from land use and impervious surfaces. This chapter deals with the identification of degraded sites and Chapter 2 will analyze the land use and impervious surface contributing factors. To further refine this analysis of degraded sites two more steps were added.

After the percentile ranking of sites and dividing the list of percentile results into five tiers, the range for the degraded water quality was selected by keeping only those sites that rank from greater than 35% to 100% of the time not meeting the analysis criteria. The next step used the geometric mean as a qualifier for the most degraded water quality at sample sites. Of the sites ranking greater than 35% to 100% that did not meet the analysis criteria, not all sites were severely degraded. For example, a site that had a rank of 42.86% for fecal coliform (FC), with an analysis criteria of 50 CFU, could have a minimum number of 8 CFU and a maximum number of 260 CFU, yet still have a geometric mean of 45.37 CFU which is lower than the analysis criteria. This would be a parameter dataset with prevailing result numbers low enough to average less than the criteria of 50 CFU. Furthermore, a site that has the same rank of 42.86% with a minimum number of 6 CFU and a maximum of 270 CFU can have a geometric mean of 57.35 CFU which is higher than the analysis criteria. This would be from the dataset with numbers that trended higher, thus giving a geometric mean result higher than the analysis criteria of 50 CFU.

To simplify the above analysis process for finding the most degraded study sample sites, I started with sites that had a tier rank of 35% and greater. Of those study sample sites, only the records that had geometric means that also meet the parameter analysis criteria (50 NTU) were selected for the final parameter ranking analysis tables. For the FC example, all records in that group with a geometric mean of 50 CFU and above were selected. Although some of the other parameter ranking records did not meet the geometric mean standard, they were still included for various reasons. Explanations will be included in the table description. The resulting tables provide lists of sites that will undergo further analysis for land use and impervious surfaces. These tables are shown in the section on Results and Conclusions in Chapter Two.

Aggregation of Ranking Results:

The methods described above created sample site ranking tables for the individual parameters (DO, FC, pH, TURB and TEMP) in each of the watersheds within this study. The individual tables do not allow for criteria failures across multiple parameters. The final step in identifying the most degraded sites for water quality was to aggregate the tables for all the parameters and rank each sample site across all parameters not meeting the criteria at least 35% of the time. This also establishes a possible correlation between parameters. For example, a lotic site that shows a high frequency of dissolved oxygen and temperatures failing to meet the analysis criteria might indicate that high temperatures could account for the low dissolved oxygen results. Thus, the aggregated tables could provide a more refined depiction of the possible causes of degraded water quality at a given site.

The ranking results aggregation tables were produced from the 35% parameter ranking and geometric mean standard, exceptions included, from all the sample sites in WRIA 11 and WRIA 13. These sample sites were in a variety of habitats including streams, creeks and rivers (lotic), and lakes, ponds and reservoirs (lentic), and included sample site locations at tide gates in WRIA 11. Because the primary purpose of this study was to identify degraded lotic sites, the sample sites were stratified into three groups; lotic, lentic, and tide gates. The lentic group was set apart as an independent variable that could have a possible influence on water quality. Tide gates are typically located at or near the mouth of a creek or stream where tidal influence is present. That places tide gates at the end of a lotic system as it merges with an estuary. In this study the tide gates were treated as an independent variable to lotic system water quality.

The above mentioned water quality data analysis process revealed some interesting observations about water quality for both lentic systems and tide gates, as well as the intended analysis for lotic systems. These findings will be discussed in detail in the Results and Conclusions section in Chapter Two. The tables created for the lotic system ranking analysis and the aggregation of ranking result tables are joined to GIS features to graphically represent the data.

GIS Spatial Data and Join Tables:

Spatial data is information that has a reference to a geographic coordinate. This information is used to create features on a map like points, lines and polygons that represent features in the real world. These features can contain information about the feature like ID, location, shape, length and area. These are stored in a geographic information system (GIS) in a tabular form. These attribute tables in GIS can be expanded by providing more information to the system. A whole database of information can be created by adding fields within the GIS software to populate the attribute tables with more feature data.

Another way to populate GIS attribute tables is by the use of joins or relates. The GIS join tables are external tabular data appended to the feature attribute table by a common field. The appended data becomes a permanent part of the feature attribute table as long as the join is not removed. Relate tables work similarly to join tables in that they need a common field to provide information to the feature attribute table. The difference is that relate tables are a lookup source of information and are not appended to the feature attribute table.

For this study, the data came from the Washington Department of Ecology's EIM database (Ecy-3, 2011). From the data extracted for WRIA11 and WRIA 13, two tables were created externally from GIS, in Microsoft Excel. One table was used for location information and to generate GIS spatial features for the water quality monitoring sites. The other table was made up of the sample results and was used for the tabular data analysis. When both steps were completed, the analysis results table was joined to the GIS location feature data so spatial analysis on the sampling sties could be performed. The external tables had two primary functions for this study. First, to show the location of sample study sites analyzed and second, to provide a colored tier ranking for the percentage of time the data set did not meet the criteria for each of the parameters. The tables for the aggregation of ranking results were used to create a set of GIS features to graphically represent those sites that were the most degraded across multiple parameters. Some of the features created for the most degraded sites were used as end points for defining flow basins and to calculate area of influence from land use. The spatial analysis for flow basins and land use is explained in Chapter Four.

Chapter Two:

Identification of Degraded Habitat in Lotic Freshwater Systems

Results and Conclusions:

The following tables, in the section on Results for WRIA 11, show the results of analysis performed on water quality data for Dissolved Oxygen (DO), Fecal Coliform (FC), Turbidity (TURB) and Temperature (TEMP) in the Nisqually Basin (WRIA 11). For the pH parameter in WRIA 11, none of the study sample sites had a percentile rank above 35%. The following tables, in the section on Results for WRIA 13, show the results of analysis for Dissolved Oxygen (DO), Fecal Coliform (FC), pH, Turbidity (TURB) and Temperature (TEMP) in the Deschutes Basin (WRIA 13). The TEMP data were subject to a different criteria method than the other parameters. The analysis criteria for DO, FC, pH and TURB were based on the high and low water quality standards (See Table 1.2) and the criteria for TEMP were based on seasonal temperature requirements for salmonids (See Table 1.3). The results in the tables below were derived from a series of criteria designed to cull out sample sites showing degraded water quality. The first step defined the percentage of times the study site samples failed to meet the criteria established for each parameter. Those results were organized in descending order by percent. The second step took all records that had a percentile criteria failure equal to or greater than 35% of the samples with the geometric mean of that dataset also not meeting each parameter's criteria. *Example 1: Criteria = FC > 50 cfu. Records > 50 cfu = 50% and Geometric Mean = 66.99. Both are greater than the criteria.* This is referred to as the 35% plus geometric mean standard. A few records equal to or above 35% and where the geometric mean did meet the parameter analysis criteria were kept in this list for various reasons. *Example 2: Criteria = FC > 50 cfu. Records > 50 cfu = 50% and Geometric Mean = 27.31. Geometric Mean not greater than the criteria.* These records were considered sites of interest and will be explained for each parameter where they occur. Usually analysis records like the second example were due to high intermittent failures to meet the criteria.

Results for WRIA 11:

The following tables were used in the Nisqually Basin analysis study. The tables in this section show results from the series parameter analysis criteria to establish those sites that show the highest potential for degraded aquatic habitat.

DO Results: The analysis criterion for this data set was < 8 mg/L. Of 59 total sites where DO samples were taken, the results shown in Table 2.1 are the 25 sites that met the 35% plus geometric mean standard described above. For this parameter, the percentile range was from 40% to 100% of the time not meeting the analysis criteria. The minimum geometric mean is 1.28 mg/L for the Site ID – TG13L (Record #4), and the maximum is 7.96 mg/L for Site ID – MEDO.O (Record # 15).

Table 2.1: Results for degraded dissolved oxygen levels (geo mean < 8mg/L) WRIA 11.
Results for DO: Twenty-five sites met the 35% plus geometric mean standard.

	Site Info		DO - Analysis Results - WRIA 11							
#	Site_ID	QA	Records	< 8mg/L	< 9.5mg/L	% 8mg/L	% 9.5mg/L	Min	Max	Geo Mean
1	HARPI11	L-5	6	6	6	100.00%	100.00%	2.14	5.37	3.60
2	WHIPI11	L-5	6	6	6	100.00%	100.00%	2.99	4.58	3.84
3	MED0.1	L-4	9	9	9	100.00%	100.00%	0.68	6.76	3.00
4	TG13L	L-4	10	10	10	100.00%	100.00%	0.39	2.66	1.82
5	TG14L	L-4	8	8	8	100.00%	100.00%	2.10	6.20	3.99
6	TG8L	L-4	5	5	5	100.00%	100.00%	4.92	7.04	5.99
7	TG9L	L-4	9	9	9	100.00%	100.00%	1.15	7.01	3.90
8	ST#TH11	L-5	9	8	9	88.89%	100.00%	2.46	8.90	4.33
9	TG10L	L-4	9	8	9	88.89%	100.00%	3.30	8.25	5.48
10	TG15L	L-4	9	8	9	88.89%	100.00%	3.07	9.02	5.07
11	TG12L	L-4	7	6	7	85.71%	100.00%	2.22	8.71	5.56
12	MC5.8	L-4	11	9	11	81.82%	100.00%	5.80	8.35	7.26
13	TG9W	L-4	7	5	5	71.43%	71.43%	2.90	13.05	6.15
14	MC4.3	L-4	10	7	10	70.00%	100.00%	5.91	9.27	7.34
15	MED0.0	L-4	6	4	5	66.67%	83.33%	6.64	10.78	7.96
16	TG4L	L-4	9	6	6	66.67%	66.67%	4.74	13.10	7.82
17	MC4.7	L-4	10	6	10	60.00%	100.00%	6.46	8.96	7.67
18	MC5.4	L-4	10	6	9	60.00%	90.00%	6.05	9.57	7.71
19	TG5L	L-4	10	6	9	60.00%	90.00%	4.13	77.00	7.75
20	MC3.1	L-4	9	5	8	55.56%	88.89%	5.93	10.39	7.77
21	MC3.7	L-4	11	6	11	54.55%	100.00%	5.60	8.46	7.46
22	MC4.3T	L-4	11	5	10	45.45%	90.91%	5.98	9.50	7.92
23	OHOPCR(RM6.3)	L-4	52	23	29	44.23%	55.77%	2.50	13.10	7.91
24	CLETH11	L-5	5	2	5	40.00%	100.00%	2.70	9.02	6.71
25	TG2L	L-4	10	4	5	40.00%	50.00%	1.46	13.90	7.31

FC 50 cfu Results: The analysis criterion for this dataset was > 50 cfu/100 ml. Out of 52 total sites where FC samples were taken, the results shown in Table 2.2 are the 16 sites that met the 35% plus geometric mean standard. For this parameter, the percentile range was from 37.5% to 80% of the times not meeting the analysis criteria. The minimum geometric mean is 50.73 cfu/100 ml for Site ID – MC3.1 (Record # 11), and the maximum is 97.26 cfu/100 ml for Site ID – SC12CS4 (Record # 1).

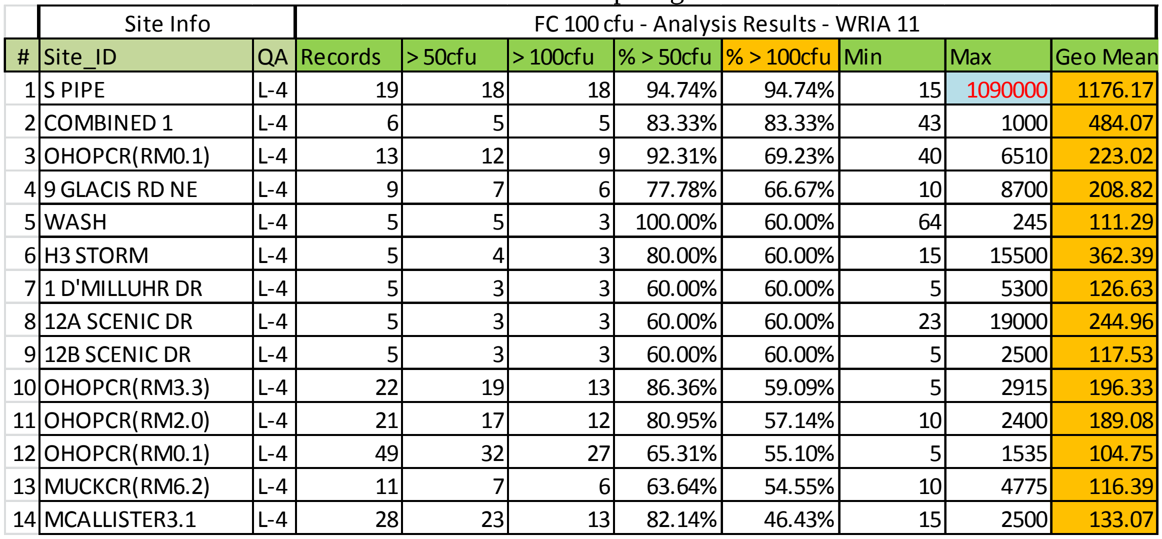
Table 2.2: Results for degraded fecal coliform levels (geo mean > 50 cfu) WRIA 11.
Results for FC 50 cfu: Sixteen sites met the 35% plus geometric mean standard.

	Site Info		FC 50 cfu - Analysis Results - WRIA 11							
#	Site_ID	QA	Records	> 50cfu	> 100cfu	% > 50cfu	% > 100cfu	Min	Max	Geo Mean
1	SC12 CS4	L-4	5	4	3	80.00%	60.00%	2	930	97.26
2	MC 3.1	L-4	8	6	1	75.00%	12.50%	35	120	62.22
3	LIITLEMASHELRV	L-4	23	14	10	60.87%	43.48%	5	2650	80.16
4	OHOPCR(RM0.1)	L-4	23	14	10	60.87%	43.48%	5	700	67.24
5	YELMCR(RM0.1)	L-4	12	7	5	58.33%	41.67%	10	385	60.40
6	RSET	L-4	12	7	2	58.33%	16.67%	23	130	53.69
7	OHOP2.0	L-4	7	4	3	57.14%	42.86%	11	330	67.31
8	OHOP3.3	L-4	7	4	3	57.14%	42.86%	8	1400	69.20
9	OHOP6.0	L-4	7	4	3	57.14%	42.86%	9	610	76.92
10	MED0.0	L-4	7	4	2	57.14%	28.57%	14	410	60.00
11	MC3.1	L-4	9	5	2	55.56%	22.22%	17	225	50.73
12	OHOP2.2D	L-4	6	3	3	50.00%	50.00%	9	610	66.99
13	YELMCR(RM0.1)	L-4	24	11	5	45.83%	20.83%	5	4000	54.69
14	N FLOW	L-4	7	3	3	42.86%	42.86%	5	5450	92.44
15	OHOP6.2T	L-4	7	3	3	42.86%	42.86%	6	270	57.35
16	TG9W	L-4	8	3	3	37.50%	37.50%	5	1700	64.63

FC 100 cfu Results: The analysis criterion for this data setwas > 100 cfu/100 ml. Of 52 total sites where FC samples were taken, the results shown in Table 2.3 are the 14 sites that met the 35% plus geometric mean standard. For this parameter, the percentile range was from 46.43% to 94.75% of the times not meeting the analysis criteria. The minimum geometric mean is 104.75 cfu/100 ml for Site ID – OHOP CR(RM0.1) (Record # 12), and the maximum is 1176.17 cfu/100 ml for Site ID – S PIPE (Record # 1). For Record # 1 the maximum parameter result number is very high at 1,090,000 cfu/100 ml (highlighted in blue with red numbers). It is possible that this is an outlier in the data. With this one record eliminated from analysis, the Site ID – S Pipe would still rank very high in this study. Without the outlier, the S PIPE site would rank

94.44% for > 100 cfu/100 ml and the maximum result is 62,000cfu/100 ml. The adjusted geometric mean for this site would be 804.71cfu, which is still the highest for this set of records.

Table 2.3: Results for degraded fecal coliform levels (geo mean > 100 cfu) WRIA 11.
Results for FC 100 cfu: Fourteen sites met the 35% plus geometric mean standard.



	Site Info		FC 100 cfu - Analysis Results - WRIA 11							
#	Site_ID	QA	Records	> 50cfu	> 100cfu	% > 50cfu	% > 100cfu	Min	Max	Geo Mean
1	S PIPE	L-4	19	18	18	94.74%	94.74%	15	1090000	1176.17
2	COMBINED 1	L-4	6	5	5	83.33%	83.33%	43	1000	484.07
3	OHOPCR(RM0.1)	L-4	13	12	9	92.31%	69.23%	40	6510	223.02
4	9 GLACIS RD NE	L-4	9	7	6	77.78%	66.67%	10	8700	208.82
5	WASH	L-4	5	5	3	100.00%	60.00%	64	245	111.29
6	H3 STORM	L-4	5	4	3	80.00%	60.00%	15	15500	362.39
7	1 D'MILLUHR DR	L-4	5	3	3	60.00%	60.00%	5	5300	126.63
8	12A SCENIC DR	L-4	5	3	3	60.00%	60.00%	23	19000	244.96
9	12B SCENIC DR	L-4	5	3	3	60.00%	60.00%	5	2500	117.53
10	OHOPCR(RM3.3)	L-4	22	19	13	86.36%	59.09%	5	2915	196.33
11	OHOPCR(RM2.0)	L-4	21	17	12	80.95%	57.14%	10	2400	189.08
12	OHOPCR(RM0.1)	L-4	49	32	27	65.31%	55.10%	5	1535	104.75
13	MUCKCR(RM6.2)	L-4	11	7	6	63.64%	54.55%	10	4775	116.39
14	MCALLISTER3.1	L-4	28	23	13	82.14%	46.43%	15	2500	133.07

Turbidity Results: The analysis criterion for this data set was > 7.8 NTU (5 NTU above background). Of 34 total sites where TURB samples were taken, the results shown in Table 2.4 show the 5 sites that met the 35% plus geometric mean standard. There are also 6 sites that were 35% or greater that didn't meet the geometric mean standard, but were of significant interest because of the maximum NTU numbers (highlighted in blue). For this parameter, the percentile range was from 36.36% to 56.25% of the times not meeting the analysis criteria. The minimum geometric mean is 4.72 NTU for Site ID – NISQUALLY (3.7) (Record # 10), and the maximum is 9.18 NTU for Site ID – 11A070 (Record # 6). The maximum result NTU numbers could be the result of mass wasting or erosion during storm events. Precipitation data would need to be added to the analysis to make that determination.

Table 2.4: Results For Degraded Turbidity Levels (Geo Mean > 7.8 NTU) WRIA 11.

Results for Turbidity: Five sites met the 35% plus geometric mean standard and 6 sites were added because of the high maximum NTU numbers that met the 35% or greater, but did not meet the geometric mean standard (blue highlight).

	Site Info		Turbidity - Analysis Results - WRIA 11							
#	Site_ID	QA	Records	> 7.8_NTU	> 12.8_NTU	% > 7.8 NTU	% > 12.8 NTU	Min	Max	Geo Mean
1	NISQUALLY(39.7)	L4	16	9	5	56.25%	31.25%	2	60	7.43
2	11A090	L5	18	10	4	55.56%	22.22%	1.5	410	8.22
3	LIITLEMASHELRV	L4	35	18	12	51.43%	34.29%	0.7	165.2	7.48
4	OHOPCR(RM0.1)	L4	68	34	16	50.00%	23.53%	1.3	248	9.15
5	OHOPCR(RM2.0)	L4	22	11	4	50.00%	18.18%	3.2	22.1	7.88
6	11A070E	L5	120	59	38	49.17%	31.67%	1.5	720	9.18
7	11A070D	L5	132	64	46	48.48%	34.85%	1.1	850	8.37
8	11A080D	L5	30	12	9	40.00%	30.00%	1	205	7.07
9	LYNCH CREEK	L4	36	14	7	38.89%	19.44%	1.2	85.2	6.24
10	NISQUALLY(3.7)	L4	16	6	2	37.50%	12.50%	1.1	50	4.72
11	OHOPCR(RM3.3)	L4	22	8	5	36.36%	22.73%	2.8	28.5	7.53

Temperature Results: The temperature analysis was broken down into four seasonal and inhabitation temperature requirements for a variety of species. The four categories were segmented from the total temperature records for each monitoring site by date range and temperature requirements for suitable species habitation. The first category (Temp 1) has a monitoring range for an entire annual cycle for char rearing and foraging. The temperature criteria for this category is 12°C (54.6°F) and the results of analysis are shown in Table 2.5 below. The second category (Temp 2) has a date range from September 16th to June 14th for fall, winter and spring (F/W/Sp) salmon and trout spawning. The temperature criteria for this category is 13°C (55.4°F) and the results of analysis are shown in Table 2.6 below. The third category (Temp 3) has a date range from June 15th – September 15th for core summer salmonid habitat. The temperature criteria for this category is 16°C (60.8°F) and the results of analysis are shown in Table 2.7 below. The fourth category (Temp 4) has a date range from September 16th – December 22nd for fall char spawning. The temperature criteria for this category is 9°C (48.2°F) and the results of analysis are shown in Table 2.8 below. All of these temperature tables show the results based on the 35% plus geometric mean standard. Information of date ranges and temperature criteria are from the Department of Ecology's

Water Quality Standards for Surface Water of the State of Washington, Chapter 173-201A WAC (WA Ecology, 2006).

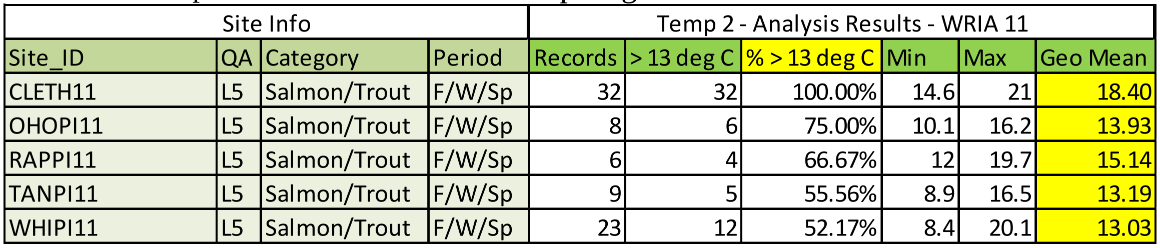
Analysis for the first category (Temp 1) all year char rearing took continuous annual water quality temperature data with an analysis criteria of 12°C (54.6°F) for WRIA 11. This resulted in 21 records that met the 35% plus geometric mean standard. The percentage of time that the data did not meet the analysis criteria ranged from 46.67% to 100% with a geometric mean range from 12.16 °C to 19.94°C. The results are listed in Table 2.5 below.

Table 2.5: All Year Temperature Results for the Char Rearing Category in WRIA 11.
Results for Temp 1: Twenty-one records met the 35% plus geometric mean standard.

Site Info				Temp 1 - Analysis Results - WRIA 11					
Site_ID	QA	Category	Period	Records	> 12 deg C	% > 12 deg C	Min	Max	Geo Mean
CLETH11	L5	Char_Rearing	All_Year	47	47	100.00%	14.6	23.1	19.41
SILVERLAKE	L4	Char_Rearing	All_Year	23	23	100.00%	13.5	25.8	19.17
TANWAXLAKE	L4	Char_Rearing	All_Year	21	21	100.00%	12.7	26.1	19.94
RAPJOHNLAKE	L4	Char_Rearing	All_Year	21	20	95.24%	12	25.8	17.73
OHOPLAKE	L4	Char_Rearing	All_Year	19	18	94.74%	11.4	24.5	18.77
RAPPI11	L5	Char_Rearing	All_Year	10	9	90.00%	12	20.2	15.85
OHOPI11	L5	Char_Rearing	All_Year	15	12	80.00%	10.1	23.1	15.70
OHOPCR(RM6.3)	L4	Char_Rearing	All_Year	51	38	74.51%	6.2	27.1	15.19
MID-LAKEDRAIN	L4	Char_Rearing	All_Year	35	25	71.43%	4.4	16.2	12.16
RSWT	L4	Char_Rearing	All_Year	7	5	71.43%	6.98	19.2	13.17
TG13L	L4	Char_Rearing	All_Year	10	7	70.00%	11.3	17.04	13.14
TANPI11	L5	Char_Rearing	All_Year	16	11	68.75%	8.9	23.6	14.84
OHOPLAKESTA2	L4	Char_Rearing	All_Year	134	92	68.66%	5.5	25.2	13.47
MINERALLAKE	L4	Char_Rearing	All_Year	25	17	68.00%	8.3	23.8	15.29
WHIPI11	L5	Char_Rearing	All_Year	42	27	64.29%	8.4	22.5	14.40
CLEARLAKE	L4	Char_Rearing	All_Year	24	15	62.50%	6.9	24.6	14.69
OHOPLAKESTA3	L4	Char_Rearing	All_Year	55	34	61.82%	5	25.9	12.90
MC4.4TLBU	L4	Char_Rearing	All_Year	5	3	60.00%	9.16	16.7	12.83
OHOPLAKESTA1	L4	Char_Rearing	All_Year	73	43	58.90%	5.8	26.1	12.46
TG9W	L4	Char_Rearing	All_Year	6	3	50.00%	8.24	20.01	12.16
MUCKCR(RM6.2)	L4	Char_Rearing	All_Year	15	7	46.67%	4.5	22.2	12.19

Analysis for the second category (Temp 2) for salmon and trout spawning took ongoing water quality temperature data that had a date range from September 16th to June 14th. This covered the fall, winter and spring (F/W/Sp) salmon and trout spawning habitation period with an analysis criteria of 13°C (55.4°F) for WRIA 11. This resulted in 5 records that met the 35% plus geometric mean standard. The percentage of time that the data did not meet the analysis criteria ranged from 52.17% to 100% with a geometric mean range from 13.03 °C to 18.40°C. The results are listed in Table 2.6 below.

Table 2.6: F/W/Sp Temperature Results for Salmon & Trout Category WRIA 11.
Results for Temp 2: Five records met the 35% plus geometric mean standard.



Site Info				Temp 2 - Analysis Results - WRIA 11					
Site_ID	QA	Category	Period	Records	> 13 deg C	% > 13 deg C	Min	Max	Geo Mean
CLETH11	L5	Salmon/Trout	F/W/Sp	32	32	100.00%	14.6	21	18.40
OHOPI11	L5	Salmon/Trout	F/W/Sp	8	6	75.00%	10.1	16.2	13.93
RAPPI11	L5	Salmon/Trout	F/W/Sp	6	4	66.67%	12	19.7	15.14
TANPI11	L5	Salmon/Trout	F/W/Sp	9	5	55.56%	8.9	16.5	13.19
WHIPI11	L5	Salmon/Trout	F/W/Sp	23	12	52.17%	8.4	20.1	13.03

The analysis for the third category (Temp 3) for core salmonid habitat, took ongoing water quality temperature data that had a date range from June 15th to September 15th. This covered the core summer salmonid habitation period with an analysis criteria of 16°C (60.8°F) for WRIA 11. This resulted in 16 records that met the 35% plus geometric mean standard. Four sites in this analysis were included that did not meet the geometric mean standard. Site ID – 11A070D had a high percentage failure of 84.85% not meeting the criteria (Blue Highlight). Three other sites (Site IDs: MINERALLAKE, CLEARLAKE and HARPI11) had a percentage criteria failure range from 40% to 56% and maximum temperature records from 23.8°C to 24.6°C (blue highlight). The percentage of time that the data in this table did not meet the analysis criteria ranged from 40% to 100% with a geometric mean range from 13.57 °C to 22.01°C. The results are listed in Table 2.7 below.

Table 2.7: Summer Temperature Results for the Core Salmonid Category in WRIA 11. Results for Temp 3: Sixteen records met the 35% plus geometric mean standard. One record had a high criteria failure rate and three records failed the criteria analysis with high maximum temperatures (blue highlight).

Site Info				Temp 3 - Analysis Results - WRIA 11					
Site_ID	QA	Category	Period	Records	> 16 deg C	% > 16 deg C	Min	Max	Geo Mean
CLETH11	L5	Core Salmonid	Summer	15	15	100.00%	20.1	23.1	21.75
OHOPCR(RM6.3)	L4	Core Salmonid	Summer	21	21	100.00%	16.5	27.1	22.01
OHOPLAKESTA3	L4	Core Salmonid	Summer	21	19	90.48%	13.6	25.9	19.31
OHOPCR(RM6.0)	L4	Core Salmonid	Summer	7	6	85.71%	14.8	24.4	18.91
11A070D	L5	Core Salmonid	Summer	33	28	84.85%	9.3	17	13.57
TANWAXLAKE	L4	Core Salmonid	Summer	21	17	80.95%	12.7	26.1	19.94
MASHELRV(RM6.0)	L4	Core Salmonid	Summer	5	4	80.00%	14.3	20.5	17.77
MUCKCR(RM6.2)	L4	Core Salmonid	Summer	5	4	80.00%	15	22.2	18.45
OHOPLAKE	L4	Core Salmonid	Summer	19	15	78.95%	11.4	24.5	18.77
SILVERLAKE	L4	Core Salmonid	Summer	23	18	78.26%	13.5	25.8	19.17
OHOPLAKESTA1	L4	Core Salmonid	Summer	28	21	75.00%	11.3	26.1	17.93
OHOPI11	L5	Core Salmonid	Summer	7	5	71.43%	12	23.1	17.99
RAPJOHNLAKE	L4	Core Salmonid	Summer	21	14	66.67%	12	25.8	17.73
OHOPLAKESTA2	L4	Core Salmonid	Summer	56	37	66.07%	11	25.2	17.21
OHOPCR(RM0.1)	L4	Core Salmonid	Summer	17	10	58.82%	12.6	21.4	16.23
WHIPI11	L5	Core Salmonid	Summer	19	11	57.89%	9.9	22.5	16.25
TANPI11	L5	Core Salmonid	Summer	7	4	57.14%	11	23.6	17.28
MINERALLAKE	L4	Core Salmonid	Summer	25	14	56.00%	8.3	23.8	15.29
CLEARLAKE	L4	Core Salmonid	Summer	24	12	50.00%	6.9	24.6	14.69
HARPI11	L5	Core Salmonid	Summer	40	16	40.00%	6.4	24.06	12.34

The analysis for the fourth category (Temp 4) for char spawning, took ongoing water quality temperature data that had a date range from September 16th to December 22nd. This covered the fall char spawning habitation period with an analysis criteria of 9°C (48.2°F) for WRIA 11. This resulted in 13 records that met the 35% plus geometric mean standard. Two sites in this analysis were included that did not meet the geometric mean standard. Site IDs OHOPCR(RM9.9) and OHOPCR(RM0.1) had a 44.44% to 46.15% percentage failure not meeting the criteria and high maximum temperatures from 13.3°C to 15°C (blue highlight). The percentage of time that the data in this table did not meet the analysis criteria ranged from 40% to 100% with a geometric mean range from 7.64 °C to 19.14°C. The results are listed in Table 2.8 below.

Table 2.8: Fall Temperature Results for the Char Spawning Category in WRIA 11. Results for Temp 4: Thirteen records met the 35% plus geometric mean standard. Two records had high maximum temperatures (blue highlight).

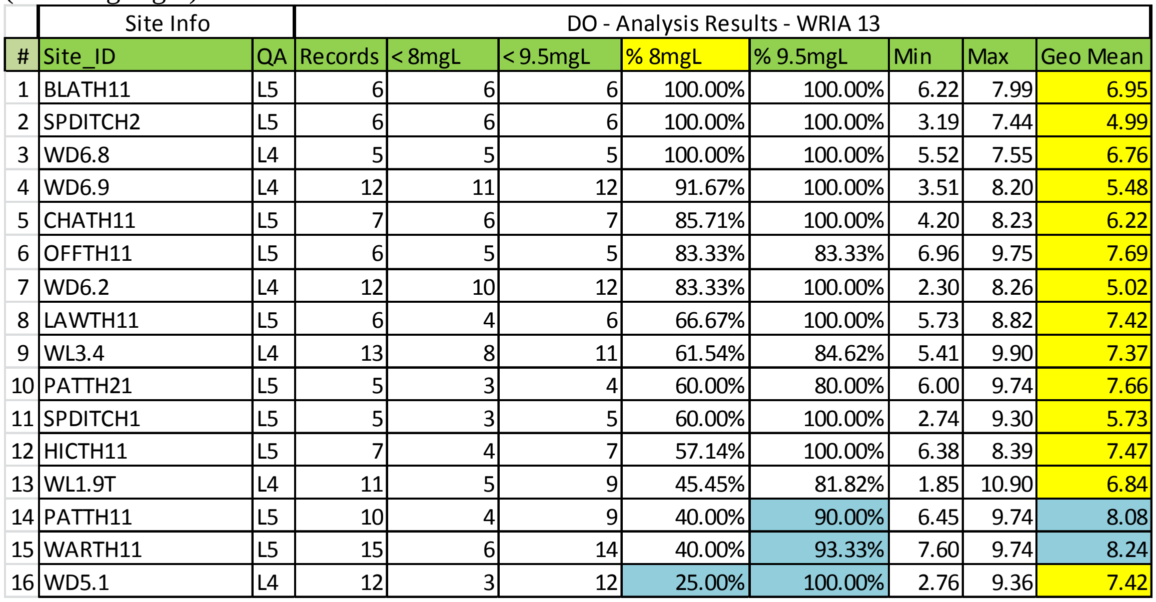
Site Info				Temp 4 - Analysis Results - WRIA 11					
Site_ID	QA	Category	Period	Records	> 9 deg C	% > 9 deg C	Min	Max	Geo Mean
CLETH11	L5	Char Spawning	Fall	16	16	100.00%	19	19.5	19.14
MC4.3	L4	Char Spawning	Fall	6	6	100.00%	9.01	9.73	9.36
MC5.4	L4	Char Spawning	Fall	6	6	100.00%	9.02	9.8	9.40
MC5.8	L4	Char Spawning	Fall	5	5	100.00%	9.06	9.77	9.34
OHOPLAKESTA2	L4	Char Spawning	Fall	41	29	70.73%	6.2	18	12.37
OHOPCR(RM6.3)	L4	Char Spawning	Fall	12	8	66.67%	6.7	18	12.04
HARTSLAKE	L4	Char Spawning	Fall	8	5	62.50%	6.9	20.8	11.93
11A070E	L5	Char Spawning	Fall	39	22	56.41%	3.6	16.4	9.18
MC4.7	L4	Char Spawning	Fall	6	3	50.00%	8.95	9.75	9.34
OHOPCR(RM9.9)	L4	Char Spawning	Fall	13	6	46.15%	4.2	13.3	8.69
OHOPCR(RM0.1)	L4	Char Spawning	Fall	18	8	44.44%	2.8	15	7.64
OHOPLAKESTA3	L4	Char Spawning	Fall	16	7	43.75%	6	18.3	10.46
MC3.7	L4	Char Spawning	Fall	7	3	42.86%	8.99	9.75	9.31
OHOPLAKESTA1	L4	Char Spawning	Fall	21	9	42.86%	6.2	18	10.52
MC4.5	L4	Char Spawning	Fall	5	2	40.00%	8.94	9.72	9.24

Results for WRIA 13:

The following tables show the results of analysis performed on water quality data for Dissolved Oxygen (DO), Fecal Coliform (FC), pH, Turbidity (TURB) and Temperature (TEMP) in the Deschutes Basin (WRIA 13). The results in the following tables were derived from a series of criteria designed to cull out sample sites showing degraded water quality. The study sites in the following tables are a list of those meeting the 35% plus geometric mean standard. These tables were used in the Deschutes Basin analysis study.

DO Results: The analysis criterion for this data set was < 8 mg/L. Of 49 total sites where DO samples were taken (See Table 2.9), there were 13 sites that met the 35% plus geometric mean standard. Included in this table are two sites, Site ID – PATTH11 (Record #14) and Site ID – WARTH11 (Record #15), that did not meet the geometric mean standard, but were above the 35 percentile. One other site of interest included was WD5.1 (Record # 16), which did meet the geometric mean standard, but was below the 35 percentile standard. These three sites are of interest because they failed to meet the dissolved oxygen analysis criteria 90% or more of the time for the high water quality standard of 9.5mg/L. For this parameter, the percentile range was from 25% to 100% of the times not meeting the analysis criteria. The minimum geometric mean is 4.99 mg/L for the Site ID – SPDITCH2 (Record #2), and the maximum is 8.24 mg/L for Site ID – WARTH11 (Record # 15).

Table 2.9: Results for Degraded Dissolved Oxygen Levels (Geo Mean < 8mg/L) WRIA 13. Results for DO: Fourteen sites met the 35% plus geometric mean standard. Three sites had low DO records and failed the criteria 90% to 100% for high water quality standards of 9.5mg/L (Blue Highlight).



	Site Info		DO - Analysis Results - WRIA 13							
#	Site_ID	QA	Records	< 8mgL	< 9.5mgL	% 8mgL	% 9.5mgL	Min	Max	Geo Mean
1	BLATH11	L5	6	6	6	100.00%	100.00%	6.22	7.99	6.95
2	SPDITCH2	L5	6	6	6	100.00%	100.00%	3.19	7.44	4.99
3	WD6.8	L4	5	5	5	100.00%	100.00%	5.52	7.55	6.76
4	WD6.9	L4	12	11	12	91.67%	100.00%	3.51	8.20	5.48
5	CHATH11	L5	7	6	7	85.71%	100.00%	4.20	8.23	6.22
6	OFFTH11	L5	6	5	5	83.33%	83.33%	6.96	9.75	7.69
7	WD6.2	L4	12	10	12	83.33%	100.00%	2.30	8.26	5.02
8	LAWTH11	L5	6	4	6	66.67%	100.00%	5.73	8.82	7.42
9	WL3.4	L4	13	8	11	61.54%	84.62%	5.41	9.90	7.37
10	PATTH21	L5	5	3	4	60.00%	80.00%	6.00	9.74	7.66
11	SPDITCH1	L5	5	3	5	60.00%	100.00%	2.74	9.30	5.73
12	HICTH11	L5	7	4	7	57.14%	100.00%	6.38	8.39	7.47
13	WL1.9T	L4	11	5	9	45.45%	81.82%	1.85	10.90	6.84
14	PATTH11	L5	10	4	9	40.00%	90.00%	6.45	9.74	8.08
15	WARTH11	L5	15	6	14	40.00%	93.33%	7.60	9.74	8.24
16	WD5.1	L4	12	3	12	25.00%	100.00%	2.76	9.36	7.42

FC 50 cfu Results: The analysis criterion for this dataset was > 50 cfu/100 ml. Of 83 total sites where the FC samples were taken, the results shown in Table 2.10 are the 14 sites that met the 35% plus geometric mean standard. Included in this table are two sites, Site ID – SWO Stormwater (Record #15) and Site ID – WL3.1T (Record #16), that did not meet the geometric mean standard, but were above the 35th percentile. These two sites were of interest because of their high cfu/100 ml count. For this parameter, the percentile range was from 36.36% to 80% of the times not meeting the analysis criteria. The minimum geometric mean is 34.79 cfu/100 ml for Site ID – SWO Stormwater (Record #15), and the maximum is 99.41 cfu/100 ml for Site ID – WL0.2 (Record # 3).

Table 2.10: Results for Degraded Fecal Coliform Levels (geo mean > 50 cfu) WRIA 13. Results for FC 50 cfu: Fourteen sites that met the 35% plus geometric mean standard. Two sites had high maximum cfu/100ml numbers (blue highlight).

	Site Info		FC >50 CFU - Analysis Results - WRIA 13							
#	Site_ID	QA	Records	> 50cfu	> 100cfu	% > 50cfu	% > 100cfu	Min	Max	Geo Mean
1	WOODLANDCR7	L4	5	4	2	80.00%	40.00%	5	163	51.81
2	WD0.0	L4	9	7	4	77.78%	44.44%	7	445	78.46
3	WL0.2	L4	12	9	7	75.00%	58.33%	6	740	99.41
4	MY0.1	L4	8	6	4	75.00%	50.00%	1	1200	90.89
5	WOODLANDCR6	L4	6	4	1	66.67%	16.67%	22	150	63.98
6	WL2.6	L4	10	6	4	60.00%	40.00%	10	650	79.12
7	WL1.95T	L4	7	4	3	57.14%	42.86%	9	380	72.93
8	WD6.9	L4	9	5	2	55.56%	22.22%	17	245	59.32
9	WL3.45	L4	11	6	4	54.55%	36.36%	6	4000	74.05
10	CC0.0	L4	11	6	2	54.55%	18.18%	11	285	54.03
11	WL2.9	L4	11	6	2	54.55%	18.18%	8	735	59.92
12	WL2.25T	L4	10	5	5	50.00%	50.00%	3	2900	70.05
13	WL3.1	L4	11	5	2	45.45%	18.18%	19	880	56.43
14	CC0.2	L4	7	3	1	42.86%	14.29%	28	260	54.09
15	SWO STORMWATER	L4	5	2	2	40.00%	40.00%	5	1700	34.79
16	WL3.1T	L4	11	4	2	36.36%	18.18%	1	63000	40.94

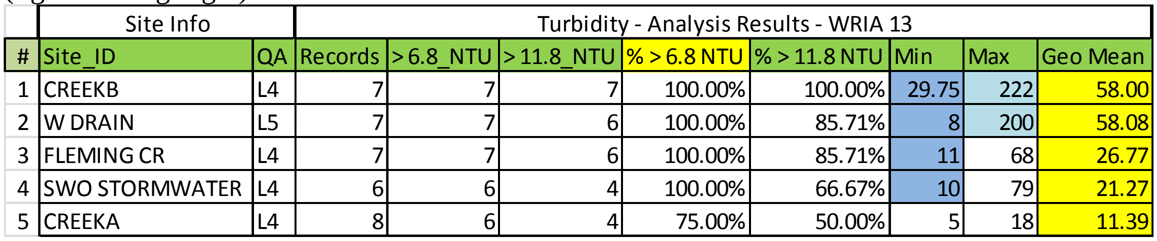
FC 100 cfu Results: The analysis criterion for this data set was > 100 cfu/100 ml. Out of 83 total sites where FC samples were taken, the results shown in Table 2.11 are the 43 sites that met the 35% plus geometric mean standard. For this parameter, the percentile range was from 45.45% to 100% of the times not meeting the analysis criteria. The minimum geometric mean is 106.09 cfu/100 ml for Site ID – SPDITCH2 (Record # 43), and the maximum is 1184.21 cfu/100 ml for Site ID – MANHOLESOUTH (Record # 12).

Table 2.11: Results for Degraded Fecal Coliform Levels (geo mean > 100 cfu) WRIA 13. Results FC 100 cfu: Forty-three sites that met the 35% plus geometric mean standard.

	Site Info		FC >100CFU - Analysis Results - WRIA 13							
#	Site_ID	QA	Records	> 50cfu	> 100cfu	% > 50cfu	% > 100cfu	Min	Max	Geo Mean
1	13-IND-BOUL-TC	L4	11	11	11	100.00%	100.00%	115	2200	373.47
2	13-IND-CENT	L4	10	10	10	100.00%	100.00%	100	1680	370.04
3	WL2.6SW	L4	6	6	6	100.00%	100.00%	280	3100	597.40
4	WOODLANDCR1	L4	4	4	4	100.00%	100.00%	452	3450	797.89
5	WOODLANDCR2	L4	6	6	6	100.00%	100.00%	125	1900	390.25
6	13-IND-QUIN	L4	11	11	10	100.00%	90.91%	90	1570	436.33
7	14MCLANEMC1	L4	11	11	10	100.00%	90.91%	90	455	232.50
8	14MCLANEMC2	L4	11	11	10	100.00%	90.91%	60	455	208.48
9	DB1.0	L5	9	9	8	100.00%	88.89%	78	5400	512.20
10	WOODLANDCR3	L4	8	8	7	100.00%	87.50%	60	5200	491.49
11	W DRAIN	L5	5	5	4	100.00%	80.00%	57	7570	303.89
12	MANHOLESOUTH	L4	5	5	4	100.00%	80.00%	90	8200	1184.21
13	MARTIN WAY	L4	5	5	4	100.00%	80.00%	55	4300	377.58
14	WOODLANDCR4	L4	8	8	6	100.00%	75.00%	62	1325	284.01
15	14MCLANEUN1	L4	10	10	7	100.00%	70.00%	73	298	130.66
16	WL1.0	L4	10	10	6	100.00%	60.00%	58	300	139.01
17	WOODLANDCR5	L4	7	7	3	100.00%	42.86%	58	6350	224.62
18	14MCLANEMC2.5	L4	11	10	8	90.91%	72.73%	30	260	142.85
19	WD2.9	L4	9	8	6	88.89%	66.67%	27	480	127.44
20	WD3.4	L4	9	8	6	88.89%	66.67%	12	610	129.10
21	WD5.1	L4	9	8	6	88.89%	66.67%	22	515	149.06
22	WL1.1T	L4	9	8	6	88.89%	66.67%	33	5200	252.52
23	WL1.2T	L4	9	8	6	88.89%	66.67%	38	930	207.43
24	FLEMING CR	L4	7	6	5	85.71%	71.43%	5	980	145.19
25	SL0.8	L4	7	6	4	85.71%	57.14%	20	670	110.35
26	CC0.6	L4	6	5	5	83.33%	83.33%	6	1800	224.89
27	CC0.4	L4	6	5	4	83.33%	66.67%	17	530	136.01
28	CREEKB	L4	6	5	3	83.33%	50.00%	25	2900	207.02
29	DB0.1	L4	11	9	8	81.82%	72.73%	18	6000	246.09
30	14MCLANEDV1	L4	11	9	7	81.82%	63.64%	30	1500	145.57
31	WD6.8	L4	5	4	4	80.00%	80.00%	20	550	162.65
32	DBTRIB0.73	L5	10	8	7	80.00%	70.00%	7	700	141.09
33	14MCLANESW1	L4	10	8	5	80.00%	50.00%	10	7000	110.55
34	DOBBS CREEK	L4	5	4	2	80.00%	40.00%	25	680	124.36
35	DB1.0	L4	8	6	5	75.00%	62.50%	2	3300	142.95
36	WL3.8T	L4	7	5	5	71.43%	71.43%	5	7800	317.16
37	DB0.1	L5	10	7	7	70.00%	70.00%	19	2900	131.14
38	DB0.731	L5	10	7	6	70.00%	60.00%	31	5300	143.51
39	DOBBSCRK	L5	10	7	6	70.00%	60.00%	35	4900	157.62
40	SL0.1	L4	10	7	5	70.00%	50.00%	4	660	106.69
41	TANGLEWILDE	L4	9	6	6	66.67%	66.67%	5	6400	219.52
42	WL1.6	L4	10	6	6	60.00%	60.00%	10	1100	108.97
43	SPDITCH2	L5	11	6	5	54.55%	45.45%	2	5800	106.09

Turbidity Results: The analysis criterion for this data set was > 6.8 NTU (5 NTU above background). Of 14 total sites where TURB samples were taken, the results shown in Table 2.12 show the 5 sites that met the 35% plus geometric mean standard. For this parameter, the percentile range was from 75% to 100% of the times not meeting the analysis criteria. The minimum geometric mean is 11.39 NTU for Site ID – CREEKA (Record # 5), and the maximum is 58.08 NTU for Site ID – W DRAIN (Record # 2). Also noteworthy in Table 2.12 is that four of the sites (Records 1 through 4) had all minimum NTU results above the analysis criteria of > 6.8 NTU (shown in dark blue). The first two sites (Records #1 & #2) also show a very high maximum NTU count (shown in light blue). The Site ID – CREEKB (Record # 1) has a minimum of 29.75 NTU and a maximum of 222 NTU. Water quality samples for the CREEKB site were taken over an eleven month period for 1/27/2000 to 11/15/2001. The Department of Ecology's EIM (Ecy-3, 2011) provided no further data for turbidity at this location after 11/15/2001. To understand the cause for high NTU counts at this site, it would be necessary to continue water quality sampling and field survey of the flow basin influence at this site to establish the source of disturbance or cause of erosion. The other maximum result NTU numbers could also result from mass wasting or erosion during storm events. Precipitation data would need to be added to the analysis to make that determination.

Table 2.12: Results for Degraded Turbidity Levels (geo mean > 6.8 NTU) WRIA 13. Five sites met the 35% plus geometric mean standard. Four site with very high minimum NTU numbers (dark blue highlight), and two of those sites with very high maximum NTU numbers (light blue highlight).



	Site Info		Turbidity - Analysis Results - WRIA 13							
#	Site_ID	QA	Records	> 6.8_NTU	> 11.8_NTU	% > 6.8 NTU	% > 11.8 NTU	Min	Max	Geo Mean
1	CREEKB	L4	7	7	7	100.00%	100.00%	29.75	222	58.00
2	W DRAIN	L5	7	7	6	100.00%	85.71%	8	200	58.08
3	FLEMING CR	L4	7	7	6	100.00%	85.71%	11	68	26.77
4	SWO STORMWATER	L4	6	6	4	100.00%	66.67%	10	79	21.27
5	CREEKA	L4	8	6	4	75.00%	50.00%	5	18	11.39

pH Results: The analysis criterion for this data set was < 6.5 or > 8.5. Of 48 total sites where pH samples were taken, the results shown in Table 2.13 are the 6 sites that met the 35% plus geometric mean standard. For this parameter, the percentile range was from 50% to 100% of the times not meeting the analysis criteria. The minimum geometric mean is 5.85 pH for Site ID – GO0.4 (Record # 1), and the maximum is 6.4 pH for Site ID – CC0.4 (Record # 5). The minimum pH is below the analysis criteria at all six sites and the maximum also has a low pH for Site ID – GO0.4 (Record # 1). The geometric means for all six sites are also below the analysis criteria. This shows a tendency for a more acidic aquatic habitat. **Note**: A lower (or more acidic) pH level has an effect on aquatic ecosystems. Acidification can indirectly affect biota by altering the availability of food, and is likely to reduce the number of microorganisms that are important to the decomposition of organic matter, thus reducing availability of nutrients to other consumers. Failure of eggs to develop or increased mortality has been demonstrated in field and lab tests. The pH in freshwater systems can widely vary from acidic to alkaline, but extremes where pH is much less than 5 or greater than 9 are found to be harmful to organisms (Allan, 1995).

Table 2.13: Results for Degraded pH Levels (geo mean < 6.5 or > 8.5) WRIA 13.
Results for pH: 6 sites met the 35% plus geometric mean standard.

	Site Info		pH - Analysis Results - WRIA 13					
#	Site_ID	QA	Records	< 6.5 or > 8.5	% < 6.5 or > 8.5	Min	Max	Geo Mean
1	GO0.4	L4	5	5	100.00%	5.6	6.2	5.85
2	CC0.6	L4	6	5	83.33%	5.88	7.68	6.29
3	CC0.2	L4	8	6	75.00%	5.92	6.86	6.39
4	SL0.8	L4	7	5	71.43%	5.9	7.8	6.39
5	CC0.4	L4	7	4	57.14%	5.95	7.07	6.40
6	SPDITCH2	L5	6	3	50.00%	4.92	7.06	6.29

Temperature Results: As with the previous section on temperature results, the analysis for temperature was broken down into four seasonal and inhabitation temperature requirements for a variety of species. The four categories were segmented from the total temperature records for each monitoring site by date range and temperature requirements for suitable species habitation. The first category (Temp 1) has a monitoring range for an entire annual cycle for char rearing and foraging. The temperature criterion for this category is 12°C (54.6°F) and the results of analysis are shown in Table 2.14. The second category (Temp 2) has a date range from September 16th to June 14th for fall, winter and spring (F/W/Sp) salmon and trout spawning. The temperature criterion for this category is 13°C (55.4°F) and the results of analysis are shown in Table 2.15. The third category (Temp 3) has a date range from June 15th – September 15th for core summer salmonid habitat. The temperature criterion for this category is 16°C (60.8°F) and the results of analysis are shown in Table 2.16. The fourth category (Temp 4) has a date range from September 16th – December 22nd for fall char spawning. The temperature criterion for this category is 9°C (48.2°F) and the results of analysis are shown in Table 2.17. All the following temperature tables show the results based on the 35% plus geometric mean standard. Information of date ranges and temperature criteria are from the Department of Ecology's Water Quality Standards for Surface Water of the State of Washington, Chapter 173-201A WAC (WA Ecology, 2006).

The analysis for the first category (Temp 1) all year char rearing took continuous annual water quality temperature data with an analysis criterion of 12°C (54.6°F) for WRIA 13. This resulted in 11 records that met the 35% plus geometric mean standard. Eight sites in this analysis were included that did not meet the geometric mean standard. One site (Site ID – SRC) failed to meet the analysis criterion 66.67% of the time. The other seven sites (Site IDs: WARTH11, G07001162238, W RM 3.7, W RM 4.2, 13A060D, W RM 3.8 and 13A060E) were included because of the high maximum temperatures greater than 6°C above analysis criterion. The percentage of time that the data did not meet the analysis criterion ranged from 35.29% to 100% with a geometric mean range from 9.63 °C to 19.16°C. The results are listed in Table 2.14 below.

Table 2.14: All Year Temperature Results for the Char Rearing Category in WRIA 13. Results for Temp 1: Eleven records met the 35% plus geometric mean standard. One record had a criteria failure of 66.67%, and seven records had high maximum temperatures (blue highlight).

Site Info				Temp 1 - Analysis Results - WRIA 13					
Site_ID	QA	Category	Period	Records	> 12 deg C	% > 12 deg C	Min	Max	Geo Mean
CHATH11	L5	Char_Rearing	All_Year	34	34	100.00%	12.8	23.8	18.86
MCITH11	L5	Char_Rearing	All_Year	58	58	100.00%	14.2	21.14	18.56
BLATH11	L5	Char_Rearing	All_Year	53	53	100.00%	13	22.3	17.92
LAWTH11	L5	Char_Rearing	All_Year	66	64	96.97%	11.8	21.7	18.19
OFFTH11	L5	Char_Rearing	All_Year	61	59	96.72%	11	25.1	18.11
PATTH21	L5	Char_Rearing	All_Year	27	26	96.30%	12	22.2	19.16
LONTH11	L5	Char_Rearing	All_Year	59	54	91.53%	9.6	23.8	17.86
MUNTH11	L5	Char_Rearing	All_Year	28	23	82.14%	10.1	22.8	15.57
LOWER	L5	Char_Rearing	All_Year	11	9	81.82%	10.9	15	12.85
PATTH11	L5	Char_Rearing	All_Year	84	60	71.43%	9.98	23.6	15.34
HICTH11	L5	Char_Rearing	All_Year	88	60	68.18%	8.86	23.7	14.88
SCR	L5	Char_Rearing	All_Year	6	4	66.67%	5.2	14.5	9.91
WARTH11	L5	Char_Rearing	All_Year	229	113	49.34%	5.9	24.4	11.91
G07001162238	L4	Char_Rearing	All_Year	26	12	46.15%	3.97	22.56	10.32
W RM 3.7	L5	Char_Rearing	All_Year	36	16	44.44%	4.3	20.4	10.85
W RM 4.2	L5	Char_Rearing	All_Year	43	19	44.19%	4.5	22.1	10.60
13A060D	L5	Char_Rearing	All_Year	120	45	37.50%	2.2	19.8	9.73
W RM 3.8	L5	Char_Rearing	All_Year	41	15	36.59%	4.4	21.1	10.67
13A060E	L5	Char_Rearing	All_Year	119	42	35.29%	2.7	18.9	9.63

Analysis for the second category (Temp 2) for salmon and trout spawning, took ongoing water quality temperature data with a date range from September 16th to June 14th. This covered the fall, winter and spring (F/W/Sp) salmon and trout spawning inhabitation period with an analysis criterion of 13°C (55.4°F) for WRIA 13. This resulted in 10 records that met the 35% plus geometric mean standard. One site (Sire ID – WARTH11) was included because of the high maximum temperatures 9°C above analysis criterion. The percentage of time that the data did not meet the analysis criterion ranged from 43.55% to 100% with a geometric mean range from 11.33 °C to 17.77°C. The results are listed in Table 2.15 below.

Table 2.15: F/W/Sp Temperature Results for Salmon & Trout Category WRIA 13. Results for Temp 2: Ten records met the 35% plus geometric mean standard. One record was at 9°C above criteria (blue highlight).

Site Info				Temp 2 - Analysis Results - WRIA 13					
Site_ID	QA	Category	Period	Records	> 13 deg C	% > 13 deg C	Min	Max	Geo Mean
MCITH11	L5	Salmon/Trout	F/W/Sp	38	38	100.00%	14.2	20.9	17.77
BLATH11	L5	Salmon/Trout	F/W/Sp	35	34	97.14%	13	19.9	16.97
PATTH21	L5	Salmon/Trout	F/W/Sp	11	10	90.91%	12	21	17.60
OFFTH11	L5	Salmon/Trout	F/W/Sp	29	26	89.66%	11	22.2	16.91
LONTH11	L5	Salmon/Trout	F/W/Sp	35	27	77.14%	9.6	20.8	15.95
CHATH11	L5	Salmon/Trout	F/W/Sp	13	10	76.92%	12.8	23.8	17.11
LAWTH11	L5	Salmon/Trout	F/W/Sp	29	21	72.41%	11.8	20	15.34
PATTH11	L5	Salmon/Trout	F/W/Sp	42	27	64.29%	10.09	22.19	14.33
HICTH11	L5	Salmon/Trout	F/W/Sp	43	23	53.49%	8.86	20.2	13.09
MUNTH11	L5	Salmon/Trout	F/W/Sp	6	3	50.00%	10.1	18.2	13.88
WARTH11	L5	Salmon/Trout	F/W/Sp	124	54	43.55%	5.9	22	11.33

The analysis for the third category (Temp 3) for core salmonid habitat, took ongoing water quality temperature data with a date range from June 15th to September 15th. This covered the core summer salmonid habitation period with an analysis criterion of 16°C (60.8°F) for WRIA 13. This resulted in 14 records that met the 35% plus geometric mean standard. Two sites in this analysis were included that did not meet the geometric mean standard. Site ID – 13A060D (blue highlight) was included because its 46.67% failure to meet analysis criterion and geometric mean was less than 1 degree below the standard. Site ID – WARTH11 (blue highlight) on Ward Lake failed to meet analysis criterion 43.81% of the time. (This was noteworthy because Ward Lake failed to meet each analysis criteria in all four temperature categories from 43.55% to 57.89% of the time.) The percentage of time that data in this table did not meet the analysis criteria ranged from 43.81% to 100% with a geometric mean range from 12.63 °C to 21.47°C. The results are listed in Table 2.16 below.

Table 2.16: Summer Temperature Results for the Core Salmonid Category in WRIA 13. Results for Temp 3: Fourteen records met the 35% plus geometric mean standard. Two sites in this analysis (blue highlight) were included that did not meet the geometric mean standard. One of those records was less than 1 degree from geometric mean standard, and the other was a lake that had high failure to meet analysis criteria year-round.

Site Info				Temp 3 - Analysis Results - WRIA 13					
Site_ID	QA	Category	Period	Records	> 16 deg C	% > 16 deg C	Min	Max	Geo Mean
BLATH11	L5	Core Salmonid	Summer	18	18	100.00%	16.8	22.3	19.94
CHATH11	L5	Core Salmonid	Summer	21	21	100.00%	17.3	23.8	20.03
LAWTH11	L5	Core Salmonid	Summer	37	37	100.00%	18.36	21.7	20.79
MCITH11	L5	Core Salmonid	Summer	20	20	100.00%	18.2	21.14	20.17
W RM 4.2	L5	Core Salmonid	Summer	5	5	100.00%	16.8	22.1	18.78
G07001162238	L4	Core Salmonid	Summer	5	5	100.00%	20.23	22.56	21.47
LONTH11	L5	Core Salmonid	Summer	24	23	95.83%	15.1	23.8	21.05
PATTH21	L5	Core Salmonid	Summer	16	15	93.75%	15.8	22.2	20.32
W RM 3.8	L5	Core Salmonid	Summer	4	3	75.00%	15.3	21.1	18.94
OFFTH11	L5	Core Salmonid	Summer	32	23	71.88%	13.4	25.1	19.26
W RM 3.7	L5	Core Salmonid	Summer	3	2	66.67%	16	20.4	18.37
HICTH11	L5	Core Salmonid	Summer	45	28	62.22%	9.63	23.7	16.83
PATTH11	L5	Core Salmonid	Summer	42	25	59.52%	9.98	23.6	16.41
MUNTH11	L5	Core Salmonid	Summer	22	12	54.55%	10.56	22.8	16.06
13A060D	L5	Core Salmonid	Summer	30	14	46.67%	11.1	19.8	15.39
WARTH11	L5	Core Salmonid	Summer	105	46	43.81%	6.21	24.4	12.63

The analysis for the fourth category (Temp 4) for char spawning, took ongoing water quality temperature data with a date range from September 16th to December 22nd. This covered the fall char spawning inhabitation period with an analysis criterion of 9°C (48.2°F) for WRIA 13. This resulted in 17 sites that met the 35% plus geometric mean standard. Nine of those sites did not have enough records for an adequate analysis. Each site contained only two records with only one result each meeting the criterion. The following sites should be recommended for further ongoing temperature monitoring, before a proper analysis could be performed: sites with Site IDs DB0.1, SL0.1, WL0.2, WL1.0, WL2.25T, WL2.6, WL2.9, WL3.1 and WL3.4. Two sites were included that did not meet the geometric mean standard; sites 13A060D and 13A060E had a 42.5% to 48.65% percentage failure rate of not meeting the criterion, and high maximum temperatures from 14°C to 14.8°C (blue highlight). Two other sites were included that did not meet the geometric mean standard; sites W RM 3.7 and W RM 4.2 had a 37.5% failure rate, not meeting the criterion, and high maximum temperatures range from

16.1°C to 17.9°C (blue highlight). One monitoring location (Site # 13A150D) failed 53.33% of the time. The percentage of time that the data in this table did not meet the analysis criteria ranged from 37.5% to 100% with a geometric mean range from 8.24 °C to 18.71°C. The results are listed in Table 2.17, below.

Table 2.17: Fall Temperature Results for the Char Spawning Category in WRIA 13. Results for Temp 4: Seventeen records met the 35% plus geometric mean standard. Nine of those sites did not have enough records for an adequate analysis (blue highlight). Four sites had high maximum temperatures (blue highlight). One site failed 53.33% of the time (blue highlight).

Site Info				Temp 4 - Analysis Results - WRIA 13					
Site_ID	QA	Category	Period	Records	> 9 deg C	% > 9 deg C	Min	Max	Geo Mean
BLATH11	L5	Char Spawning	Fall	9	9	100.00%	18.1	19.2	18.71
LONTH11	L5	Char Spawning	Fall	7	7	100.00%	16.7	18.9	18.06
OFFTH11	L5	Char Spawning	Fall	8	8	100.00%	15.9	19.6	18.53
PATTH11	L5	Char Spawning	Fall	15	15	100.00%	10.09	22.19	13.73
G07001162238	L4	Char Spawning	Fall	7	6	85.71%	5.85	17.93	11.48
W RM 3.1	L5	Char Spawning	Fall	10	7	70.00%	7.5	11.4	9.46
WD0.0	L4	Char Spawning	Fall	3	2	66.67%	8.86	15.8	10.95
WARTH11	L5	Char Spawning	Fall	57	33	57.89%	6.44	21.85	11.86
13A150D	L5	Char Spawning	Fall	15	8	53.33%	2.7	13.1	7.82
DB0.1	L4	Char Spawning	Fall	2	1	50.00%	8.57	11.28	9.83
SL0.1	L4	Char Spawning	Fall	2	1	50.00%	7.9	12.25	9.84
WL0.2	L4	Char Spawning	Fall	2	1	50.00%	7.64	12.69	9.85
WL1.0	L4	Char Spawning	Fall	2	1	50.00%	7.88	11.55	9.54
WL2.25T	L4	Char Spawning	Fall	2	1	50.00%	7.42	11.47	9.23
WL2.6	L4	Char Spawning	Fall	2	1	50.00%	7.86	11.23	9.40
WL2.9	L4	Char Spawning	Fall	2	1	50.00%	7.9	11.1	9.36
WL3.1	L4	Char Spawning	Fall	2	1	50.00%	7.82	10.99	9.27
WL3.4	L4	Char Spawning	Fall	2	1	50.00%	8.1	11.22	9.53
13A060D	L5	Char Spawning	Fall	37	18	48.65%	2.2	14	8.54
13A060E	L5	Char Spawning	Fall	40	17	42.50%	2.7	14.8	8.33
W RM 3.7	L5	Char Spawning	Fall	8	3	37.50%	4.3	16.1	8.55
W RM 4.2	L5	Char Spawning	Fall	8	3	37.50%	4.5	17.9	8.24

Final Site Selection for Degraded Water Quality:

The final step in identifying the most degraded sites for water quality was to aggregate the analysis result tables for all the parameters and rank each sample site across all those qualifying parameters (parameters meeting the 35% plus geometric mean standard). The sample sites were ranked in descending order from the most degraded over-all water quality. The effects on water quality are also influenced by the type of system, whether it is lotic (flowing) like streams and rivers, or lentic (still or slow-movement) like found in wetlands, lakes and ponds. The data sets for WRIA 11 also included another type influence, tide gates on water quality. This is a system that fluctuates between lotic and lentic (as tide gates open and close) during tidal cycles and therefore was set apart from those other two categories. The data analysis results had also revealed a high number of stream channel monitoring sites failing to meet the analysis criteria for fecal coliform (FC). Those sites became yet another category for the lotic system analysis. One thing to note about the aggregation of analysis data on the tables for fecal coliform (FC) is that the qualifier for entry in these tables was to meet the 35% plus geometric mean standard for 50 cfu/100 ml. The data that met the analysis criterion of 100 cfu/100 ml was also included in the table for the qualifying sites, even if it was below the 35% plus geometric mean standard, in order to refine the over-all degraded water quality value for FC at the selected sites. These categories are represented in the aggregation tables for both Nisqually (WRIA 11) and the Deschutes (WRIA 13). The categories are as follows:

- Lotic Systems
- Lentic Systems
- Lotic System Tide Gates (WRIA 11 Only)
- Lotic Systems FC

WRIA 11 Lotic Systems: The aggregated analysis results across multiple parameters for the Nisqually streams, creeks and rivers produced 49 monitoring sites with an over-all percentage range from 34.2% to 90.91% degraded water quality. The number of qualifying parameters in Table 2.18 (Below) ranged from 1 to 5 entries. For the Nisqually Basin, there were no significant analysis results for lotic system pH. The lotic site location table for these 49 monitoring sites is in Appendix Table A1.

Table 2.18: Aggregated Lotic Results Across Multiple Parameters WRIA 11.
Forty-nine monitoring sites with an Over-All percentage range from 34.2% to 90.91%.

	DO	FC 50	FC 100	Turbidity	Temp 1	Temp 2	Temp 3	Temp 4	
Site_ID	% < 8mgL	% > 50cfu	% > 100cfu	% > 7.8 NTU	% > 12 deg C	% > 13 deg C	% > 16 deg C	% > 9 deg C	% Over All
MC5.8	81.82%							100.00%	90.91%
MC4.3	70.00%							100.00%	85.00%
MED0.1	100.00%				43.75%		100.00%		81.25%
MID-LAKEDRAIN					71.43%			83.33%	77.38%
OHOPCR(RM6.3) G93					50.00%		100.00%		75.00%
RSWT					71.43%	75.00%		75.00%	73.81%
11A070D				48.48%			84.85%		66.67%
OHOPCR(RM6.3) G95	44.23%				74.51%	43.33%	100.00%	66.67%	65.75%
NISQUALLY(39.7)				56.25%				75.00%	65.63%
OHOPCR(RM2.0) G93		80.95%	57.14%	50.00%					62.70%
OHOPCR(RM3.3)		86.36%	59.09%	36.36%			75.00%	50.00%	61.36%
MUCKCR(RM6.2)		63.64%	54.55%		46.67%		80.00%		61.21%
OHOPCR(RM0.1) TAX		92.31%	69.23%		41.18%		58.82%	44.44%	61.20%
MC4.4TLBU					60.00%				60.00%
MASHELRV(RM6.0) TAX					38.89%		80.00%		59.44%
OHOPCR(RM6.0) TAX					52.94%		75.00%	50.00%	59.31%
RSET		58.33%	16.67%					100.00%	58.33%
OHOPCR(RM0.1) G93		65.31%	55.10%	50.00%					56.80%
MC3.1	55.56%	55.56%	22.22%				50.00%	100.00%	56.67%
OHOPCR(RM6.0) G93					37.93%		85.71%	44.44%	56.03%
MC5.4	60.00%	44.44%	11.11%					100.00%	53.89%
11A090D				55.56%				50.00%	52.78%
LIITLEMASHELRV		60.87%	43.48%	51.43%					51.93%
MC4.7	60.00%	44.44%						50.00%	51.48%
MED0.0	66.67%	57.14%	28.57%						50.79%
OHOPCR(RM2.0) G93							50.00%	50.00%	50.00%
MUCK01								50.00%	50.00%
MUCKCR(RM0.1)								50.00%	50.00%
MASHELRV(RM6.0) G9							50.00%		50.00%
YELMCR(RM0.1) TAX		58.33%	41.67%					50.00%	50.00%
MC3.7	54.55%							42.86%	48.70%
MASHELRIVER					47.37%		50.00%		48.68%
OHOPCR(RM9.9) G95					50.98%			46.15%	48.57%
11A080D				40.00%				55.56%	47.78%
11A070E				49.17%	35.83%			56.41%	47.14%
NISQUALLY(3.7) TAX				37.50%	57.89%		42.86%	50.00%	47.06%
LAC05					50.00%		50.00%	40.00%	46.67%
SOUTHCK03					50.00%		50.00%	40.00%	46.67%
MUCK22					45.83%				45.83%
MASHELRV(RM3.2)		41.67%	25.00%				50.00%	60.00%	44.17%
TANWAXCR(RM0.3) TAX		38.46%	30.77%		52.63%			50.00%	42.97%
MUCK04					35.00%		50.00%		42.50%
MC4.5	44.44%							40.00%	42.22%
MUCK24					40.00%				40.00%
MUCK18					41.67%		37.50%		39.58%
MUCK23					38.46%				38.46%
LYNCH CREEK		50.00%	13.64%	38.89%				50.00%	38.13%
TANWAX(RM10.2)		40.00%	20.00%		42.86%				34.29%
MC4.3T	45.45%	42.86%	14.29%						34.20%

WRIA 11 Lentic Systems: The aggregated analysis results across multiple parameters for Nisqually lakes, ponds and reservoirs produced 18 monitoring sites with an over-all percentage range from 40% to 90.48% degraded water quality. The environmental effects on lentic system water quality differ from those on streams and creeks due to the still or slow-movement of water. Ambient heat and direct sunlight, especially in the summer, raise water temperature in impoundments because of their exposed surface area lacking adequate shade. The number of qualifying parameters in Table 2.19 below ranged from 1 to 5 entries. Note that the majority of failures to meet the analysis criteria are in the four temperature columns. For the Nisqually Basin, there were no significant analysis results for lentic system pH. The lotic site location table for these 18 monitoring sites is in Appendix Table A2.

Table 2.19: Aggregated Lentic Results Across Multiple Parameters WRIA 11.
Eighteen monitoring sites with an Over-All percentage range from 40% to 90.48%.

	DO	FC 50	FC 100	Turbidity	Temp 1	Temp 2	Temp 3	Temp 4	
Site_ID	% < 8mgL	% > 50cfu	% > 100cfu	% > 7.8 NTU	% > 12 deg C	% > 13 deg C	% > 16 deg C	% > 9 deg C	% Over All
TANWAXLAKE					100.00%		80.95%		90.48%
SILVERLAKE					100.00%		78.26%		89.13%
CLETH11	40.00%				100.00%	100.00%	100.00%	100.00%	88.00%
OHOPLAKE					94.74%		78.95%		86.84%
RAPJOHNLAKE					95.24%		66.67%		80.95%
OHOPI11					80.00%	75.00%	71.43%		75.48%
RAPPI11					90.00%	66.67%	50.00%		68.89%
WHIPI11	100.00%				64.29%	52.17%	57.89%		68.59%
OHOPLAKESTA3					61.82%		90.48%	43.75%	65.35%
OHOPLAKESTA2					68.66%	46.15%	66.07%	70.73%	62.90%
ST#TH11	88.89%				36.27%				62.58%
HARPI11	100.00%				47.62%		40.00%		62.54%
MINERALLAKE					68.00%		56.00%		62.00%
TANPI11					68.75%	55.56%	57.14%		60.48%
OHOPLAKESTA1					58.90%		75.00%	42.86%	58.92%
CLEARLAKE					62.50%		50.00%		56.25%
HARTSLAKE					45.71%	50.00%		62.50%	52.74%
ST_TH11					40.00%				40.00%

WRIA 11 Lotic System Tide Gates: The EIM dataset for Nisqually (WRIA 11) included water quality data for monitoring sites at tide gates. Although analyzing the tide gates was not the original intent of this thesis, the data analysis revealed that tide gates seem to have a significant effect on water quality. When WRIA 11 data were aggregated across multiple parameters and divided into lotic and lentic, tide gates did not fit

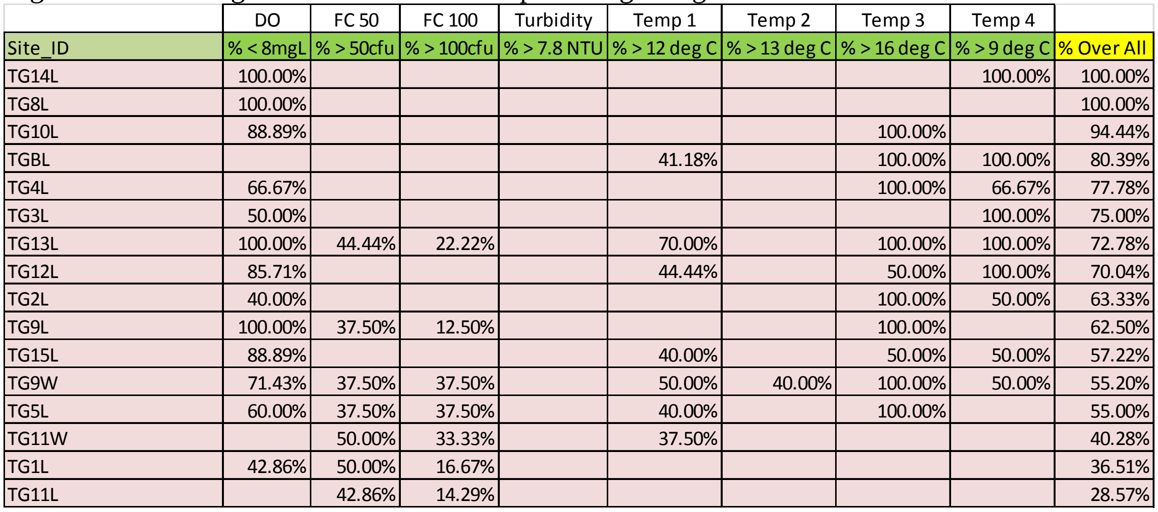
completely in the lotic category. This is because tide gates open and close on tidal cycles, thus creating temporary barriers to stream flow and salmonid migration. Figure 2.1 shows a typical tide gate in Western Washington. The lotic system tide gate location descriptions are shown in Appendix Table A3.

Figure 2.1: Tide Gate in Westport, Washington.
Tide Gates Open and Close During Tidal Cycles Causing Intermittent Barriers to Stream Flow and Fish Passage.

The multiple parameter aggregation in Table 2.20 below showed a failure to meet the analysis criteria that ranged across 1 to 7 parameters, where the tables for lotic showed a criteria failure across 1 to 5 parameters out of 8 possible parameter categories. Of the 16 tide gate monitoring sites, 13 failed to meet the criteria for DO ranging from 40% to 100%. In the FC50 category, 7 sites failed in a range from 37.5% to 50%. In the FC100 category, 7 sites failed in a range from 14.29% to 37.5%. (Reminder: The results for FC100 were included in all cases where FC50 failed the 35% plus geometric mean standard, whether FC100 met that standard or not.) The turbidity category did not show failure to meet the 35% plus geometric mean standard at tide gates. The number of sites and failure rate for tide gates varied widely by seasonal use, and are given below for all 4 temperature categories:

- Temp 1 (All Year Char Rearing) 7 of 16 sites failed from 40% to 70%
- Temp 2 (F/W/Sp Salmon & Trout Spawning) 1 of 16 sites failed 40%
- Temp 3 (Core Summer Salmonid Habitat) 10 of 16 sites failed from 50% to 100%
    - Note: 2 sites failed 50% and 8 sites failed 100% of the time.
- Temp 4 (Fall Char Spawning) 9 of 16 sites failed from 50% to 100%

Table 2.20: Aggregated Tide Gate Results Across Multiple Parameters WRIA 11. Eighteen monitoring sites with an Over-All percentage range from 28.57% to 100%.

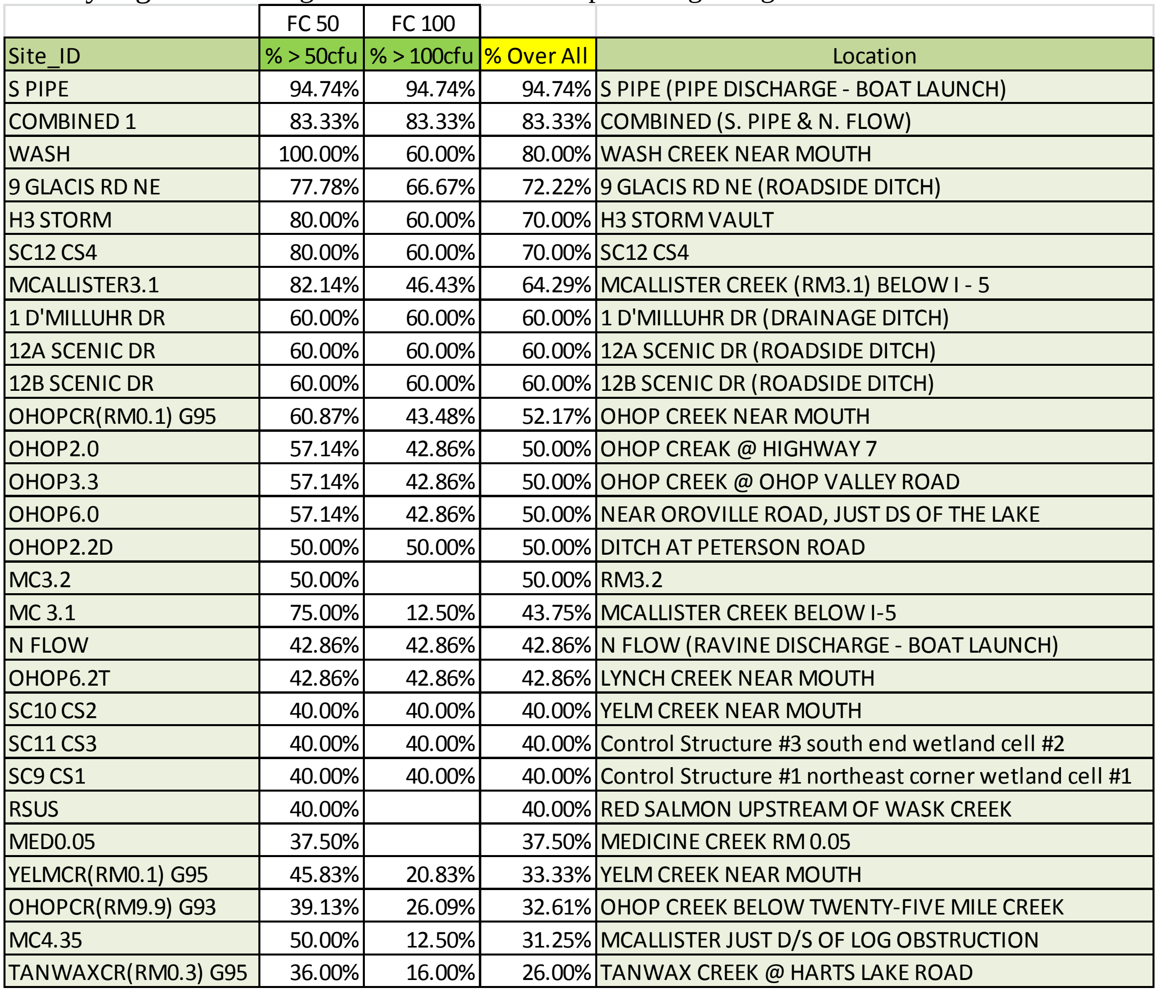


	DO	FC 50	FC 100	Turbidity	Temp 1	Temp 2	Temp 3	Temp 4	
Site_ID	% < 8mgL	% > 50cfu	% > 100cfu	% > 7.8 NTU	% > 12 deg C	% > 13 deg C	% > 16 deg C	% > 9 deg C	% Over All
TG14L	100.00%							100.00%	100.00%
TG8L	100.00%								100.00%
TG10L	88.89%						100.00%		94.44%
TGBL					41.18%		100.00%	100.00%	80.39%
TG4L	66.67%						100.00%	66.67%	77.78%
TG3L	50.00%							100.00%	75.00%
TG13L	100.00%	44.44%	22.22%		70.00%		100.00%	100.00%	72.78%
TG12L	85.71%				44.44%		50.00%	100.00%	70.04%
TG2L	40.00%						100.00%	50.00%	63.33%
TG9L	100.00%	37.50%	12.50%				100.00%		62.50%
TG15L	88.89%				40.00%		50.00%	50.00%	57.22%
TG9W	71.43%	37.50%	37.50%		50.00%	40.00%	100.00%	50.00%	55.20%
TG5L	60.00%	37.50%	37.50%		40.00%		100.00%		55.00%
TG11W		50.00%	33.33%		37.50%				40.28%
TG1L	42.86%	50.00%	16.67%						36.51%
TG11L		42.86%	14.29%						28.57%

WRIA 11 Lotic Systems FC: This aggregated analysis was for fecal coliform as it affects shellfish beds (50 cfu/100 ml) and for recreational primary contact (100 cfu/100 ml). The qualifier for being listed in this table (Table 2.21 below) was lotic monitoring sites (not including tide gates) where fecal coliform > 50 cfu/100 ml (FC 50) met the 35% plus geometric mean standard. The analysis criterion of > 100 cfu/100 ml (FC 100) was included with the qualifying monitoring sites even though the 35% plus geometric mean standard was not met for the FC 100 category. This method allowed for identification of those sites that had degraded water quality for both shellfish beds and recreational primary contact, or just for shellfish beds.

The aggregated analysis results for the two fecal coliform categories in Nisqually streams, creeks and rivers produced the 28 monitoring sites listed in Table 2.21 below (location description included). The FC 50 category had a percentage range from 36% to 100% that met the 35% plus geometric mean standard, and the FC 100 category had a range from 12.5% to 94.74%. The over-all percentage range for fecal coliform aggregated results analysis ranged from 26% to 94.74% for degraded water quality.

Table 2.21: Aggregated Fecal Coliform Results Across Two Parameters WRIA 11. Twenty-eight monitoring sites with an Over-All percentage range from 26% to 94.74%.



	FC 50	FC 100		
Site_ID	% > 50cfu	% > 100cfu	% Over All	Location
S PIPE	94.74%	94.74%	94.74%	S PIPE (PIPE DISCHARGE - BOAT LAUNCH)
COMBINED 1	83.33%	83.33%	83.33%	COMBINED (S. PIPE & N. FLOW)
WASH	100.00%	60.00%	80.00%	WASH CREEK NEAR MOUTH
9 GLACIS RD NE	77.78%	66.67%	72.22%	9 GLACIS RD NE (ROADSIDE DITCH)
H3 STORM	80.00%	60.00%	70.00%	H3 STORM VAULT
SC12 CS4	80.00%	60.00%	70.00%	SC12 CS4
MCALLISTER3.1	82.14%	46.43%	64.29%	MCALLISTER CREEK (RM3.1) BELOW I - 5
1 D'MILLUHR DR	60.00%	60.00%	60.00%	1 D'MILLUHR DR (DRAINAGE DITCH)
12A SCENIC DR	60.00%	60.00%	60.00%	12A SCENIC DR (ROADSIDE DITCH)
12B SCENIC DR	60.00%	60.00%	60.00%	12B SCENIC DR (ROADSIDE DITCH)
OHOPCR(RM0.1) G95	60.87%	43.48%	52.17%	OHOP CREEK NEAR MOUTH
OHOP2.0	57.14%	42.86%	50.00%	OHOP CREAK @ HIGHWAY 7
OHOP3.3	57.14%	42.86%	50.00%	OHOP CREEK @ OHOP VALLEY ROAD
OHOP6.0	57.14%	42.86%	50.00%	NEAR OROVILLE ROAD, JUST DS OF THE LAKE
OHOP2.2D	50.00%	50.00%	50.00%	DITCH AT PETERSON ROAD
MC3.2	50.00%		50.00%	RM3.2
MC 3.1	75.00%	12.50%	43.75%	MCALLISTER CREEK BELOW I-5
N FLOW	42.86%	42.86%	42.86%	N FLOW (RAVINE DISCHARGE - BOAT LAUNCH)
OHOP6.2T	42.86%	42.86%	42.86%	LYNCH CREEK NEAR MOUTH
SC10 CS2	40.00%	40.00%	40.00%	YELM CREEK NEAR MOUTH
SC11 CS3	40.00%	40.00%	40.00%	Control Structure #3 south end wetland cell #2
SC9 CS1	40.00%	40.00%	40.00%	Control Structure #1 northeast corner wetland cell #1
RSUS	40.00%		40.00%	RED SALMON UPSTREAM OF WASK CREEK
MED0.05	37.50%		37.50%	MEDICINE CREEK RM 0.05
YELMCR(RM0.1) G95	45.83%	20.83%	33.33%	YELM CREEK NEAR MOUTH
OHOPCR(RM9.9) G93	39.13%	26.09%	32.61%	OHOP CREEK BELOW TWENTY-FIVE MILE CREEK
MC4.35	50.00%	12.50%	31.25%	MCALLISTER JUST D/S OF LOG OBSTRUCTION
TANWAXCR(RM0.3) G95	36.00%	16.00%	26.00%	TANWAX CREEK @ HARTS LAKE ROAD

WRIA 13 Lotic: The aggregated analysis results across multiple parameters for the Deschutes streams, creeks and rivers produced 37 monitoring sites with an over-all percentage range from 34.85% to 93.33% degraded water quality. The number of qualifying parameters in Table 2.22 below ranged from 1 to 5 entries. The lotic site location table for these 37 monitoring sites is in Appendix Table A4.

Table 2.22: Aggregated Lotic Results Across Multiple Parameters WRIA 13.
Thirty-seven monitoring sites with an Over-All percentage range from 34.85% to 93.33%.

	DO	FC 50	FC 100	pH	Turbidity	Temp 1	Temp 2	Temp 3	Temp 4	
Site_ID	% 8mgL	% > 50cfu	% > 100cfu	% < 6.5 or > 8.5	% > 7.8 NTU	% > 12 deg C	% > 13 deg C	% > 16 deg C	% > 9 deg C	% Over All
W DRAIN		100.00%	80.00%		100.00%					93.33%
WD6.8	100.00%	80.00%	80.00%							86.67%
FLEMING CR		85.71%	71.43%		100.00%					85.71%
CC0.6		83.33%	83.33%	83.33%						83.33%
LOWER						81.82%				81.82%
CREEKB		83.33%	50.00%		100.00%					77.78%
G07001162238						46.15%		100.00%	85.71%	77.29%
CREEKA					75.00%					75.00%
SL0.8		85.71%	57.14%	71.43%						71.43%
WL1.0		100.00%	60.00%						50.00%	70.00%
W RM 3.1									70.00%	70.00%
CC0.4		83.33%	66.67%	57.14%						69.05%
DB0.1 (DSAR)		70.00%	72.73%						50.00%	64.24%
WD0.0		77.78%	44.44%						66.67%	62.96%
SPDITCH2	100.00%	54.55%	45.45%	50.00%						62.50%
WL0.2		75.00%	58.33%						50.00%	61.11%
GO0.4		50.00%	33.33%	100.00%						61.11%
W RM 4.2						44.19%		100.00%	37.50%	60.56%
WD5.1	25.00%	88.89%	66.67%							60.19%
SWO STORMWATER		40.00%	40.00%		100.00%					60.00%
SPDITCH1	60.00%									60.00%
SL0.1		70.00%	50.00%						50.00%	56.67%
WD6.9	91.67%	55.56%	22.22%							56.48%
W RM 3.8						36.59%		75.00%		55.79%
13A150D									53.33%	53.33%
WL3.4	61.54%	54.55%	36.36%						50.00%	50.61%
WD6.2	83.33%	44.44%	22.22%							50.00%
WL2.25T		50.00%	50.00%						50.00%	50.00%
WL2.6		60.00%	40.00%						50.00%	50.00%
WL1.9T	45.45%									45.45%
SCR		44.26%	22.95%			66.67%				44.63%
13A060D						37.50%		46.67%	48.65%	44.27%
CC0.2		42.86%	14.29%	75.00%						44.05%
W RM 3.7		37.50%	29.17%			44.44%		66.67%	37.50%	43.06%
WL2.9		54.55%	18.18%						50.00%	40.91%
13A060E						35.29%			42.50%	38.90%
WL3.1		36.36%	18.18%						50.00%	34.85%

WRIA 13 Lentic: Aggregated analysis results across multiple parameters for the Deschutes lakes, ponds and reservoirs produced 11 monitoring sites with an over-all percentage range from 46.92% to 100% degraded water quality. The environmental effects on lentic system water quality differ from that of streams and creeks, due to the still or slow-movement of water. Ambient heat and direct sunlight, especially in the summer, raise water temperature in impoundments, because of open non-shaded areas. Note that the majority of failures to meet the analysis criteria were in the dissolved oxygen (DO) and three to the four temperature categories. The number of site failures and failure rates for DO and all 4 temperature categories are as follows:

- Dissolved Oxygen (DO) 8 of 11 sites failed from 40% to 100%
- Temp 1 (All Year Char Rearing) 11 of 11 sites failed from 49.34% to 100%
- Temp 2 (F/W/Sp Spawning) 11 of 11 sites failed 43.55% to 100%
- Temp 3 (Summer Salmonid Habitat) 11 of 11 sites failed from 43.81% to 100%
- Temp 4 (Fall Char Spawning) 5 of 11 sites failed from 57.89% to 100%
    - Note: 1 site failed 57.89% and 4 sites failed 100% of the time

The number of qualifying parameters in Table 2.23 below ranged from 3 to 5 entries. The lotic site location table for these 11 monitoring sites is found in Appendix Table A5.

Table 2.23: Aggregated Lentic Results Across Multiple Parameters WRIA 13.
Eleven monitoring sites with an Over-All percentage range from 46.92% to 100%.

	DO	FC 50	FC 100	pH	Turbidity	Temp 1	Temp 2	Temp 3	Temp 4	
Site_ID	% 8mgL	% > 50cfu	% > 100cfu	% < 6.5 or > 8.5	% > 7.8 NTU	% > 12 deg C	% > 13 deg C	% > 16 deg C	% > 9 deg C	% Over All
MCITH11						100.00%	100.00%	100.00%		100.00%
BLATH11	100.00%					100.00%	97.14%	100.00%	100.00%	99.43%
LONTH11						91.53%	77.14%	95.83%	100.00%	91.13%
CHATH11	85.71%					100.00%	76.92%	100.00%		90.66%
OFFTH11	83.33%					96.72%	89.66%	71.88%	100.00%	88.32%
PATTH21	60.00%					96.30%	90.91%	93.75%		85.24%
LAWTH11	66.67%					96.97%	72.41%	100.00%		84.01%
PATTH11	40.00%					71.43%	64.29%	59.52%	100.00%	67.05%
MUNTH11						82.14%	50.00%	54.55%		62.23%
HICTH11	57.14%					68.18%	53.49%	62.22%		60.26%
WARTH11	40.00%					49.34%	43.55%	43.81%	57.89%	46.92%

WRIA 13 Lotic Systems FC: The same standard was applied for this analysis as for the fecal coliform aggregated table for WRIA 11 (See Table 2.21). The aggregated analysis was for fecal coliform as it affects shellfish beds (50 cfu/100 ml) and recreational primary contact (100 cfu/100 ml). The qualifier for being listed in Table 2.24 below was lotic monitoring sites where fecal coliform > 50 cfu/100 ml (FC 50) met the 35% plus geometric mean standard. The analysis criterion of > 100 cfu/100 ml (FC 100) was included with the qualifying monitoring sites even though the 35% plus geometric mean standard was not met for the FC 100 category. This method allowed identification of sites that had degraded water quality for both shellfish beds and recreational primary contact, or just for shellfish beds.

The aggregated analysis results for the two fecal coliform categories in Deschutes streams, creeks and rivers produced the 39 monitoring sites listed in Table 2.24 below. The FC 50 category had a percentage range from 36.36% to 100% that met the 35% plus geometric mean standard. The FC 100 category had a range from 16.67% to 100%. The over-all percentage for the fecal coliform aggregated results analysis ranged from 27.27% to 100% for degraded water quality.

Conclusions WRIA 11:

The lotic and fecal coliform aggregation tables were analyzed for the Nisqually River Basin (WRIA 11) and revealed a cluster of multiple parameter failures for the Ohop Creek monitoring sites. The lotic aggregation table had 10 of 49 monitoring sites in the Ohop Creek system with failure across multiple parameters, with an over-all failure range from 48.57% to 70%. The fecal coliform aggregation table had 4 of 28 monitoring sites across multiple parameters with an over-all failure range from 32.25% to 52.17%. The 14 Ohop Creek sites with indications of degraded water quality across multiple parameters were selected for further spatial analysis in GIS (Chapter 4). This study area was selected for land use influences on water quality.

Conclusions WRIA 13:

Fecal coliform analysis for WRIA 13 revealed a cluster of monitoring sites in the Henderson Inlet sub-basin. Of 39 sites in this analysis, 17 monitoring site streams have their discharge point in the area of the Henderson Inlet shellfish beds. The monitoring sites are on the following streams: Woodland Creek, Woodard Creek, Dobbs Creek and Quail Creek. Table 2.24 includes the location description for these creeks. There is enough concentrated failure to meet FC standards that the Henderson Inlet flow basin was chosen for spatial analysis in GIS (Chapter 3).

Table 2.24: Aggregated Fecal Coliform Results Across Two Parameters WRIA 13.

Thirty-nine monitoring sites with an Over-All percentage range from 27.27% to 100%. Of the 39 lotic monitoring sites in the Henderson Inlet Sub-Basin, 4 streams, with 17 monitoring site in this table, have their discharge points to the Henderson Inlet shellfish beds.

	FC 50	FC 100		
Site_ID	% > 50cfu	% > 100cfu	% Over All	Location
13-IND-BOUL-TC	100.00%	100.00%	100.00%	INDIAN CREEK AT BOULEVARD RD SE
13-IND-CENT	100.00%	100.00%	100.00%	INDIAN CREEK AT CENTRAL ST SE
WL2.6SW	100.00%	100.00%	100.00%	STORMWATER @ 21ST COURT NE
WOODLANDCR1	100.00%	100.00%	100.00%	WOODLANDCR1 (@ HAWKS PRAIRIE RD)
WOODLANDCR2	100.00%	100.00%	100.00%	WOODLANDCR2 (NEAR HOLLYWOOD DRIVE)
13-IND-QUIN	100.00%	90.91%	95.45%	INDIAN CREEK NEAR MOUTH
14MCLANEMC1	100.00%	90.91%	95.45%	MCLANE MTH AT DS MOST DELPHI RD CROSSING
14MCLANEMC2	100.00%	90.91%	95.45%	MCLANE AT UPSTREAM DELPHI RD. CROSSING
DB1.0 (BEDI)	100.00%	88.89%	94.44%	DOBBS CREEK U/S OF CAMP GROUND
WOODLANDCR3	100.00%	87.50%	93.75%	WOODLANDCR3 (@ PLEASANT GLADE ROAD)
MANHOLESOUTH	100.00%	80.00%	90.00%	MANHOLE NEAR CARPENTER ROAD
MARTIN WAY	100.00%	80.00%	90.00%	ROADWAY SURFACE RUNOFF @ MARTIN WAY
WOODLANDCR4	100.00%	75.00%	87.50%	WOODLANDCR4 (@ DRAHAM ROAD)
14MCLANEUN1	100.00%	70.00%	85.00%	UN-NAMED WEST TRIB MOUTH AT DELPHI RD
14MCLANEMC2.5	90.91%	72.73%	81.82%	MCLANE AT 2901 DELPHI DRIVEWAY BRIDGE
WD2.9	88.89%	66.67%	77.78%	WOODARD CREEK OFF LIBBY ROAD
WD3.4	88.89%	66.67%	77.78%	WOODARD CREEK @ 36TH AVE
WL1.1T	88.89%	66.67%	77.78%	QUAIL CREEK @ MOUTH
WL1.2T	88.89%	66.67%	77.78%	JORGENSON CREEK
DB0.1 (BEDI)	81.82%	70.00%	75.91%	DOBBS CREEK AT JOHNSON POINT ROAD
DBTRIB0.73	80.00%	70.00%	75.00%	CULVERT - downstream sampling location D2
14MCLANEDV1	81.82%	63.64%	72.73%	UN-NAMED EAST TRIB AT 2542 DELPHI RD
WL3.8T	71.43%	71.43%	71.43%	TANGLEWILDE STORMWATER TO WOODLAND CREEK
WOODLANDCR5	100.00%	42.86%	71.43%	WOODLANDCR5 (@ MARTIN WAY)
DB1.0 (DSAR)	75.00%	62.50%	68.75%	DOBBS CREEK U/S OF CAMP GROUND
TANGLEWILDE	66.67%	66.67%	66.67%	BURIED STORMWATER PIPE @ MARTIN WAY
14MCLANESW1	80.00%	50.00%	65.00%	SWIFT CREEK MOUTH AT DELPHI RD
DB0.731	70.00%	60.00%	65.00%	D2 - First large bridge crossing mainstem Dobbs
DOBBSCRK	70.00%	60.00%	65.00%	D3 - Bridge over mainstem on Elm Road
MY0.1	75.00%	50.00%	62.50%	MYER CREEK AT MOUTH
DOBBS CREEK	80.00%	40.00%	60.00%	DOBBS CREEK @ JOHNSON PT ROAD
WOODLANDCR7	80.00%	40.00%	60.00%	WOODLANDCR7 (@ UNION MILLS ROAD SE)
WL1.6	60.00%	60.00%	60.00%	WOODLAND CREEK AT PLEASANT GLADE
WL1.95T	57.14%	42.86%	50.00%	PALM CREEK
WL3.45	54.55%	36.36%	45.45%	WOODLAND CREEK AT TROUT FARM
WOODLANDCR6	66.67%	16.67%	41.67%	WOODLANDCR6 (@ PACIFIC AVENUE)
CC0.0	54.55%	18.18%	36.36%	COLLEGE CREEK @ MOUTH
WL3.1	45.45%	18.18%	31.82%	WOODLAND CREEK D/S OF I-5
WL3.1T	36.36%	18.18%	27.27%	WOODLAND CREEK @ I-5

Chapter Three:

Anthropogenic Land Use and Impervious Surfaces Adjacent to Salmon Habitat and Shellfish Beds

Introduction:

Human development has altered landscapes and ecosystems in a variety of ways. These impacts can, and do, alter ecosystem habitats that have been evolving for thousands of years. Species have been able to adapt to environmental stressors over long periods of time, but many species struggle to adapt to the rapid growth of the human impact and hydrological alteration of their ecosystem habitats.

Different types of Land use can affect aquatic systems in many ways, by nutrient loading that can cause eutrophication, toxic algal blooms, the depletion of dissolved oxygen and contaminate loading which can affect plant and aquatic species diversity and abundance. Nutrient loading can come in the form of fertilizers used on lawns and gardens by urban areas residents, or the runoff from agricultural farms. Residential wastewater treatment failure of septic systems or leaky sewage treatment lines not only adds to nutrient loading, but can also increase pathogenic health risks in recreational waterways. Residential areas, whether urban or rural, generate a lot of waste. Landfills contain the castoffs of products, broken or unwanted, many which have been manufactured with harmful toxic chemicals. Plastic packaging and other plastic products containing phthalates find their way into dump sites, roadway ditches, empty lots, the gullets of seabirds and even all the way to the large plastic floating island the size of Texas in the middle of the Pacific Ocean.

Contaminants come in many forms from highly toxic to cloudy water due to suspended solids. These can affect aquatic species in many ways by making water too turbid for invertebrate habitation, changing the pH balance, subjecting biota to lethal or sub-lethal doses of pesticides and herbicides, and mutation and reproductive issues from endocrine disrupting chemicals and pharmaceuticals.

Natural Systems vs. Developed Systems:

The pristine environment provides near ideal solutions for storm water runoff and pollution control. As rainwater infiltrates into the ground, it is treated by plants and organisms and is filtered, cleaned, taken up and utilized to sustain life, and returned to the atmosphere through evapotranspiration. When the infiltrated ground is saturated, excess rainwater runs off into naturally occurring channels, from creeks to streams to rivers, and is ultimately returned to the ocean, where it evaporates and begins the hydrologic cycle all over again in the form of clouds and rain. Each stage of the hydrologic cycle provides benefits to plants that give us air to breath and even some plants used for food crops. Mammal and aquatic species also gain benefit from this natural occurring system for sustenance and suitable habitats. This entire ecosystem service is provided to us all free of charge, yet we spend a lot of time and money to change and control it.

It has been known for some time now that human development has altered landscapes and ecosystems in a variety of ways. A Google Scholar ™ search on the words “Anthropogenic Impact” quickly yields about 142,000 articles on the subject. Adding to that search the words “…Water Quality,” produces over 84,000 articles. These published sources demonstrate our awareness of the effect we have on habitat and species, from the activities we engage in on land and water. These impacts can and do alter ecosystem habitats that have been long established and evolved for thousands of years, long before humans set foot on these shores. Species struggle to adapt with the rapid growth of human impact and hydrological alteration of those ecosystems. We have become aware of the problems brought on by our presence, yet the question remains, “How do we fix those problems?” This is fundamentally not an easy question to answer! Many scientists, biologists, academia, student and volunteer groups seek to understand ecosystem function, in the hopes of solving at least some of the distress imposed upon species and habitat. People will continue to build and develop urban areas, as well as create new urban areas in pristine ecosystems, so the idea is not to inhibit this growth and development, but rather to find solutions that reduce our impervious footprint, toxic contamination and nutrient loading and to help us grow and develop in smarter ways to reduce the effect of our existence.

What ever is deposited on the land and infiltrates into the ground will eventually make its way into drainage ditches, creeks, streams, rivers and ultimately to the estuaries and oceans. What we do on land can and does effect marine ecosystems. One example is how bacteria and pathogens flowing downstream to discharge points in the estuaries that host shellfish beds. Referring to Table 1.2 from the Washington State surface water quality standards in chapter one, the one parameter in this water analysis for bacteria levels does not pertain to salmonids and their habitat as much as it does for the protection of shellfish beds and recreational use. In this thesis fecal coliform data, which is a by-product of human and other mammal excretion, were used for analysis. The point sources of fecal coliform contamination are from failure in septic and wastewater systems, domestic pets and wildlife, farm animals and agriculture. This can result in the discharge of pathogens from land use to shellfish beds.

Land Use and Estuarine Habitats:

The focus of the following literature review is the anthropogenic impact on shellfish beds in the Puget Sound, although studies outside this area were also used to help develop an understanding of how humans affect estuarine habitats. Stressors to a variety of shellfish species have impacts that depend on the proximity to anthropogenic changes to the ecosystem, and the needs of specific species to propagate and remain productive. According to Dr. Megan N. Dethier (2006), the “human effects on habitat attributes” are defined as: “direct loss of habitat; alteration of substrate type; pollution or other alterations in nearshore characteristics; alteration of runoff from land and beach porewater; changes in nearshore plankton, introduced species; increased susceptibility to predators and parasites;” and “nearshore aquaculture.” The relationship between human nearshore development and bacteriological quality of water samples taken from their respective watersheds was also studied. It was found that there is a significant demographic and land use association with an abundance of fecal coliform in a populated watershed. Turbidity, which could be caused by anthropogenic activities, was also found to be related with bacterial abundance. The higher levels of bacteria found in these estuarine systems can have an increased health risk to humans (Mallen, et al., 2000). Shellfish play an important role in filtration of nutrients and toxins that run off nearshore lands, which makes them a valuable indicator species for monitoring land use and evaluating the quality of water that runs off that land and into our estuaries and oceans. Ultimately the quality and quantity of nutrients, microorganisms, and toxins that are taken up by shellfish, and then recreationally and commercially harvested, are returned for human consumption.

Threats to Puget Sound Shellfish:

Shellfish survival and productivity can come under threat in a number of ways. The most obvious may be from over-harvest by recreational or commercial methods. Less apparent are those due to alterations of primary ecosystem functions from human activity and development. Because each shellfish species has distinctive habitat requirements, for example, sediment type for growth and recruitment, alterations to these habitats can have a negative impact on shellfish population and productivity. Different species have preference to different substrate types. Any process, natural or anthropogenic, that alters substrate habitats by amount of sediment loading, organic material, and grain size can have a negative effect on shellfish populations. Changes in river and stream runoff from the land can alter the sediment loads on shellfish beds (Dethier, 2006). For example, these changes can be sourced by upstream erosion, landslides or disturbances caused by development, agriculture or logging.

Key parameters according to Dr. Megan N. Dethier (2006) are temperature, turbidity, salinity, dissolved oxygen, [toxins], pollutants, and food type, all of which can be affected by land use and shoreline modification. These parameters need to remain at optimal levels for shellfish to remain productive. When physical conditions of a habitat deteriorate by anoxic water or excessive sediment, this will place pressures on productivity. Geoduck juveniles have some mobility for avoiding poor conditions, but the adults are immobile and subject to higher mortality. Geoduck habitats have been destroyed by marine construction, and aquaculture projects have competed for their space (Goodwin & Pease, 1989). Littleneck clams in the larval stage can be affected not only by salinity and temperature, but high turbidity can reduce their survival rate. High siltation in their habitats can smother their populations. Dredging nearby or upland development adds silt to the water columns that will settle upon habitat substrates. The littleneck clams have also been known to be very susceptible to high concentrations of copper from paint used on boat bottoms (Dethier, 2006).

Impact of Development and Fecal Coliform:

Over a four year period, Michael Mallin (2000) and his research team produced a study to analyze the distribution and abundance of enteric pathogens in estuaries near population demographics and development. Their report suggests that nearshore development poses an increased health risk to humans and has significant consequences to the environment. The research was performed in the Chesapeake Bay area, but the fundamentals could apply anywhere there is nearshore development.

Mallin et al., (2000) found a significant correlation between the abundance of bacteria and turbidity, and fecal coliform bacteria associated with suspended solids in the water column. This suggests that suspended sediments are a transport mechanism for fecal bacteria in aquatic systems. Fecal bacteria are known to survive longer in association with particles of sediment, and disturbance of these sediments can re-release the fecal bacteria into the water (Mallen, et al., 2000). This occurs with disturbances such as storm event erosion or clearing land for development.

Input of bacteria into coastal water can have either point or nonpoint sources. Most point sources can come from failing septic systems and occasionally from leaky sewer mains or wastewater treatment failures. Nonpoint inputs can vary depending on land use and demographics. Research by Michael Mallin (2000) revealed a significant relationship between bacterial loading in the estuaries and watershed population size. He states that a likely important source of bacterial loading is population. More humans mean more domesticated animals, which leads to more fecal bacteria deposited on the land. Also, population size was significantly correlated with the area of estuarine closures to shellfish beds. The consequence of this is the economic loss to the local community (Mallen, et al., 2000; Maiolo and Tschtter, 1981).

As it turns out, this study reveals that the percent of impervious surfaces in a watershed is the most important anthropogenic aspect that contributes to fecal coliform loads. The impervious surfaces taken into account here are parking lots, driveways, roads, sidewalks and roof tops. Impervious surfaces tend to concentrate and rapidly pass on storm water that picks up and concentrates pollutants as it rushes to streams and rivers on its way to the awaiting shellfish in the estuary. A linear regression analysis was performed and indicated that the area of impervious surfaces alone explained 95% of variability in average fecal coliform abundance in estuaries, suggesting that urban coastal areas can reduce their environmental impact by land use practices that reduce impervious surface area. Methods for doing this include incorporating bioswales, raingardens, and constructed wetlands into development (Mallen, et al., 2000).

Reports and Surveys:

In order to get a graphic understanding of the relationship between land use and nearshore habitats specific to shellfish, spatial and tabular data were acquired from the Washington State Department of Health (DOH) and tabular data from the Washington State Department of Ecology (DOE). The spatial data from DOH represents commercial growing areas for shellfish in Western Washington including Puget Sound, and marine water sampling stations in nearshore habitats. Tabular data from DOE represents water quality sample stations and results from surface water samples taken at those sites.

Classifications:

Shoreline surveys for the Department of Health had evaluated the drainage system discharges, agricultural activities, on-site sewage systems as well as wastewater treatment plants, which could have potential adverse effect on the classification of commercial shellfish growing areas. The actual and possible pollution sources were defined in these reports according to the following categories (taken verbatim from the Shoreline Surveys of Berbells (2003 & 2007) and Zabel-Linclon (2005)):

> *Direct Impact* – A “Direct Impact” is a pollution source that is defined by the National Shellfish Sanitation Program (NSSP) as any waste discharge that has an immediate adverse effect on the growing area.
>
> *Indirect Impact* – An “Indirect Impact” is a pollution source that is defined by the NSSP as any waste discharge that reaches the growing area in a roundabout way.

> *Potential Source* – A “Potential Source” is a pollution source that may influence the water quality in the area. Inadequate setbacks, neglect or abuse of sewage disposal systems, overgrazed pastures and a large number of wildlife are examples that could cause a site to be identified as a potential source of contamination.
>
> *No Impact* – “No Impact” means the potential source is managed via proper on-site practices or treatment methods so that there is no negative impact on water quality.
>
> Segments of the shellfish growing areas are presently “classified as APPROVED, RESTRICTED, UNCLASSIFIED, OR PROHIBITED” which is based on the identification of pollution source and water quality (Zabel-Linclon, 2005)

The classification of “Conditionally Approved” is in part on wastewater treatment plant disruptions, but primarily based on rainfall events. A rainfall event that is equal to or greater than one inch during a 24-hours period will have an imposed restriction to commercial shellfish harvest for a period of five days. This is true for entire growing areas classified as conditionally approved (Berbells, 2003). The reasoning behind the five day wait to lift the restriction on a conditionally approved site after a rainfall event was revealed during an informational interview with Lawrence Sullivan from the DOH. A heavy rainfall event will wash contaminates into storm drains, ditches, streams and river channels. Bacteria are DOH’s contamination of concern, for public health reasons. Surface water runs off the land and into estuaries where the shellfish are waiting to filter whatever comes their way. The five day wait period is broken down as, three days for the bacteria to clean out of the bay to return to a good water quality. Two days after that for the shellfish to flush out and start taking in water that meets standards.

Criteria:

Shellfish growing areas are classified based on meeting criteria levels for bacteria. The water samples are taken over a period of time, once a month until approximately 30 samples have been taken. Then these samples are tested for fecal coliform and the results (organisms/100ml) are recorded. The results are statistically tested for geometric mean and 90th percentile. The approved standard for shellfish growing waters is stated as: the geometric mean is “not greater than 14 organisms/100ml,” and a “90th percentile not greater than 43 organisms/100ml (Berbells, 2003 & 2007; Zabel-Linclon, 2005).

Study Areas:

Two areas were selected in South Puget Sound to highlight how human activities and development have affected commercial shellfish growing areas. The selected areas were picked for various reasons. One is a wildlife preserve (Nisqually Wildlife Refuge) that is influenced by activities in its upper watershed; another one is subject to wastewater treatment, and an area that has been listed with the Department of Ecology as a 303d for not meeting water quality standards (Henderson Inlet). The reports from DOH cover the Sanitary Survey and Shoreline Survey for each of these areas.

Description of Growing Area: (As described in reports)

> **Nisqually Reach:** The Nisqually Reach shellfish area is located in southern Puget Sound in Thurston County. The area extends from Johnson Point at the northwest to Dupont at the southeast. The Nisqually River, which is the largest river in the southern Puget Sound, discharges into the southeast end of the area. The total area of the Nisqually Reach shellfish area, including all “Approved”, “Restricted”, “Prohibited”, and “Unclassified” areas, is approximately 4380 acres. Within this area there are approximately 2800 acres classified as “Approved”. A marina closure zone, classified as “Prohibited”, occupies an area of approximately 80 acres located at Baird Cove. Approximately 190 acres between Mill Bight and Puget Marina are “Unclassified”. Fifty acres of shellfish beds located immediately north of the mouth of McAllister Creek are classified as “Restricted”, and approximately 1500 acres of the Nisqually River delta located east and west of the river mouth are classified as “Prohibited” (Melvin, 2006).
>
> The Nisqually Reach shellfish area is located in southern Puget Sound approximately nine miles east of Olympia.” . . . “Oysters, clams, and geoducks are harvested commercially from the area. Most of the intertidal oyster and clam harvest takes place on shellfish beds located at the western edge of the Nisqually River delta. Subtidal commercial geoduck beds are located along the entire length of the area. The majority of the area is classified as “Approved” for commercial shellfish harvest (Melvin, 2006).

> **Henderson Inlet:** Henderson Inlet is located at the southern end of the Puget Sound. The inlet and its watersheds are within the boundaries of Thurston County. Henderson Inlet is a narrow, shallow embayment approximately six miles in length with an average width of one half mile. The inlet is open at the north with Dana Passage to the west, Case Inlet to the north, and Nisqually Reach to the east (Melvin, 2007).
>
> Development along the marine shoreline and the adjacent uplands is rural residential. All of the homes along the shoreline and in the adjacent uplands use on-site systems for the treatment and disposal of sewage. The city of Lacey and a portion of the city of Olympia are located in watersheds that drain into Henderson Inlet. Urban development associated with the cities of Lacey and Olympia is connected to a sewage treatment system. The outfall for this system is located in the southern end of Budd Inlet, approximately 9.5 miles from the mouth of Henderson Inlet (Melvin, 2007).
>
> Henderson Inlet is an active commercial shellfish harvest area. Oysters, hard-shell clams, and geoducks are harvested from the inlet. There are no recreational shellfish beaches in Henderson Inlet (Melvin, 2007).
>
> The Henderson Inlet commercial shellfish area is located in southern Puget Sound. The northern half of the inlet is classified as approved for commercial shellfish harvest and the southern half is classified as conditionally approved and prohibited. Shellfish harvest in the conditionally approved area is based on rainfall with a five day closure resulting from 24 hour rainfall totals of one-half inch or more. Oysters and hard shell clams are harvested commercially from the area (Melvin, 2007).

Reports by Washington State Department of Health:

Nisqually Reach: The Nisqually Reach shellfish beds are directly impacted by discharges from the Nisqually River and McAllister Creek. There are 32 marine water sampling stations in the Nisqually Reach shellfish bed areas. Four of those sites did not meet water quality standards. Those are sites numbers 224, 234, 235 and 236 (Table 3.1 Below). The sites listed exceeded both the geometric mean and 90th percentile. Sites 224 and 234 are located at the mouth of McAllister Creek, and sites 235 and 236 are located at the mouth of the Nisqually River. The shellfish beds in the delta from these two aquatic systems have been classified as Prohibited. No sites within the Nisqually Reach have been classified as Conditionally Approved.

Table 3.1: DOH Sites Not Meeting Water Quality Standards for Nisqually Reach. Sites in the Prohibited area (Melvin, 2006).

Site #	Geometric Mean	Est. 90th Percentile
224	14.6	70
234	19.1	69
235	16.7	70
236	15.2	73

Henderson Inlet: Henderson has been placed on the 303(d) list as defined by the Clean Water Act for exceeding the Total Daily Maximum Load for fecal coliform bacteria. Five sites did not meet the geometric mean, while six sites did not meet the standard for the 90th percentile (Table 3.2 Below). To be de-listed, a site must meet both geometric mean and 90th percentile. The site locations are in the southern end of Henderson Inlet where they are influenced by several discharge points. Table 3.3 shows the sites classified as Conditionally Approved.

Table 3.2: DOH Sites Not Meeting Water Quality Standards for Henderson Inlet. Sites in the Prohibited area (Melvin, 2007).

Site #	Geometric Mean	Est. 90th Percentile
185	26.7	185
186	17.8	107
187	12.4	69
188	14.3	89
189	14.0	80
212	16.1	63

Table 3.3: Sites Classified As Conditionally Approved Plus Two Approved Sites. Henderson Inlet Sites classified as Conditionally Approved (CA). The results show a spike in fecal coliform (FC) in November of 2005. The table only lists spikes in FC at CA sites. Note: the two sites normally classified as Approved were also affected by this storm event (Melvin, 2007).

Site #	Date	CFU/100ML	Conditional	Approved
199	Sep-03	46	Yes	
197	Jan-04	70	Yes	
198	Jan-04	33	Yes	
200	Jan-04	79	Yes	
200	Feb-04	33	Yes	
200	Jun-04	46	Yes	
198	Aug-04	33	Yes	
194	Oct-04	240	Yes	
200	Oct-04	540	Yes	
190	Nov-05	240	Yes	
191	Nov-05	240	Yes	
192	Nov-05	110		Yes
193	Nov-05	350		Yes
194	Nov-05	350	Yes	
195	Nov-05	350	Yes	
197	Nov-05	350	Yes	
198	Nov-05	350	Yes	
199	Nov-05	540	Yes	
200	Nov-05	240	Yes	
201	Nov-05	110	Yes	

The 24 hour rainfall of 1.68 inches on Nov 1st 2005 caused high levels of bacterial loading in marine waters at several sample stations. Table 3.3 above shows sites that are classified as Conditionally Approved with the addition of two sites that are normally classified as Approved. The results show a spike in fecal coliform loading in November

2005 storm event. The table only lists spikes in FC at CA sites. Note: two sites normally classified as Approved were affected by this storm event (Melvin, 2007).

Report by Washington State Department of Ecology:

The federal Clean Water Act requires that the Washington State Department of Ecology (DOE) conduct a Total Maximum Daily Load (TMDL) study of bodies of water on the 303(d) list. The 303(d) list is for those bodies of water that do not meet water quality standards. Four creeks in this study are; Meyers Creek, Sleepy Creek, Dobbs Creek and Goose Creek. All four of these creeks discharge directly into Henderson Inlet. TMDL samples were taken during critical storm events when bacterial loading is higher. Sites that consistently exceed the standard of 100 cfu/100ml are placed on the 303(d) listing until they meet the target standard. The four sites mentioned (Table 3.4 Below) failed to meet either the geometric mean or the 90th percentile. Table 3.4 also defines the percent of fecal coliform reduction needed to meet the target value of 100 cfu/100ml (Sargeant, et al., 2006).

Table 3.4: Creeks Not Meeting TMDL Standards.
Creeks in Henderson Inlet flow basin not meeting TMDL standards for geometric mean, 90th percentile and the needed percentile reduction of fecal coliform to meet water quality standards (Sargeant, et al., 2006).

Site Name	**Geometric Mean**	**Est. 90th Percentile**	**FC Reduction Needed**
Meyer Creek	109	741	87%
Sleepy Creek	90	835	88%
Dobbs Creek	299	2420	96%
Goose Creek	54	773	87%

Land Use:

The need to define land use increased with population size. Thousands of years ago indigenous people lived with nature and within its natural cycles. Some peoples were nomadic as they searched for the things they needed to survive and to be productive. Some peoples found lands that supplied their every need and they tended to stay more localized. Whatever the productive strategies of humans were, it was successful and populations grew. As populations developed in more localized areas, mainly for the availability of resources, the need to define how the land was used and by who increased.

With increased populations, it became necessary to draw judicial boundaries and enforce resource management practices. You could do certain activities on your own property, but your activities were regulated by how they affected your neighbors. With the need to provide food, water, energy and shelter for a growing population, environmental issues were generally considered local. With the worldwide changes to farmland, forests and waterways now upon us, this leaves us facing many challenges to manage trade-offs in sharing the planet's resources (Foley, et al., 2005).

Our ancient ancestors lived at a time when ecosystems were mostly pristine and their impact on the environment was minimal. With the large populations of today, our impact on the environment is being felt, and many of the disposable products of modern society are coming back to haunt us. Even hundreds of years ago we could throw something away and this wonderful planet we lived on would just absorb it. But now we are discovering that there is no place called "Away." Our ecosystems have become so impacted by our activities and our byproducts that those things we thought we could throw away are now revisiting us through our food, air and water.

Never before in our long human history has it been so important that we change our thinking on how we use the land we have been given. October 31st 2011 was the day set by the United Nation's Demographers when it was stated that the world human population would hit 7 Billion (Biello, 2011). Our large population has surpassed our carrying capacity and we face an increased need to share global resources. We have overseen an incredible loss of biodiversity and increase of pollution to air and water (Foley, et al., 2005). Our land use problem is two-fold. We need to identify and fix the errors of past land use practices, and also change the way we use our land in order to minimize our ecological footprint upon it.

Land Use Types: Anthropogenic land use has an effect on the quality of runoff water from different types of land uses such as urban, commercial, agriculture, industrial, forestry and recreational. With increasing population and the need for urban and industrial development, the burden of our environmental footprint increases. River systems and the watersheds that supply them with runoff water have had their hydrology altered by increased development. More urban development means more impervious surfaces. A study by Park et al. (2007) used LANDSAT data to show that land use is a significant factor in the contribution of pollutant loading. Impervious surfaces and current stormwater management systems contribute to rapid storm surge into streams and rivers that normally reach capacity during heavy storm events. Along with impervious surfaces, the system of creeks and streams that have been channelized into long straight ditches contribute to storm surge. The purpose of these ditches is to quickly remove runoff water from developed locations, to prevent water from ponding on property and agricultural fields. The problem with channelization is the destruction of habitat, undercutting roads and utilities, increase in non-point pollution, contributions to flooding downstream, and the devaluation of property in those flood prone areas (US EPA, Date Unknown).

WRIA 11 Parcels: The boundary for the Nisqually River Basin cuts through three counties: Thurston, Pierce and Lewis. Parcel data were collected for all three of those counties and the parcels specific to WRIA 11 were extracted from those data using GIS procedures. A categorical data method was used on the Nisqually River Basin parcel data set to create different land use types for calculating area and percent of the overall land use totals. The categorical information for land use types was taken from the land use code field in each parcel data set.

All the land use type parcels contained within that boundary cover an area of 483,420.90 acres (100% of all land use types). The dominate land use type in the Nisqually watershed was determined to be Forest at 264,653.17 acres, or 54.75% of the total land use. That was followed by land that was Underdeveloped, Undeveloped or

Open Spaces at 102,412.10 acres, or 21.18% of total. Smaller land use types were for Residential (58,530.15 acres, or 12.11%) and Agriculture (26,708.06 acres, or 5.52%). All the land use totals for WRIA 11 can be seen in Table 3.5. The breakdown of totals per county is in Table 3.6.

Table 3.5: Totals for Land Use Type in WRIA 11.

WRIA 11 Parcels	**Land Use Totals**	
Land Use Type	**Total Acreage**	**% of Total**
All Parcels	483420.90	100.00%
Forest	264653.17	54.75%
Under & Undeveloped & Open Spaces	102412.10	21.18%
Residential	58530.15	12.11%
Agriculture	26708.06	5.52%
Other (Gov., Schools, Exemptions, etc)	12635.96	2.61%
Timber	7158.29	1.48%
Manufacturing	4061.95	0.84%
Recreation & Cultural	3100.28	0.64%
Parks	2612.74	0.54%
Industry	915.64	0.19%
Service	378.14	0.08%
Retail	254.42	0.05%

Table 3.6: Totals for Land Use Type by County in WRIA 11.

WRIA 11 Parcels	**Thurston County**		**Pierce County**		**Lewis County**	
Land Use Type	**Acreage**	**% Land Use**	**Acreage**	**% Land Use**	**Acreage**	**% Land Use**
All Parcels	108490.24	100.00%	208707.29	100.00%	166223.37	100.00%
Forest	29042.39	26.77%	73268.33	35.11%	162342.45	97.67%
Under & Undeveloped & Open Spaces	40577.08	37.40%	61799.71	29.61%	35.31	0.02%
Residential	20296.44	18.71%	36331.45	17.41%	1902.26	1.14%
Agriculture	10686.00	9.85%	15625.06	7.49%	397.00	0.24%
Other (Gov., Schools, Exemptions, etc)	3319.03	3.06%	8443.58	4.05%	873.35	0.53%
Timber	584.93	0.54%	6205.36	2.97%	368.00	0.22%
Manufacturing	49.82	0.05%	3928.83	1.88%	83.30	0.05%
Recreation & Cultural	2680.77	2.47%	243.40	0.12%	176.11	0.11%
Parks	591.14	0.54%	1983.12	0.95%	38.48	0.02%
Industry	458.48	0.42%	457.16	0.22%	0.00	0.00%
Service	92.70	0.09%	278.75	0.13%	6.69	0.00%
Retail	111.46	0.10%	142.54	0.07%	0.42	0.00%

WRIA 13 Parcels: The boundary for the Deschutes River Basin cuts through two counties, Thurston and Lewis. Parcel data were collected for both counties and the parcels specific to WRIA 13 were produced and calculated in the same manner as in WRIA 11.

All the land use type parcels contained within the Deschutes River Basin (WRIA 13) cover an area of 225,395.53acres (100% of all land use types). The dominate land use type in the Deschutes watershed was determined to be Forest at 76,356.76 acres, or 33.88% of the total land use. That was followed by Residential at 47,509.72 acres, or 21.08% of the total land use. The next land use type category was Other (Gov., Schools, Exemptions, etc.). Another way to look at this category is that of public lands or public use parcels. This land use type covers 42,837.00 acres, or 19.01% of the total land use total. Underdeveloped, Undeveloped or Open Spaces was the next largest land use at 31,813.41 acres, or 14.11% of the total. Smaller areas of land were used for and Agriculture (9,277.41 acres, or 4.12%), Recreation & Cultural (5,713.41 acres, or 2.53%), Industry (4,679.23, or 2.08%) and Manufacturing (2,980.15 acres, or 1%). The remaining land use categories were less than 1% each. All the land use totals for WRIA 13 can be seen in Table 3.7. To see the breakdown of totals per county, see Table 3.8 below.

Table 3.7: Totals for Land Use Type in WRIA 13.

WRIA 13 Parcels	**Land Use Totals**	
Land Use Type	**Total Acreage**	**% of Total**
All Parcels	225395.53	100.00%
Forest	76356.76	33.88%
Residential	47509.72	21.08%
Other (Gov., Schools, Exemptions, etc.)	42837.00	19.01%
Under & Undeveloped & Open Spaces	31813.41	14.11%
Agriculture	9277.41	4.12%
Recreation & Cultural	5713.56	2.53%
Industry	4679.23	2.08%
Manufacturing	2980.15	1.32%
Parks	1209.14	0.54%
Retail	1075.50	0.48%
Service	1009.58	0.45%
Timber	933.57	0.41%

Table 3.8: Totals for Land Use Types by County in WRIA 13.

WRIA 13 Parcels	Thurston County		Lewis County	
Land Use Type	**Acreage**	**% Land Use**	**Acreage**	**% Land Use**
All Parcels	198545.78	100.00%	26849.75	100.00%
Forest	49507.01	24.93%	26849.75	100.00%
Residential	47509.72	23.93%	0.00	0.00%
Other (Gov., Schools, Exemptions, etc.)	42837.00	21.58%	0.00	0.00%
Under & Undeveloped & Open Spaces	31813.41	16.02%	0.00	0.00%
Agriculture	9277.41	4.67%	0.00	0.00%
Recreation & Cultural	5713.56	2.88%	0.00	0.00%
Industry	4679.23	2.36%	0.00	0.00%
Manufacturing	2980.15	1.50%	0.00	0.00%
Parks	1209.14	0.61%	0.00	0.00%
Retail	1075.50	0.54%	0.00	0.00%
Service	1009.58	0.51%	0.00	0.00%
Timber	933.57	0.47%	0.00	0.00%

Impervious Surfaces:

Anthropogenic growth and development have generated a continuing expansion of impervious surfaces. Many of these come in the form of roads, parking lots, rooftops, sidewalks and driveways. Impervious surfaces can diminish water quality in two primary ways. First, contaminates are deposited on surfaces, like roads, parking lots and driveways, and are then washed into drainage systems that discharge directly into streams and creeks during rain events. Second, runoff water from rain events and especially heavy storm events discharge quickly into streams and creeks that cause channel and bank erosion. This erosion causes high turbidity and can erode or even cover prime spawning habitat substrate. Because impervious surfaces inhibit storm water from percolation into the soil, a storm surge discharge is generated. This abnormally high discharge of water enters the lotic systems earlier than it would otherwise, thus creating higher water levels and higher flow velocity. This also generates higher flood risk to susceptible communities. Impervious surfaces remove the natural buffers that would slow down runoff water and help to recharge groundwater.

We pave over the permeable surfaces, erect huge box stores, build our homes, lay down roads so we can get from one place to the other, and for our convenience cluster stores together in large impermeable Mega-Malls, so we can shop from store to store without having to move our car. These parking lots and malls with huge box stores create a very large impervious footprint that thwarts the natural hydrological cycle.

The Problem: The built environment comes with external cost for which we have not accounted. The increasing numbers of buildings, parking lots and roads have created impervious surfaces that block the natural infiltration of rainwater into the ground. The urbanization of a watershed has profound effects that degrade downstream habitats, as well as increase flood frequency and decrease the base flow of a river (Asleson, et al., 2009). U.S. urban land use is projected to increase from 3.1% in the year 2000 to 8.1% in 2050, an area larger than the state of Montana. The growth in urban land necessitates the need for more planning and regional management of resources and ecosystem services for this growing population (Nowak & Walton, 2005). Currently, to deal with the rainwater not infiltrated into groundwater, we build an infrastructure of ditches and modify stream channels to more quickly and effectively shed excess surface water away from buildings and parking lots. As long as we are living on higher ground, it may seem like a good solution to rapidly remove unwanted water downstream to the river. But, what of the logic that challenges practical ecological reasoning; the need we have to build in the river’s flood plain.

We build in flood plains because it is flat, easy and cheaper to build there (seldom mindful the reason it is called a flood plain). Rivers flood from time to time as part of their natural cycle. This flooding event replenishes nutrients to habitats for free. Also, that rich soil is a desirable influence for living and working there. So, we build up the flood plain with more impervious surfaces, the last place for rainwater to get absorbed into the ground before reaching the river and ultimately the ocean. The efficient drainage system created to shed storm water, now adds extra water to the river’s flood stage during storm events. To protect our need to build in the flood plain, we invest more money to build dikes and levees to protect our flood plain investment, and dams to hold back runoff water. Those solutions come at of big cost to economy and ecosystems.

Another unexpected consequence of impervious surfaces is the contaminant deposits upon them that get washed directly into streams and rivers, thus impacting habitats and the species that occupy aquatic habitats. Our growing population and the increase of urbanization and industrialization are considered the primary factors responsible for the increase of pollution of our aquatic systems. These water bodies receive residential and industrial waste from surface runoff. We now have to build conventional methods for treating this waste, which are generally costly and not ecofriendly (Dhote & Dixit, 2009). In contrast, there are systems being developed that mimic a more natural self-purification, water impoundment and infiltration system. A study by Scholz & Kazemi Yazdi (2009) showed that runoff water and pollution levels can be successfully reduced by utilization of storm water detention areas.

With increasing population and the need for urban and industrial development, the burden of our environmental footprint increases. River systems and the watersheds that supply them with runoff water have been hydrology altered by this increased development. More urban development means more impervious surfaces. A study by Park et al., (2007) used LANDSAT data to show that land use as a significant factor in the contribution of pollutant loading. Impervious surfaces and current storm water management systems contribute to rapid storm surge into streams and rivers that normally reach capacity during heavy storm events. Along with impervious surfaces that contribute to storm surge are the system of creeks and streams that have been channelized into long straight ditches. The purpose of these ditches is to quickly remove runoff water from developed locations, to prevent water from ponding on property and agricultural fields. The problem with channelization is that it destroys habitat, undercuts roads and utilities, increases non-point pollution, contributes to flooding downstream, and the devaluation of property in those flood prone areas (US EPA, Date Unknown).

To sum it up, urban areas are growing, and with this growth we generate a larger ecological footprint. The question we should be asking ourselves in our quest for development is, “Do we want the land we build on to inhibit the natural hydrologic cycle, or do we want it to work with the natural cycles to reduce the negative impact of our presence upon it?”

The effect of urban growth with its impervious surfaces is a big problem to tackle, and some communities show a growing desire to work with natural system to solve the problems created by growth. Mallin (2000) suggests low-impact development practices can solve many of the problems produced by the urban impervious footprint.

Analysis of the Lower Henderson Inlet Sub-Basin Septic Systems as Source of Fecal Coliform Loading on Shellfish Beds:

The WRIA 13 water quality parameter tabular data analysis, discussed in Chapter 2, revealed 17 monitoring sites on streams having their discharge points into the Henderson Inlet shellfish beds. Henderson Inlet sub-basin is divided into an upper and lower flow basin. The upper basin sheds water from a variety of residential and commercial land use parcels. This area is drained by two main creek systems, Woodland Creek and Woodard Creek. Woodland Creek flows north through the residential and commercial districts of the City of Lacey, and discharges at the southern end of Henderson Inlet estuary. Woodard Creek flows north and drains parts of east Olympia and western parts of Lacey, before it discharges into the mid portion of Henderson Inlet estuary on the west side.

Lower Henderson Inlet basin sheds water from residential, agricultural and forest land adjacent to the inlet on it west and east banks. Figure 3.1 shows the boundary of the lower basin in the shaded area on the map and the shellfish beds area. Many of the residential and agricultural parcels in this area have septic systems for wastewater treatment. Also, seven of the monitoring sites in this basin failed to meet the analysis criterion for FC 50 at the 35% plus geometric mean standard. Lower Henderson Inlet basin was chosen for GIS spatial analysis because of the density of parcels within it with septic systems. This analysis was set up to identify potential point sources of fecal coliform bacterial contamination. Upper Henderson Inlet flow basin also contained parcels on septic systems, but are more spread out. The same methods for spatial analysis can be used in both upper and lower flow basins. The density of septic systems and the close proximity to shellfish beds is why the lower flow basin was chosen for this study.

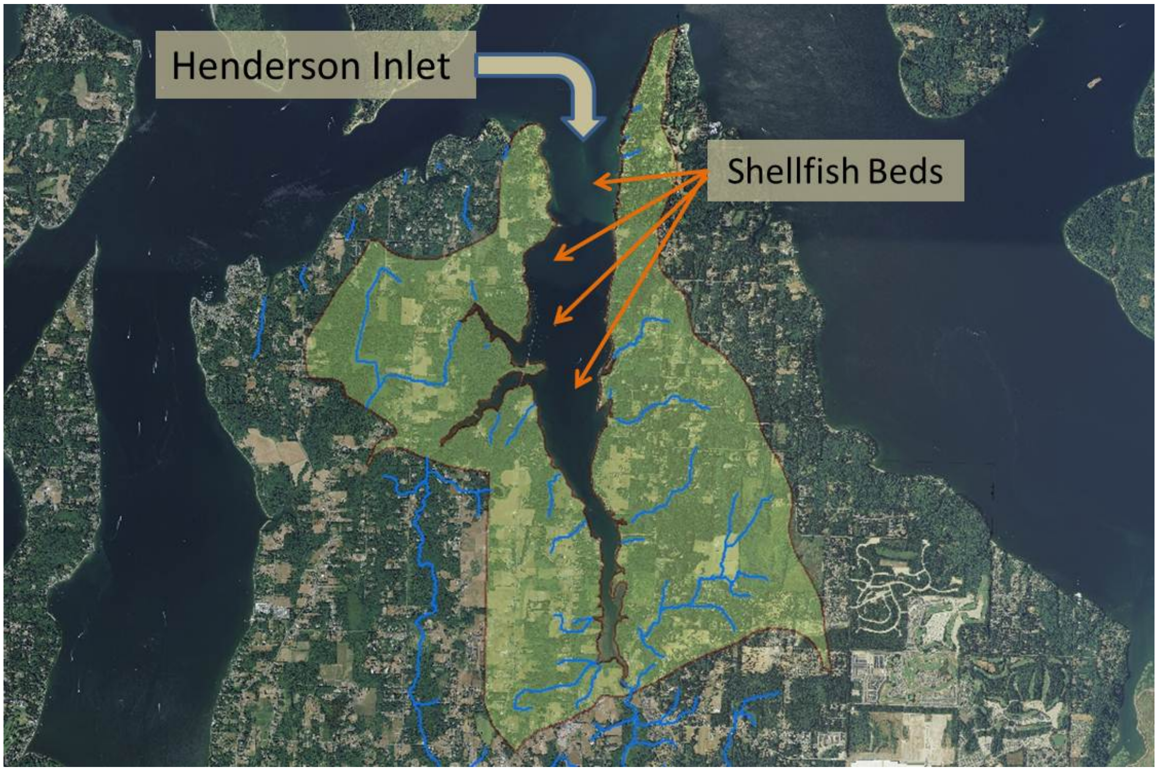


Figure 3.1: The Lower Henderson Inlet Sub-Basin and Shellfish Bed Area.
The Lower Henderson Inlet Sub-Basin (Shaded) and the General Location of Shellfish Beds (Orange Arrows).

Point and Non-Point Source Pollution: The source of pollution can be placed in two categories, point source and non-point source. Point source is when a specific location can be identified as the discharge of a pollutant. Some examples of this would be effluence for industry or wastewater treatment. Non-point is when the source of a pollutant cannot be determined by a specific source. Some examples of this would be open area where domesticated or wild animals defecate, especially near streams, creeks and drainage systems. The point source exception to this for domesticated animals would be where cattle have direct access to lotic systems. When livestock are known to use the fields next to flowing water and have access to it for drinking water, the chances of fecal matter getting mixed into the stream are highly suspect.

The Lower Henderson Inlet basin has some agricultural farms with livestock and this may be a source for fecal coliform in the local creeks, but the more likely scenario is failing septic systems. This was the reason that identifying potential failed septic systems as the point source was chosen for spatial analysis using GIS. The section on Spatial Analysis below shows the results of locating septic systems as a possible point source of the fecal coliform concentrations in local creeks.

Spatial Analysis: All the site locations in WRIA 13 were created using the site location coordinates provided with the water quality data collected from the Department of Ecology's EIM system (Ecy-3, 2011). The geographic coordinate locations were then turned into point features that identified locations of each monitoring sites. The tables that were created from the tabular analysis of water quality results were joined to those monitoring site features. An attribute query was performed to identify those sites where FC 50 failed to meet the 35% plus geometric mean standard. The result of the attribute query is shown in Figure 3.2. The seven site features are shown as yellow dots in the map.

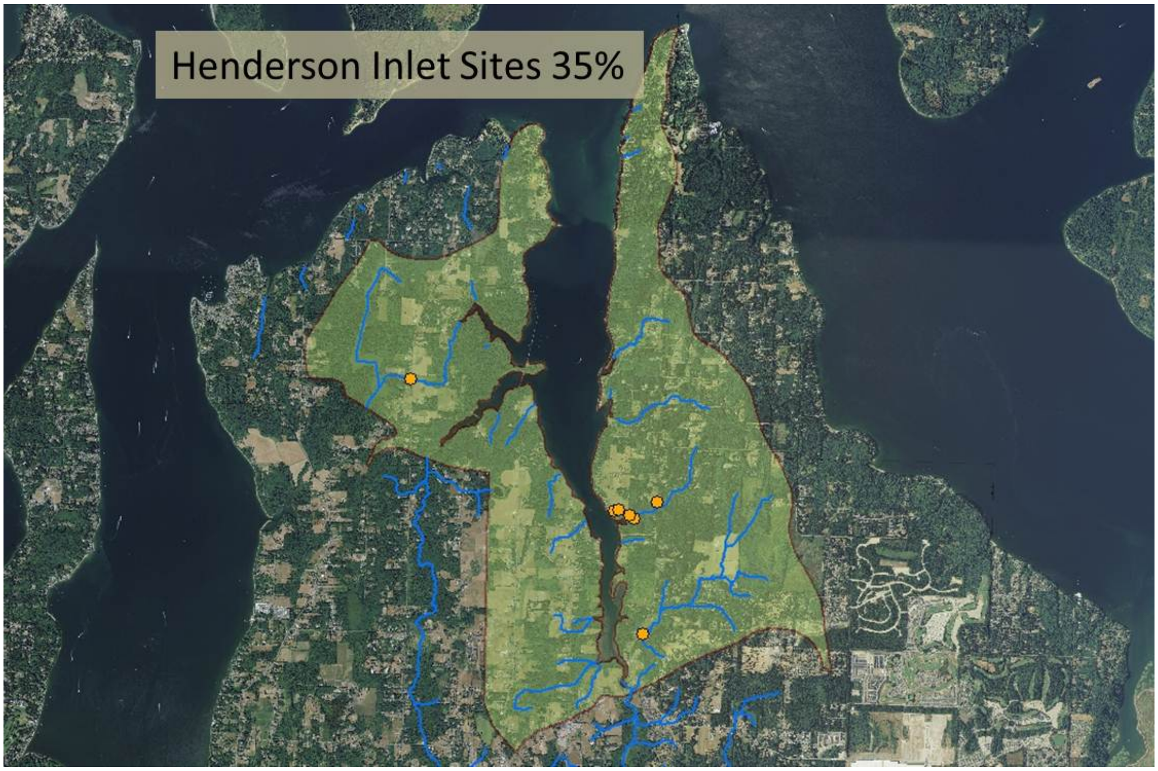


Figure 3.2: The 35% FC 50 Monitoring Sites in the Lower Henderson Inlet.
The FC 50 monitoring sites with results of 35% plus geometric mean standard are shown as yellow dots.

The next step was to identify and create new line features for the creek systems where the target monitoring sites were located. The new features represent Dobbs Creek, Sleepy Creek and Swayne Creek. Swayne Creek was not identified in the EIM (Ecy-3, 2011) data, but the Creek name was acquired from a Department of Ecology report on Henderson Inlet TMDL (Sargeant, et al., 2006). Figure 3.3 shows the new creek features with red lines.

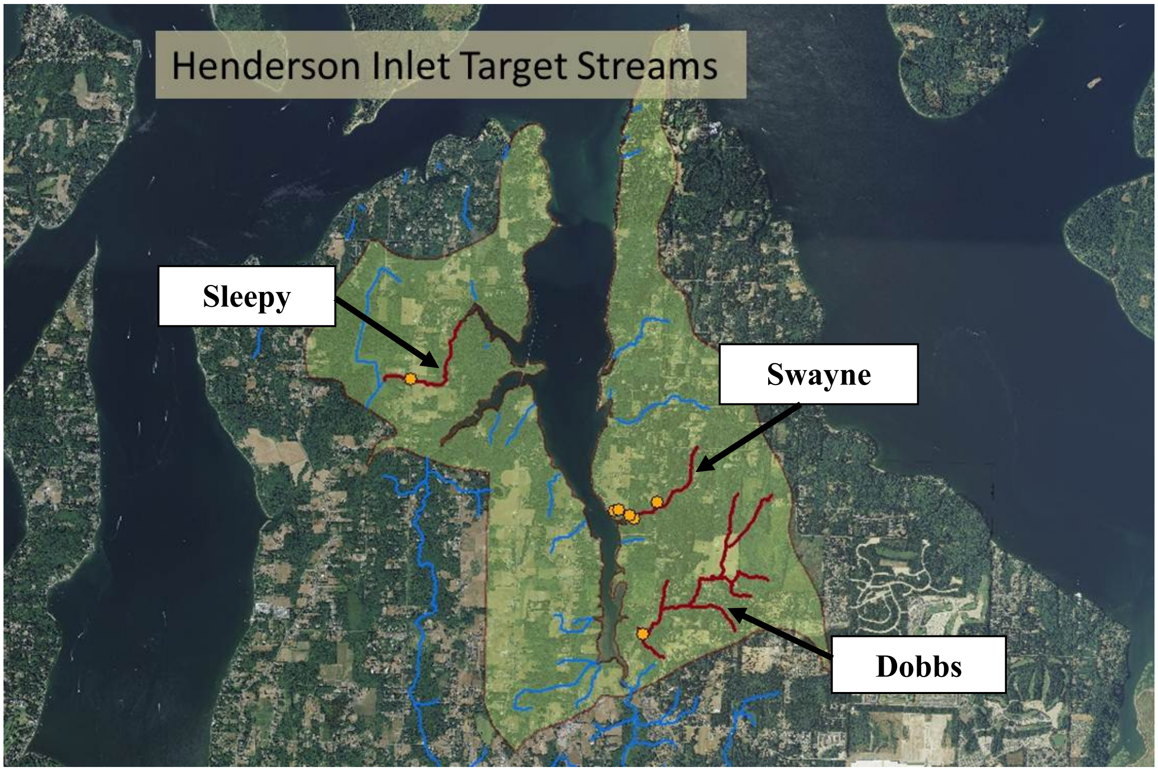


Figure 3.3: The FC 50 Target Creeks in the Lower Henderson Inlet.
The FC 50 Target Creeks Identified are Dobbs Creek, Sleepy Creek and Swayne Creek.

The next step identified the target of single residential parcels with septic systems. Single resident parcels are the dominant land use type in the lower Henderson Inlet which is why they were the first choice in looking for failed septic systems. If this spatial analysis investigation were followed through to conclusion, and no failing septic systems were found among the single dwellings, then the analysis parameters would be expanded to greater distances from creek channels and to also include multiple dwelling residential and agricultural land use.

The “locate by distance” (spatial analysis tool) of 1000 feet was selected for parcel boundary proximity from the target creeks. The distance was arbitrarily picked to gain information on septic systems closest to the target creeks. Note: this is just a place to start the search for failing septic systems. This method narrows the search pattern on the number of locations to begin checking septic systems. If no failing septic systems are found in the first search, then the "locate by distance" can query for those parcels 2000 feet and so on. The target septic systems are the parcels in Figure 3.4 (below) highlighted in red boundaries.

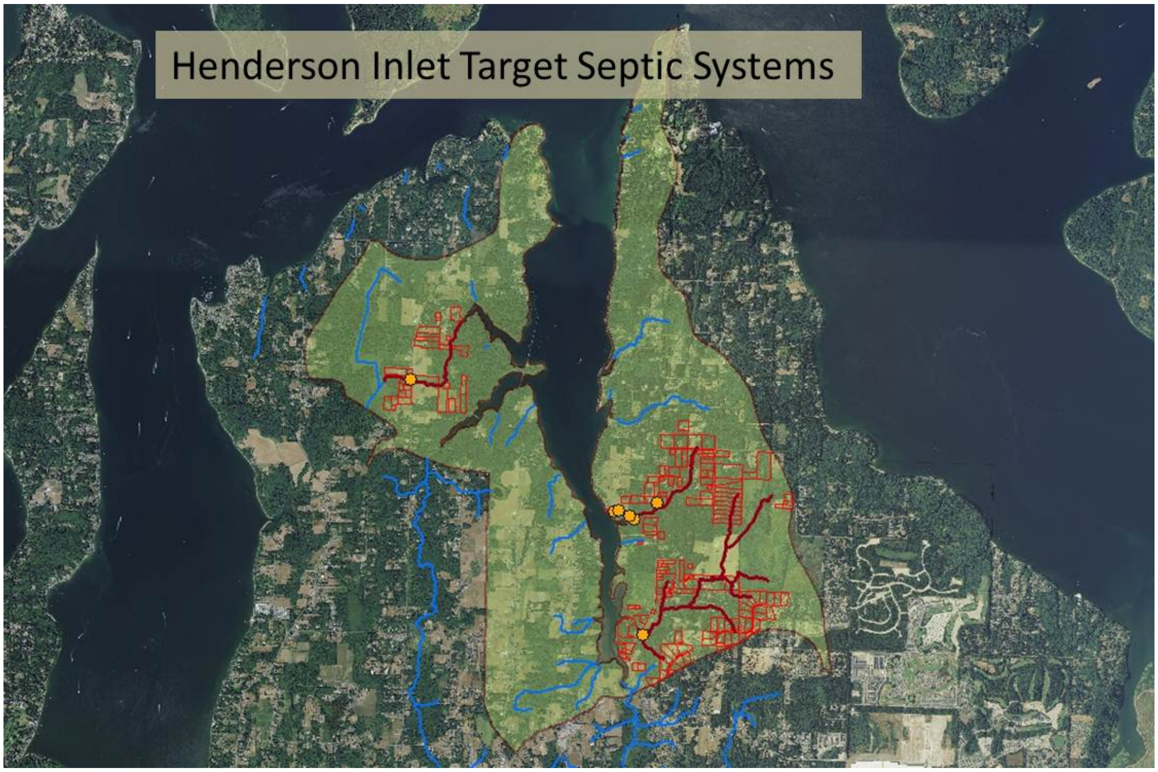


Figure 3.4: Target Parcels with Septic Systems in the Lower Henderson Inlet.
Parcel Boundaries are within a distance of 1000 feet of the Target Creeks.

Conclusions: This spatial analysis method successfully identified those single resident parcels with septic systems that are in close proximity to the target creeks. Each of the parcel data records contains information on the parcel owner, contact and location. From this information a list of target septic systems can be generated for the Department of Health or the Department of Ecology to investigate possible failure of septic systems that discharge wastewater into the local creeks. This method was based on the fecal coliform standards of 50 cfu/100ml (WA Ecology, 2006) as analysis criterion to protect against the contamination of shellfish beds. The spatial analysis method used here can also be applied for recreational primary contact by changing the fecal coliform standard to 100 cfu/100ml (WA Ecology, 2006) as the analysis criterion. Review of these water quality standards can be found in Table 1.2 in Chapter One.

The easiest phase of the identification of parcels with target septic systems was performed with the GIS software. The majority of the work in this study was the management of the water quality tabular data. Those data records needed to be proofed for quality assurance, organized by monitoring sites, algorithms created for each parameter based on water quality criteria, a tier ranking system defined, ranking results tables created, aggregation tables created across multiple parameters and ranking tables prepared as join table for the GIS location features.

The GIS preparation for the Henderson Inlet study needed the acquisition and creation of spatial layers in part for display purposes and spatial analysis. The layers for map image display started with an orthophoto (geographically referenced aerial photo) of Thurston County. On this image were two other layers, a boundary of the lower Henderson Inlet flow basin and a hydrology layer for the Henderson Inlet basin creeks. To create a land use layer for the lower Henderson Inlet, Thurston County parcel data were used (refer to the section on Land Use / WRIA 13 Parcels). The Geoprocessing Clip tool in ArcGIS® was used to create parcel features for the lower Henderson Inlet flow basin area. The water quality data downloaded from EIM (Ecy-3. 2011) provided the coordinates for the location of each monitoring site. The coordinates were converted to point features in GIS and used to join the ranking tables for analysis. The last layer needed was the target creeks that were generated from the first phase of the analysis process. These were turned into a feature for the next phase of identifying target parcels with septic systems.

This method for identification of target parcels works well with the above mentioned analysis structure. This method can be easily replicated for other flow basins where sewer system types are part of the parcel data. Thurston County did include that type of information, whereas Pierce and Lewis Counties did not. Other sources of data would need to be obtained if this type of analysis were performed for Pierce or Lewis Counties.

Chapter Four:

Defining Flow Basin Influence on Degraded Lotic Systems

Introduction:

Identifying degraded water quality at specific sampling sites in streams and rivers is only one part of the picture of degraded habitats. To understand what is influencing the water quality results at these sample sites, one must also understand the potential contributing factors to those results. Water flows downhill, therefore the drainage area above these water quality sampling sites would be the potential influence on the results acquired from those sample sites. This area is defined as the flow basin to each of those sample sites. Within those flow basins are different aquatic systems like streams and creeks, wetlands, as well as forest and many different other land use types.

Flow basins are digitally defined by using ArcGIS® hydrology tools to analyze digital elevation models (DEM) for flow direction and accumulation. This method can be used to calculate area for any spatial data flow point; in the case of this thesis those points represent the water quality sampling sites of interest. The points of interest are sites not meeting water quality standard for the highest percentage of time sampled. Once the flow basin is generated, it is used to calculate the different land use types within its boundary. The different land use types are extracted from parcel layers provided by the counties represented by watersheds in this study. The parcel information comes from Thurston, Peirce and Lewis Counties in western Washington State.

Before defining the land use influences, it is important to describe the types of impacts from anthropogenic activities from those different land uses.

Watershed Function and Stressors:

Watersheds support diverse components of an ecosystem, while providing a system that purifies water by filtering out pollution, sediments, and toxins. Increased population, economic activities, and development have put stresses on watersheds by added pollution and depletion of resources. This anthropogenic activity may well cause a decline in living standards and destabilize the integrity of the ecosystem. Ranking among the most urgent issues facing us today, by 200 leading scientists from more than 50 countries, sustainable watershed management should receive some of the highest priorities (Levy et al., 2006).

It should also be noted that flowing aquatic systems like streams, rivers, and even drainage ditches have not only that which can be seen within their channels, but also include the unseen system and the not so obvious. A watershed does what it says; it sheds water and ultimately flows down slope to its lowest point. Watersheds are integrated systems of water channels, wetlands, runoff, and ground water. Watersheds are also complex ecosystems that have established equilibrium of plants and animals over thousands of years. These complex ecosystems cycle nutrients and basic elements throughout the watershed with the help of down slope movement, runoff from rainfall, and animals spreading nutrients throughout local and upstream habitats, to just name a few. Water seen in a channel actually extends beyond its banks as groundwater. If the water table is high, the ground water flows toward the open stream channel, and if the water table is low, the water in the channel will saturate the surrounding soils and replenish the groundwater. Lipophilic organic toxins in stream water can bond with soil. In low water table conditions, these contaminants can become imbedded in the soils around the stream banks as water saturates the surrounding soils. In high water table conditions, and especially during storm events, lipophilic toxins can enter the aquatic system through soil erosion. Any contaminants deposited on the ground follow along the same complex system as do the nutrients and elements. This is why it is so important to have a functional riparian zone along the edge of flowing systems to filter and uptake contaminants. A riparian zone is nature’s plant and microorganism remediation system. This is how nature takes care of itself, but what about anthropogenic disturbances to nature’s filtration system?

Urban development has impacted greatly the health and equilibrium of watersheds. Urban watersheds should be perceived as integrated physical systems. Their function is dependent on the interaction of chemicals, ecological elements, and the hydrology of the system. Urbanization can have a negative impact in a cumulative manner as drainage systems and smaller streams contribute higher peak flows as well as heavy sediment and pollutant loads to the higher order waterways downstream. As waterways travel further downstream through heavily urbanized areas, the stream conditions worsen. The accumulated impairment is passed down to and affects public economic and social costs. These impairments correspond to a loss of ecological services. The communities downstream are often forced to offset these loses (Platt, 2006). Where natural systems are obstructed by urban development, the best approach is the establishment of green zones to replace nature's riparian zones. Planting trees and shrubs, constructed wetlands and other bioretention areas can be incorporated into these green zones help mitigate toxic urban runoff.

Spatial Analysis of Ohop Creek in WRIA 11:

The tabular analysis of water quality data (Chapter Two) for the Nisqually River Basin (WRIA 11) revealed a cluster of multiple parameter failures for the Ohop Creek monitoring sites. The aggregation table showed 10 of 49 monitoring sites in the Ohop Creek system had failures across multiple parameters. The Ohop Creek sites, with several indications of degraded water quality, were selected in this study for further spatial analysis in GIS.

As many of the 10 monitoring sites were clustered in groups and would have been cumbersome to generate flow basins to each of the 10 sites to perform an analysis of the Ohop Creek system. To make the analysis manageable, four of the sites were selected. The protocol for selection was that all sites had to have failure across multiple parameters, have an over-all failure rate of 60% or greater and must be spaced at least one river mile (R.M.) from each other. The four sites selected are listed in Table 4.1 below with a description of each site.

Table 4.1: Ohop Creek Site Selections.
Site ID, over-all percent failure rate, river mile (R.M.) and description of the location.

	Site ID	Over-All %	R.M.	Location Description
Site 1	OHOPCR(RM0.1)_TAX	61.2 %	0.1	Ohop Creek Near Mouth
Site 2	OHOPCR(RM2.0)_G93	62.7%	2.0	Ohop Creek @ Highway 7
Site 3	OHOPCR(RM3.3	61.36%	3.3	Ohop Creek @ Ohop Valley Rd.
Site 4	OHOPCR(RM6.3)_G95	65.75%	6.3	250 Ft. Below Ohop Lk. Outlet

To prepare the water quality tabular data for spatial analysis, the GIS features were created for the Ohop Creek flow basin. Because the Ohop Creek sub-basin is within WRIA 11 and did not have its own defined flow basin feature in GIS, therefore one had to be created. The other challenge was creating flow basins for each of the four monitoring sites on Ohop Creek. First the features for four monitoring sites were created as a separate layer. These four feature points became the flow points in the next step. This step was accomplished by use of the GIS hydrology tools on a 30 meter DEM to define flow basins to those specific flow points. With the Ohop flow basin created, it then was used to clip out the hydro layers for streams and lakes, and to clip out the Ohop parcel layer from the Pierce County parcel data. The parcel data were grouped into land use types and their boundaries recalculated. The recalculation of parcel area was necessary because the Ohop flow basin boundary line cut through some parcels on its edges.

Flow Basins: The Ohop flow basin was generated as a single feature with four polygons each representing an area above each of the flow points (see Figure 4.1). The purpose of this was to define all the drainage areas that terminated at those specific monitoring sites, and delineates the specific areas of influence on water quality sample results taken at each monitoring site. The entire Ohop flow basin feature was used to clip out all the land use parcels contained within it (See Figure 4.2). Table 4.2 gives the number of parcels within the Ohop flow basin and the calculated land use area in acres and the percent of the total each land use type represents.

Finally the Ohop flow basin feature was divided into four separate polygon features that represent the flow basins to each of the monitoring sites (flow points).These polygons represented the area of flow between monitoring sites or from headwaters to monitoring sites. Each polygon was used as segments to clip land use features for each of those segments, and to calculate the area of land use types within each segment. More detail on the land use analysis of each flow basin segment in the following sections.

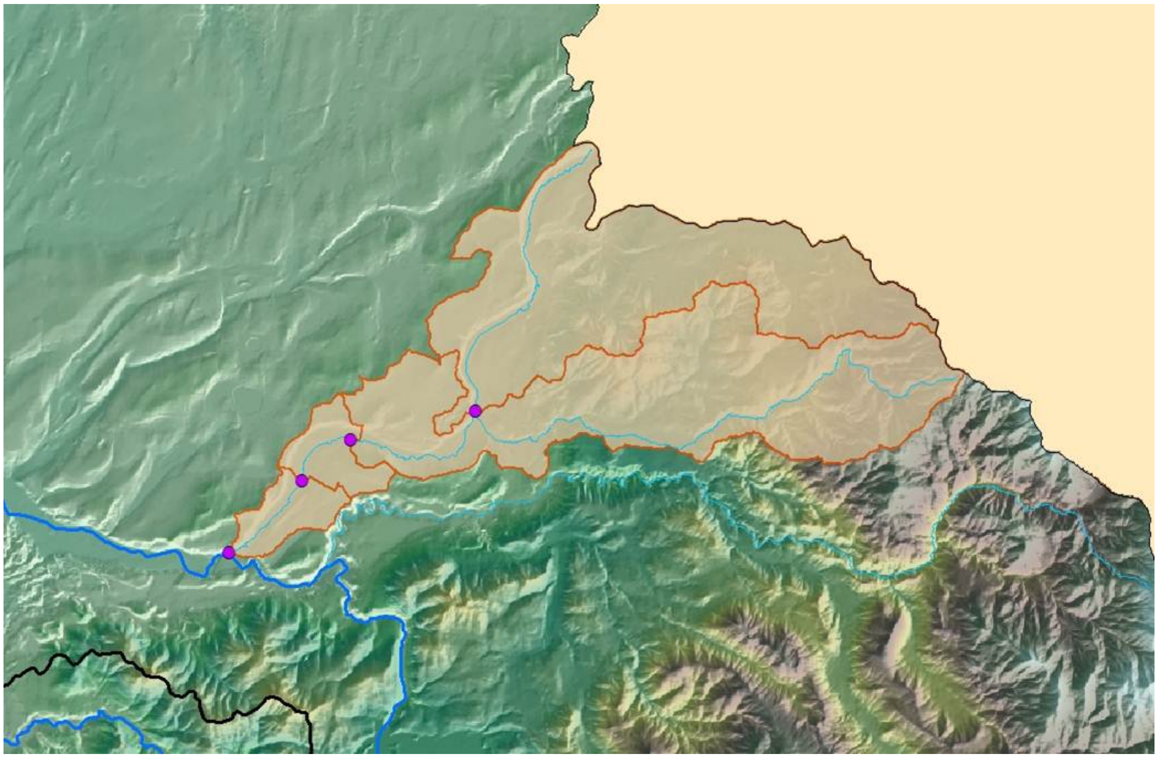


Figure 4.1: The Ohop Flow Basin Feature.
Flow basin single feature showing 4 polygons, one to each flow point.

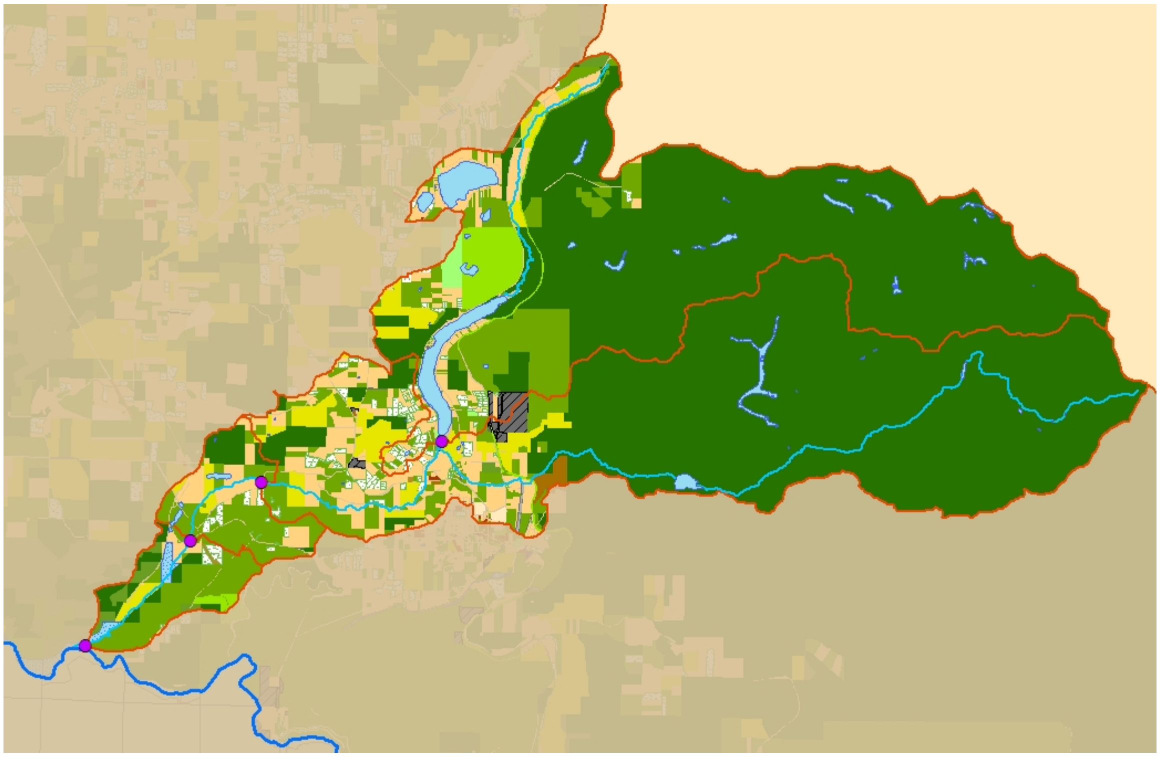


Figure 4.2: The Ohop Flow Basin with Land Use Features.
Flow basin with land use features clipped from the Pierce County parcel data.

Table 4.2: Ohop Flow Basin Calculated Land Use.
Land use type, number of parcels, calculated acreage and the percent land use.

Land Use	Num. of Parcels	Acres	Percent
FOREST	138	18411.58	68.69%
UNDEVELOPED	547	3501.21	13.06%
RESIDENTIAL	1204	2154.43	8.04%
AGRICULTURE	57	1035.57	3.86%
PARKS	29	555.20	2.07%
MISC.	163	482.25	1.80%
TIMBER	22	171.02	0.64%
GOVERNMENT	6	165.74	0.62%
RECREATION	5	96.15	0.36%
FLOODWAY	10	71.58	0.27%
INDUSTRIAL	3	71.40	0.27%
SCHOOLS	12	33.46	0.12%
TRANSPORT.	23	25.05	0.09%
UTILITIES	5	11.58	0.04%
WATER	4	7.64	0.03%
SERVICES	9	5.77	0.02%
RETAIL	8	5.15	0.02%
FIRE STATION	1	0.05	0.00%

Joining Spatial and Tabular Data: The objective of the Ohop Creek study was to look for possible relationships between land use and the quality of water that flows through the Ohop Basin. Two types of data were needed to assess the effects of land use on water quality, the spatial data in GIS and the tabular water quality data from the analysis in Chapter Two. The spatial data were geographic features such as hydrology layers, the flow basin layer and the parcel layer. In order to join the tabular data to this map, point features had to be created to represent the locations of the monitoring sites. The spatial site location layer was then joined with the water quality tabular data. The water quality tabular data was the aggregated ranking table (results across multiple parameters) that was then joined to the point features by site ID.

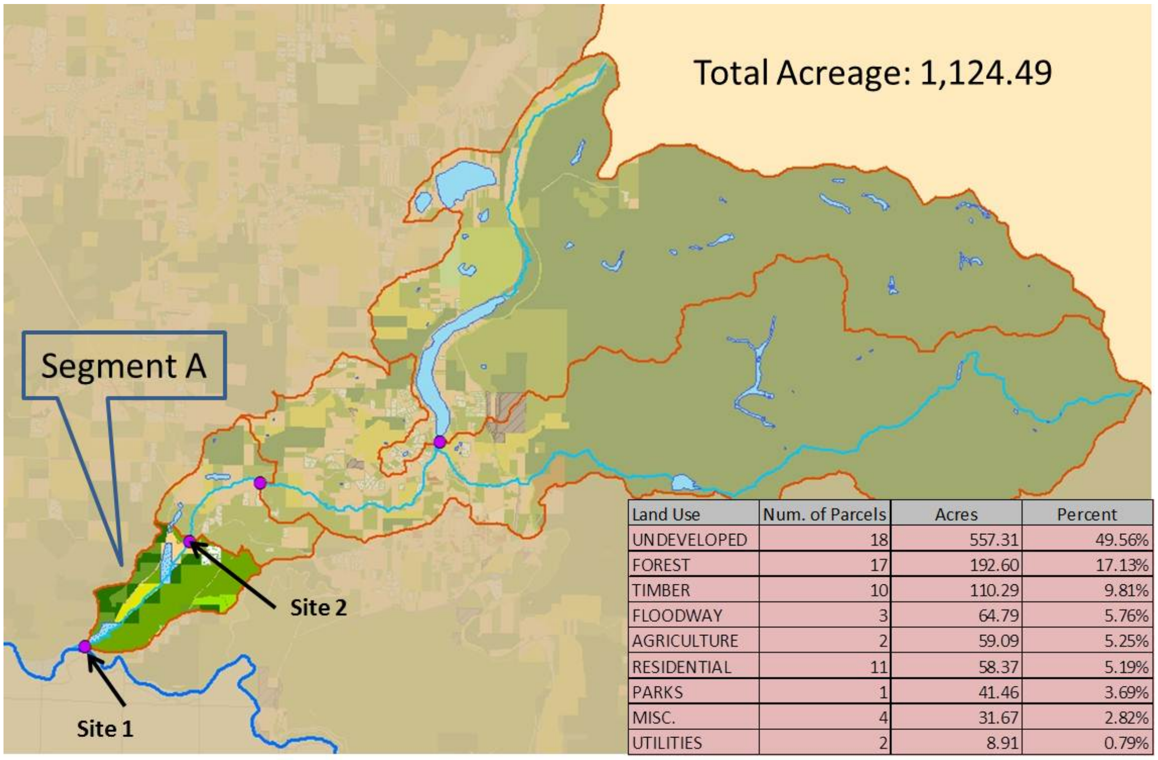
Flow Basin Analysis: When all the spatial and tabular data were set up for this section, the next step was to perform the analysis. The four water quality monitoring sites on Ohop Creek divided the Ohop flow basin into four segments. Each segment represented an area of land use types, number of parcels for each type, acreage of each parcel type and the percentage each land use type represented in the total of its own segment. This method showed the variation of land use between each monitoring site. Once the variation of land use was related to the variation of water quality ranking results, the relationship between the two could be assessed.

Analysis of Flow Basin Land Use: The Ohop Flow Basin was divided into four flow basin segments based on monitoring site locations and all down gradient flows to each monitoring site. Each segment was created as an individual polygon feature that represented land area that drained to each specific monitoring site. These flow basin polygons were divided between upper to lower site and headwaters to the next lowest site, so that there was no overlap of land use area. The segmented flow basins are defined as follows:

- Segment A: Between Site 1 (Lower) and Site 2 (Upper)
- Segment B: Between Site 2 (Lower) and Site 3 (Upper)
- Segment C: Between Site 3 (Lower) and Eastern Tributary Headwaters (Upper)
- Segment D: Between Site 4 (Lower) and Northern Tributary Headwaters (Upper)

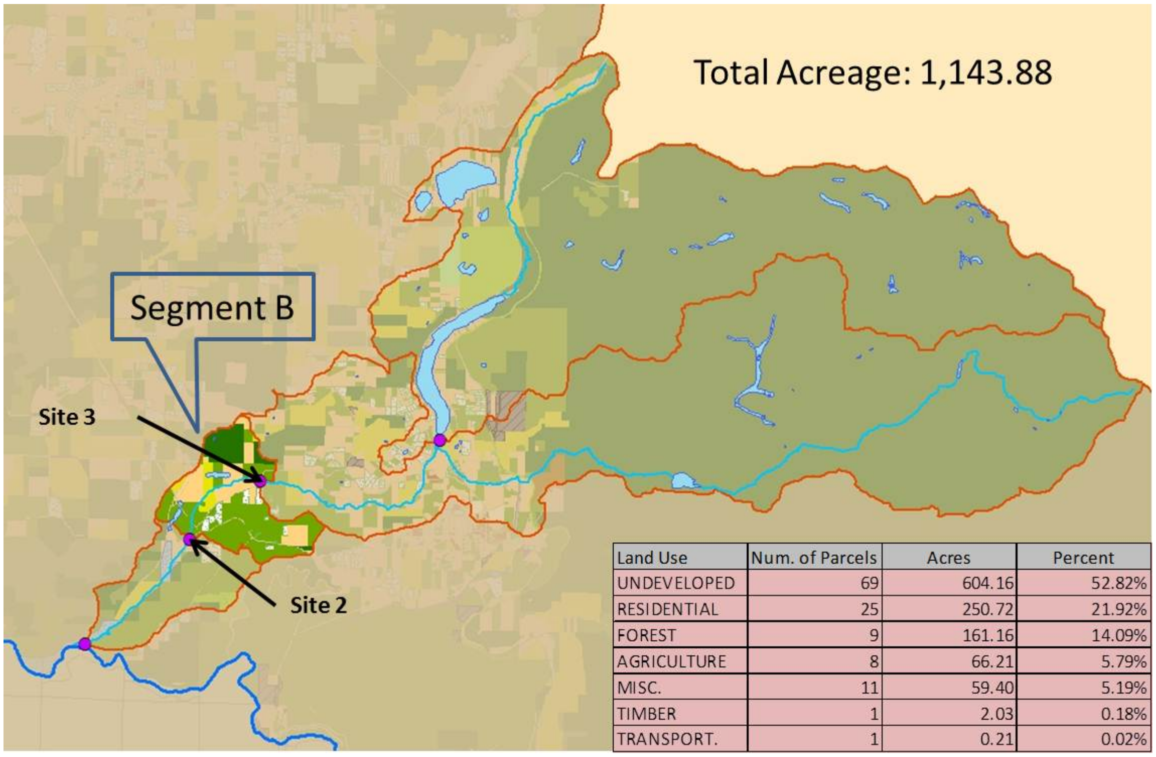
The four flow basin segment polygons were used to clip parcel data from the Pierce County parcel data. The parcel data segments were used to identify the different land use types within each of the segments. Before the analysis of land use type area, each parcel segment was recalculated so that it accurately represented the total amount of acreage per parcel. As mentioned previously, the necessity for recalculation was due to the flow basin boundaries that had clipped off boundary edges on of some parcels.

The following figures show the map location of each segment, total acreage of each segment, and the breakdown of each land use type by number of parcels, total acreage of each land use type and the percent rank of each land use type of the total acreage per segment. For detailed information see Figure 4.3 for Segment A, Figure 4.4 for Segment B, Figure 4.5 for Segment C and Figure 4.6 for Segment D.



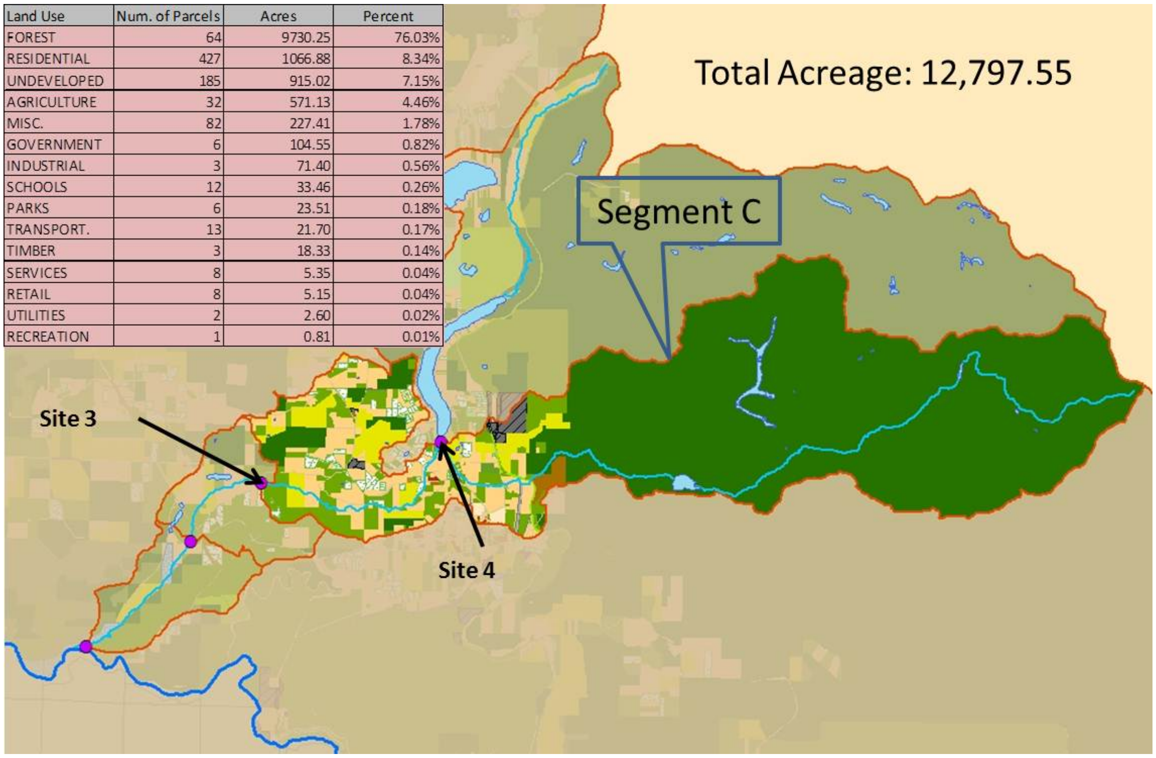
Land Use	Num. of Parcels	Acres	Percent
UNDEVELOPED	18	557.31	49.56%
FOREST	17	192.60	17.13%
TIMBER	10	110.29	9.81%
FLOODWAY	3	64.79	5.76%
AGRICULTURE	2	59.09	5.25%
RESIDENTIAL	11	58.37	5.19%
PARKS	1	41.46	3.69%
MISC.	4	31.67	2.82%
UTILITIES	2	8.91	0.79%

Figure 4.3: Segment A of the Ohop Land Use Analysis.
Land use details: number of parcels, acres and percent of total.



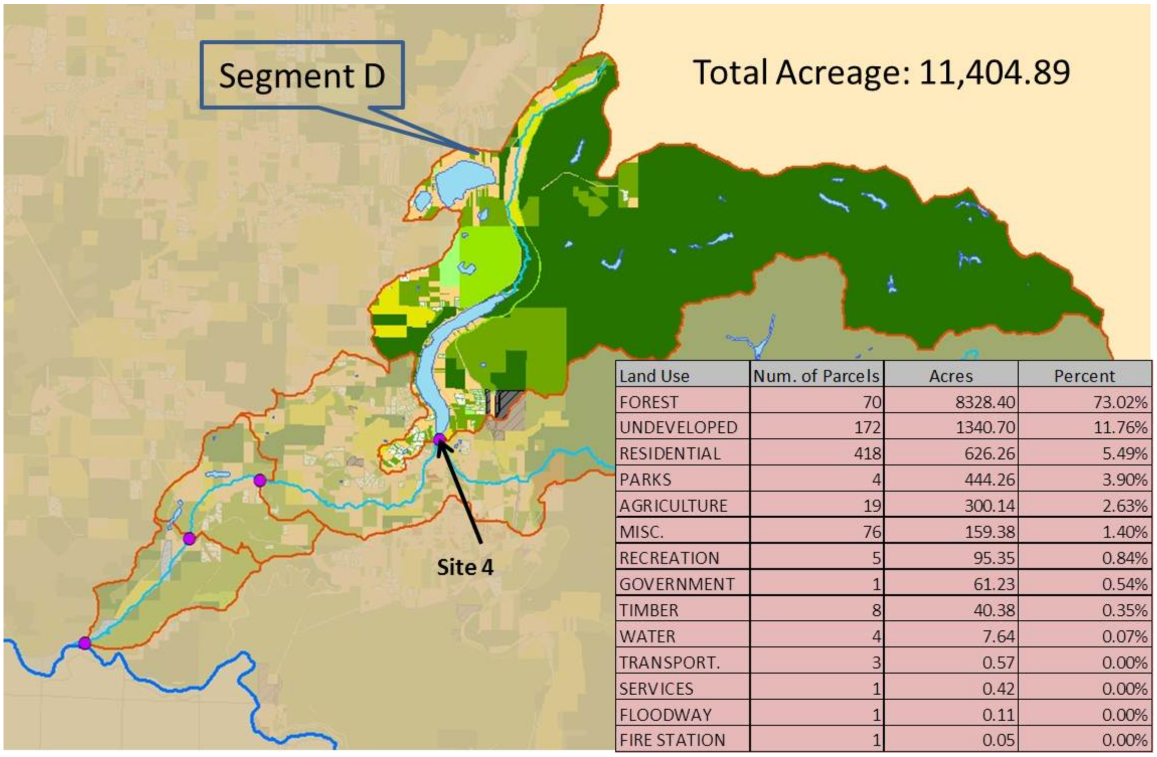
Land Use	Num. of Parcels	Acres	Percent
UNDEVELOPED	69	604.16	52.82%
RESIDENTIAL	25	250.72	21.92%
FOREST	9	161.16	14.09%
AGRICULTURE	8	66.21	5.79%
MISC.	11	59.40	5.19%
TIMBER	1	2.03	0.18%
TRANSPORT.	1	0.21	0.02%

Figure 4.4: Segment B of the Ohop Land Use Analysis.
Land use details: number of parcels, acres and percent of total.



Land Use	Num. of Parcels	Acres	Percent
FOREST	64	9730.25	76.03%
RESIDENTIAL	427	1066.88	8.34%
UNDEVELOPED	185	915.02	7.15%
AGRICULTURE	32	571.13	4.46%
MISC.	82	227.41	1.78%
GOVERNMENT	6	104.55	0.82%
INDUSTRIAL	3	71.40	0.56%
SCHOOLS	12	33.46	0.26%
PARKS	6	23.51	0.18%
TRANSPORT.	13	21.70	0.17%
TIMBER	3	18.33	0.14%
SERVICES	8	5.35	0.04%
RETAIL	8	5.15	0.04%
UTILITIES	2	2.60	0.02%
RECREATION	1	0.81	0.01%

Figure 4.5: Segment C of the Ohop Land Use Analysis.
Land use details: number of parcels, acres and percent of total.



Land Use	Num. of Parcels	Acres	Percent
FOREST	70	8328.40	73.02%
UNDEVELOPED	172	1340.70	11.76%
RESIDENTIAL	418	626.26	5.49%
PARKS	4	444.26	3.90%
AGRICULTURE	19	300.14	2.63%
MISC.	76	159.38	1.40%
RECREATION	5	95.35	0.84%
GOVERNMENT	1	61.23	0.54%
TIMBER	8	40.38	0.35%
WATER	4	7.64	0.07%
TRANSPORT.	3	0.57	0.00%
SERVICES	1	0.42	0.00%
FLOODWAY	1	0.11	0.00%
FIRE STATION	1	0.05	0.00%

Figure 4.6: Segment D of the Ohop Land Use Analysis.
Land use details: number of parcels, acres and percent of total.

Analysis of Land Use and Water Quality: With the land use analysis and the water quality data analysis (Chapter Two) completed, the next step was comparing land use to water quality results. Much of analyzing that relationship was subjective, because it lent itself to assumptions based on known causes of degraded water quality. For example: disturbances to soil can cause elevated turbidity levels, fertilizer for gardens and agriculture can elevate bacterial and nutrient levels, agribusiness feedlots can contaminate streams with fecal coliform, higher stream temperatures and eutrophication can deplete dissolved oxygen, lack of riparian zones can elevate stream temperature, acidic or alkaline chemical contamination can alter stream pH, and impervious surfaces can alter stream hydrology. These are only a few examples, and GIS is just a representation of the real world. To know what causes degraded water quality, it would take a real-world focused study of an affected area. The benefit of doing the analysis first in GIS is that it helps identify those areas to focus on for the on-the-ground studies.

The land use totals were presented in the above Figures 4.3 through 4.6. To compare the land use by segment, the next step was to identify the percent rank failure to meet water quality standards at the flow points for each of those segments. This is provided by the GIS join tables that contained those results. What remained was to look at the water quality parameter failure ranking and the higher percentages of land use that could be influencing the results of water quality sampling. Those comparisons are in the following section on conclusions.

Notice the relationship of each of the monitoring sites (see Figure 4.7 below) to the land use segments (Refer to Figure 4.3 through Figure 4.6 above). Everything that flows to Segment A arrives from all the upper segments (B, C & D). Everything that flows to Segment B arrives from Segment C and Segment D. Segment D enters Segment C’s flow basin at two-thirds of the way down its flow basin after the forested parcels of Segment C. Segment D is the only one not influenced by other land use flow basins.

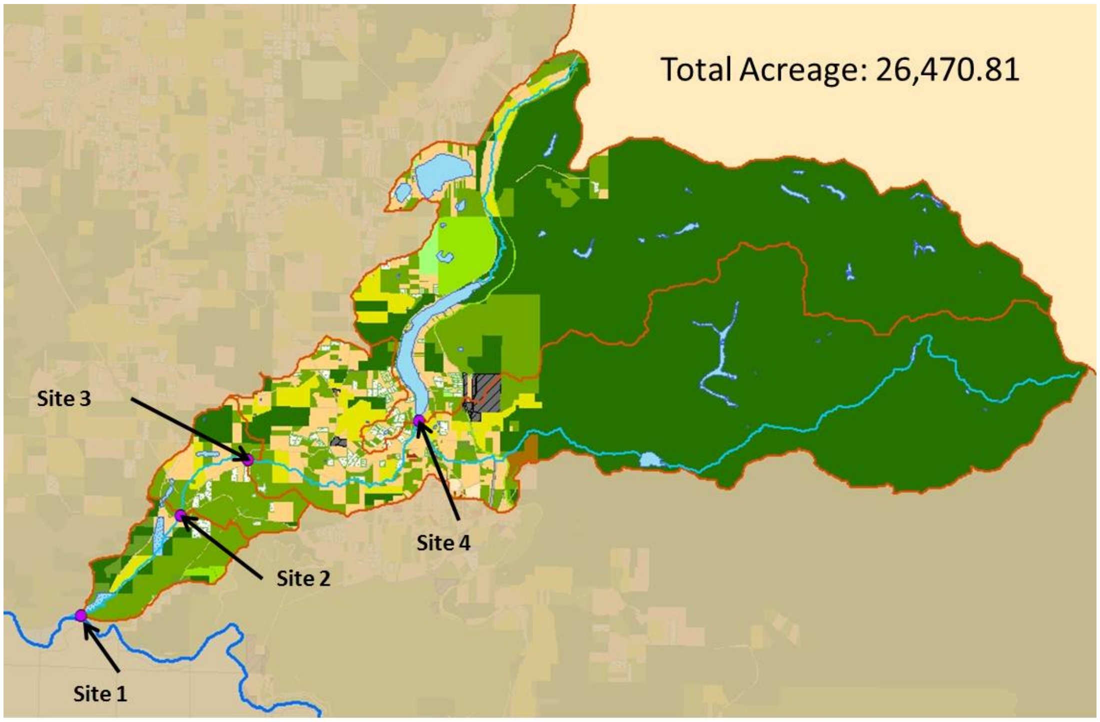
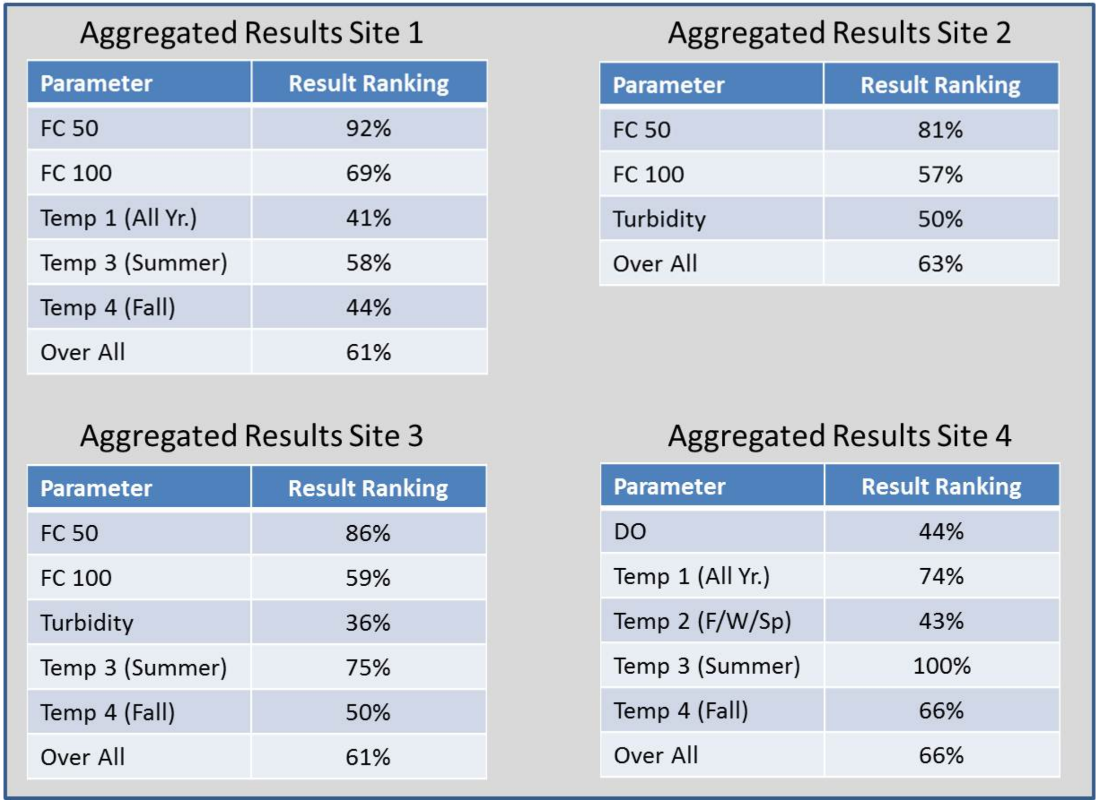


Figure 4.7: The Ohop Flow Basin Four Monitoring Sites.
Ohop flow basin's monitoring sites in relation to land use.

Table 4.3: Aggregated Water Quality Results for the Ohop Monitoring Sites.



Aggregated Results Site 1

Parameter	Result Ranking
FC 50	92%
FC 100	69%
Temp 1 (All Yr.)	41%
Temp 3 (Summer)	58%
Temp 4 (Fall)	44%
Over All	61%

Aggregated Results Site 2

Parameter	Result Ranking
FC 50	81%
FC 100	57%
Turbidity	50%
Over All	63%

Aggregated Results Site 3

Parameter	Result Ranking
FC 50	86%
FC 100	59%
Turbidity	36%
Temp 3 (Summer)	75%
Temp 4 (Fall)	50%
Over All	61%

Aggregated Results Site 4

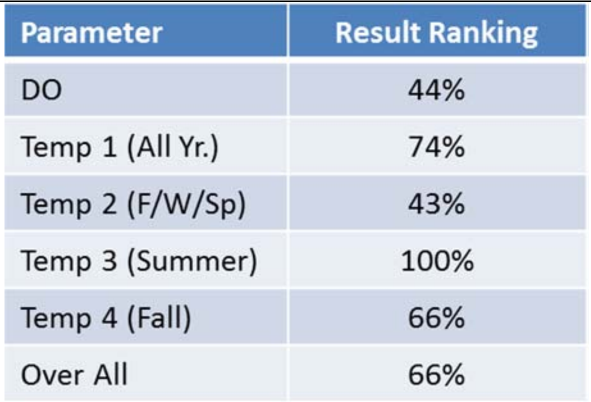
Parameter	Result Ranking
DO	44%
Temp 1 (All Yr.)	74%
Temp 2 (F/W/Sp)	43%
Temp 3 (Summer)	100%
Temp 4 (Fall)	66%
Over All	66%

Conclusions: By looking at the relationship of water quality to land use by each land use segment, we see that water quality sample results are affected by what happens up stream, including the other upstream land use segments. To analyze this relationship I emphasize that inferring a causal effect on water quality due to surrounding land use is subjective. The methods outlined in this study are not the end point for resolving water quality issues, but rather a beginning. The objective of this study is to identify problem areas.

The Ohop flow basin is a holistic system and to understand how water quality effects changes throughout this basin, it was logical to track those changes from headwaters to the mouth of Ohop Creek. Starting with the water quality ranking at Site 4, the primary issues were temperature and dissolved oxygen (see Table 4.4). Site 4 is located near the outlet of the large water body of Ohop Lake. Large bodies of water normally tend to absorb heat from the sun and have higher general temperatures than the surrounding creeks and streams. There is a strong correlation between water temperature and dissolved oxygen. As water temperature increases, the dissolved oxygen in the water is released into the atmosphere. The primary land use in Segment D is forest and undeveloped land. In respect to land use and water quality it would seem that the land use types are not the main factor for the water quality results, but rather the large body of water from Ohop Lake.

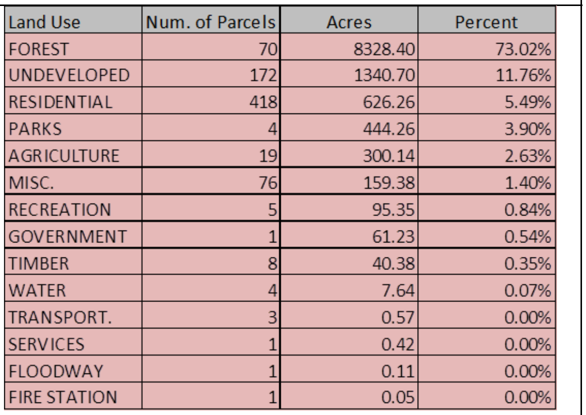
Table 4.4: Site 4 Water Quality Result Ranking, Segment D Land Use Totals.

Site 4



Parameter	Result Ranking
DO	44%
Temp 1 (All Yr.)	74%
Temp 2 (F/W/Sp)	43%
Temp 3 (Summer)	100%
Temp 4 (Fall)	66%
Over All	66%

Segment D

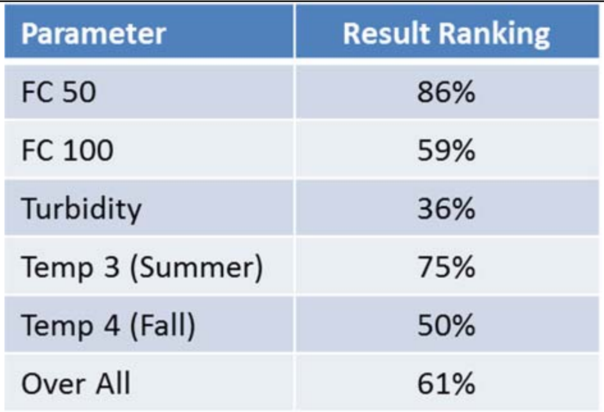


Land Use	Num. of Parcels	Acres	Percent
FOREST	70	8328.40	73.02%
UNDEVELOPED	172	1340.70	11.76%
RESIDENTIAL	418	626.26	5.49%
PARKS	4	444.26	3.90%
AGRICULTURE	19	300.14	2.63%
MISC.	76	159.38	1.40%
RECREATION	5	95.35	0.84%
GOVERNMENT	1	61.23	0.54%
TIMBER	8	40.38	0.35%
WATER	4	7.64	0.07%
TRANSPORT.	3	0.57	0.00%
SERVICES	1	0.42	0.00%
FLOODWAY	1	0.11	0.00%
FIRE STATION	1	0.05	0.00%

Downstream from Site 4 is Site 3 and Segment C where water quality seems to be more influenced by land use. For this land use segment, water temperature result ranking had decreased from the results upstream. Fecal coliform had emerged as an issue at Site 3 (See Table 4.5).

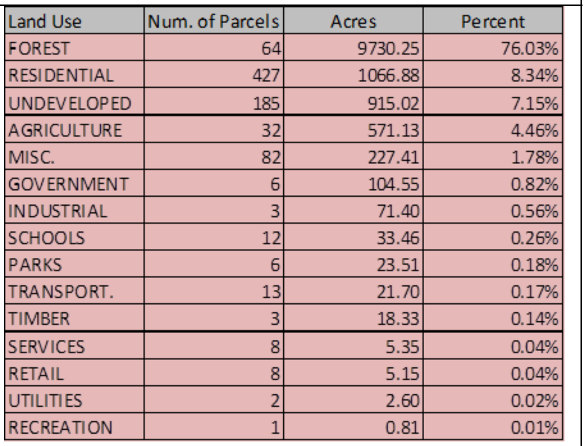
Table 4.5: Site 3 Water Quality Result Ranking, Segment C Land Use Totals.

Site 3



Parameter	Result Ranking
FC 50	86%
FC 100	59%
Turbidity	36%
Temp 3 (Summer)	75%
Temp 4 (Fall)	50%
Over All	61%

Segment C



Land Use	Num. of Parcels	Acres	Percent
FOREST	64	9730.25	76.03%
RESIDENTIAL	427	1066.88	8.34%
UNDEVELOPED	185	915.02	7.15%
AGRICULTURE	32	571.13	4.46%
MISC.	82	227.41	1.78%
GOVERNMENT	6	104.55	0.82%
INDUSTRIAL	3	71.40	0.56%
SCHOOLS	12	33.46	0.26%
PARKS	6	23.51	0.18%
TRANSPORT.	13	21.70	0.17%
TIMBER	3	18.33	0.14%
SERVICES	8	5.35	0.04%
RETAIL	8	5.15	0.04%
UTILITIES	2	2.60	0.02%
RECREATION	1	0.81	0.01%

First taking the relationship of stream temperature to land use, the notable changes are in the summer and fall monitoring period. The summer change went from 100% of the time not meeting water quality standards in Segment D, to 75% of the time. Fall went from 66% to 50% of the time. There are a couple of land use features that could affect the drop in result ranking by the time the stream flow reached Site 3. The majority of parcels in Segment C consist of forested land. This amounts to 76.03% of the total land use (9730.25 acres) in Segment C, most of which is located in the headwaters of the upper basin. Forested stretches of stream channels tend to stay cool in temperature because of shading. This majority of forested land is also above the point where Site 4 discharges water from Ohop Lake into Segment C. The mixing of cooler forested stream water with warmer water from Ohop Lake could account for the reduction in failure rates to meet analysis criteria. Another factor that could influence the results at Site 3 is the riparian zones along its banks throughout the Ohop Creek's pathway in the developed areas of Segment C. A visual survey could be made of this by looking at an orthophoto of this area.

The next notable change in Segment C is the emergence of issues with fecal coliform in the stream water. The result ranking for FC 50 (Protection of Shellfish Beds) is 86% and FC 100 (Primary Recreational Contact) is 59% of the times samples failed the water quality standards. Wildlife could be a contributing factor, but more likely for these high numbers the problem lies with land use development. From the developed areas the possible contributors to fecal coliform in the stream water would be residential and agriculture. The next highest land use to forest parcels is residential with 427 parcels covering 1066.88 acres, and fourth in line is agriculture at 32 parcels covering 571.13 acres or 4.46% of the total land use in Segment C. The limiting factor for further analysis on the fecal coliform relationship is the Pierce County's parcel data, which did not include information on sewer system types. The fecal coliform problem could be caused by leaky or failing septic systems, livestock and domestic animals or a combination thereof. To get a better answer to the question of the fecal coliform source is to acquire information on Pierce County septic systems and livestock populations as well as how many of the livestock have direct access to Ohop Creek. Because the Ohop Creek flow basin is completely within Pierce County, the same need for further research information will also be needed for all the other land use segments.

The next downstream relationship is Site 2 and Segment B. The most notable change here is that the water temperature result ranking has improved. There were no ranking failure rates above 35%, which could be an outcome of the cooler stream water from the forested headwaters and riparian zones in Segment C. Fecal coliform still remains an issue at around the same result ranking as with Site 3. For this segment, turbidity has emerged as an issue (see Table 4.6). From a visual survey of this area of an orthophoto, two things become apparent: the reduction of riparian zones and Ohop Creek being adjacent to large open agriculture field and small residential farms. The second largest percent of land use in this segment is residential with 25 parcels at 250.72 acres or 21.92% of total land use. The fourth largest percentage is agriculture with eight parcels consisting of 66.21 acres at 5.79% of total land use. The large open access to Ohop Creek could be a possible cause of the higher levels of turbidity. This could be a result from bank erosion of livestock access to the creek. Further site surveys would be needed before a conclusion could be made in that respect.

Table 4.6: Site 2 Water Quality Result Ranking, Segment B Land Use Totals.

Site 2

Parameter	Result Ranking
FC 50	81%
FC 100	57%
Turbidity	50%
Over All	63%

Segment B

Land Use	Num. of Parcels	Acres	Percent
UNDEVELOPED	69	604.16	52.82%
RESIDENTIAL	25	250.72	21.92%
FOREST	9	161.16	14.09%
AGRICULTURE	8	66.21	5.79%
MISC.	11	59.40	5.19%
TIMBER	1	2.03	0.18%
TRANSPORT.	1	0.21	0.02%

This brings the water quality land use relationship study to the termination point at Site 1 of the Ohop Creek flow basin. The direct land use influences here are from Segment A and are contributed to by all the other upstream land use segments. At Site 1 there is a noticeable increase in the analysis criteria rates for fecal coliform. There was an 11% increase for FC 50 to a result ranking of 92% failure of water quality standards. There was also an increase in FC 100 to a 69% result ranking (see Table 4.7). This would suggest that Segment A has additional point/non-point source contributions of fecal coliform to Ohop Creek. In this land use segment residential and agriculture are roughly a little more than 5% each of the total land use. As with the other land use segments, more information is needed on septic systems and livestock populations.

Table 4.7: Site 1 Water Quality Result Ranking, Segment A Land Use Totals. Fecal coliform issues increased at Site 1 from ranking at Site 2 & Site 3 Water temperature result ranking issues reemerged at Site 1.

Site 1

Parameter	Result Ranking
FC 50	92%
FC 100	69%
Temp 1 (All Yr.)	41%
Temp 3 (Summer)	58%
Temp 4 (Fall)	44%
Over All	61%

Segment A

Land Use	Num. of Parcels	Acres	Percent
UNDEVELOPED	18	557.31	49.56%
FOREST	17	192.60	17.13%
TIMBER	10	110.29	9.81%
FLOODWAY	3	64.79	5.76%
AGRICULTURE	2	59.09	5.25%
RESIDENTIAL	11	58.37	5.19%
PARKS	1	41.46	3.69%
MISC.	4	31.67	2.82%
UTILITIES	2	8.91	0.79%

The final notable change in Segment A is that stream water temperature issues have returned. This could be a result from the lack of riparian vegetation on both sides of Ohop Creek. A portion of the creek runs through open fields and then is only shaded by trees to the southeast of the channel. This allows the creek to get a good exposure of afternoon sunlight. Riparian plantings on both sides of Ohop Creek may help to resolve the temperature issues.

Final Thoughts:

Using water quality data analysis and developing the land use types for analyzing the relationship between the two has been an arduous process, but well worth the effort. This type of study can become a useful tool for the decision making process of groups and agencies to identify those areas best suited for planning the use of restoration dollars. The maps produced in this type of study give good geographical and tabular information for potential project sites. The GIS information produced can be used as a platform to receive further information as well as the creation of new spatial data as field projects move forward.

There are two other things to acknowledge in this study about the identification of degraded water quality in Henderson Inlet and Ohop Creek. Those two sites had already been decided on as part of this thesis study when it was discovered those two locations had been assigned actual restoration projects. The Department of Health and Department of Ecology launched a Total Maximum Daily Load (TMDL) study of Henderson Inlet. The Nisqually Indian Tribe, USFWS, South Puget Sound Salmon Enhancement Group, National Fish and Wildlife Foundation, Stream Team and the Nisqually Land Trust did enhancement work on the Ohop Creek channel and added plantings of riparian vegetation. The discovery of these two major projects, midway through this thesis study, was taken as a validation of the important work in this thesis to identify areas best suited for environmental restoration and enhancement projects.

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Appendix

Table A1: Lotic Site Locations WRIA 11

Site_ID	% Over All	Location
MC5.8	90.91%	MCALLISTER BELOW WETLAND
MC4.3	85.00%	MCALLISTER CREEK AT BLUE BRIDGE
MED0.1	81.25%	MEDICINE CREEK UPSTREAM FROM MOUTH
MID-LAKEDRAIN	77.38%	MID-LAKE DRAINAGE (W OF 391ST)
OHOPCR(RM6.3) G93	75.00%	OHOP CREEK BELOW OHOP LAKE
RSWT	73.81%	WEST TRIB. OF RED SALMON CREEK
11A070D	66.67%	NISQUALLY RIVER AT NISQUALLY
OHOPCR(RM6.3) G95	65.75%	OHOP CREEK 250 FEET BELOW OHOP LAKE OUTLET
NISQUALLY(39.7)	65.63%	NISQUALLY RIVER ABOVE MASHEL RV
OHOPCR(RM2.0) G93	62.70%	OHOP CREEK @ HIGHWAY 7
OHOPCR(RM3.3)	61.36%	OHOP CREEK @ OHOP VALLEY ROAD
MUCKCR(RM6.2)	61.21%	MUCK CREEK AT ROY (WARREN AVE)
OHOPCR(RM0.1) TAX	61.20%	OHOP CREEK NEAR MOUTH
MC4.4TLBU	60.00%	TRIB OPPOSITE MEDICINE CREEK, L/B U/S
MASHELRV(RM6.0) TAX	59.44%	MASHEL RIVER @ ALDER CUT-OFF RD
OHOPCR(RM6.0) TAX	59.31%	OHOP CREEK BELOW OHOP LAKE
RSET	58.33%	EAST TRIB. OF RED SALMON
OHOPCR(RM0.1) G93	56.80%	OHOP CREEK NEAR MOUTH
MC3.1	56.67%	MCALLISTER CREEK BELOW I-5
OHOPCR(RM6.0) G93	56.03%	OHOP CREEK BELOW LYNCH CREEK
MC5.4	53.89%	U/S OF LITTLE MCALLISTER
11A090D	52.78%	Nisqually R abv Powell Cr
LIITLEMASHELRV	51.93%	LITTLE MASHEL RIVER @ HIGHWAY 161
MC4.7	51.48%	MCALLISTER CREEK AT STEILACOOM ROAD
MED0.0	50.79%	MEDICINE CREEK AT MOUTH
OHOPCR(RM2.0) G93	50.00%	OHOP CREEK @ HIGHWAY 7
MUCK01	50.00%	MUCK CR AT MOUTH
MUCKCR(RM0.1)	50.00%	MUCK CREEK NEAR MOUTH
MASHELRV(RM6.0) G9	50.00%	MASHEL RIVER @ ALDER CUT-OFF RD
YELMCR(RM0.1) TAX	50.00%	YELM CREEK NEAR MOUTH
MC3.7	48.70%	MCALLISTER CREEK ABOVE MARTIN WAY
MASHELRIVER	48.68%	MASHEL RIVER @ MOUTH
OHOPCR(RM9.9) G95	48.57%	OHOP CREEK BELOW TWENTY-FIVE MILE CREEK
11A080D	47.78%	Nisqually R @ McKenna
11A070E	47.14%	NISQUALLY RIVER AT NISQUALLY
NISQUALLY(3.7) TAX	47.06%	NISQUALLY RIVER @ HANDICAP ACCESS
LAC05	46.67%	LACAMAS CR AT 8TH AVE S.
SOUTHCK03	46.67%	SOUTH CR NEAR 294TH ST E. PIERCE CO.
MUCK22	45.83%	MUCK CR AT 8TH AVE E.
MASHELRV(RM3.2)	44.17%	MASHEL RIVER @ HIGHWAY 7
TANWAXCR(RM0.3) TAX	42.97%	TANWAX CREEK @ HARTS LAKE ROAD
MUCK04	42.50%	MUCK CR AT WARREN STREET, NEAR ROY
MC4.5	42.22%	MCALLISTER BELOW RESIDENTIAL AREA
MUCK24	40.00%	MUCK CR AT 70TH AVE E.
MUCK18	39.58%	MUCK CR AT 8TH AVE S.
MUCK23	38.46%	MUCK CR AT WEILER RD, PIERCE CO.
LYNCH CREEK	38.13%	LYNCH CREEK @ OHOP VALLEY EXTENSION RD
TANWAX(RM10.2)	34.29%	TANWAX CREEK @ 352ND AVE
MC4.3T	34.20%	TRIB TO MCALLISTER D/S OF BLUE BRIDGE

Table A2: Lentic Site Locations WRIA 11

Site_ID	% Over All	Location
TANWAXLAKE	90.48%	TANWAXLK (MIDDLE) Lake/Pond/Reservoir
SILVERLAKE	89.13%	SILVERLK (MIDDLE) Lake/Pond/Reservoir
CLETH11	88.00%	CLEAR Lake/Pond/Reservoir
OHOPLAKE	86.84%	OHOPLK (MIDDLE) Lake/Pond/Reservoir
RAPJOHNLAKE	80.95%	RAPJOHNLK (MIDDLE) Lake/Pond/Reservoir
OHOPI11	75.48%	OHOP Lake/Pond/Reservoir
RAPPI11	68.89%	RAPJOHN Lake/Pond/Reservoir
WHIPI11	68.59%	WHITMAN Lake/Pond/Reservoir
OHOPLAKESTA3	65.35%	OHOP LAKE STATION 3 (NORTH END) Lake/Pond/Reservoir
OHOPLAKESTA2	62.90%	OHOP LAKE STATION 2 (MIDDLE) Lake/Pond/Reservoir
ST#TH11	62.58%	ST. CLAIR Lake/Pond/Reservoir
HARPI11	62.54%	HARTS Lake/Pond/Reservoir
MINERALLAKE	62.00%	MINERALLK (MIDDLE) Lake/Pond/Reservoir
TANPI11	60.48%	TANWAX Lake/Pond/Reservoir
OHOPLAKESTA1	58.92%	OHOP LAKE STATION1 (SOUTH END)
CLEARLAKE	56.25%	CLEARLK (MIDDLE) Lake/Pond/Reservoir
HARTSLAKE	52.74%	HARTSLK (MIDDLE) Lake/Pond/Reservoir
ST_TH11	40.00%	ST. CLAIR Lake/Pond/Reservoir

Table A3: Lotic System Tide Gate Locations WRIA 11

Site_ID	% Over All	Location
TG14L	100.00%	TIDE GATE 14 BY LAND
TG8L	100.00%	TIDE GATE 8 BY LAND
TG10L	94.44%	TIDE GATE 10 BY LAND
TGBL	80.39%	TIDE GATE B BY LAND
TG4L	77.78%	TIDE GATE 4 BY LAND
TG3L	75.00%	TIDE GATE 3 BY LAND
TG13L	72.78%	TIDE GATE 13 BY LAND
TG12L	70.04%	TIDE GATE 12 BY LAND
TG2L	63.33%	TIDE GATE 2 BY LAND
TG9L	62.50%	TIDE GATE 9 BY LAND
TG15L	57.22%	TIDE GATE 15 BY LAND
TG9W	55.20%	TIDE GATE 9 BY WATER
TG5L	55.00%	TIDE GATE 5 BY LAND
TG11W	40.28%	LITTLE MCALLSITER AT MOUTH
TG1L	36.51%	TIDE GATE 1 BY LAND
TG11L	28.57%	STORMWATER D/S OF LITTLE MCALLISTER

Table A4: Lotic Site Locations WRIA 13. Numerals in Red indicate monitoring sites where only one water quality parameter failed to meet analysis criteria.

Site_ID	Count	Over All	Location
W DRAIN	3	93.33%	WOODLAND CREEK (STORM DRAIN)
WD6.8	3	86.67%	WOODARD CREEK @ PACIFIC AVE
FLEMING CR	3	85.71%	FLEMINGCR (CREEKC) (@ JOHNSON POINT RD)
CC0.6	3	83.33%	COLLEGE CREEK @ BIKE PATH
LOWER	1	81.82%	INDIAN CREEK
CREEKB	3	77.78%	CREEKB (NW OF FLEMING CREEK)
G07001162238	3	77.29%	BLACK R. @ Belmore Rd.
CREEKA	1	75.00%	CREEKA (EAST OF SWAYNE DR NE)
SL0.8	3	71.43%	SLEEP CREEK @ MOUTH
WL1.0	3	70.00%	WOODLAND CREEK AT HOLLYWOOD DRIVE
W RM 3.1	1	70.00%	WOODLAND CREEK (RM 3.1)
CC0.4	3	69.05%	COLLEGE CREEK @ CENTURY COURT
DB0.1 (DSAR)	3	64.24%	DOBBS CREEK AT JOHNSON POINT ROAD
WD0.0	3	62.96%	WOODARD CREEK @ WOODARD BAY
SPDITCH2	4	62.50%	SMITH PRAIRIE DITCH 2
WL0.2	3	61.11%	WOODLAND CREEK @ HAWKS PRARIE ROAD
GO0.4	3	61.11%	BLACK R. @ Belmore Rd.
W RM 4.2	3	60.56%	WOODLAND CREEK (RM 4.2)
WD5.1	3	60.19%	WOODARD CREEK OFF LINDELL ROAD
SWO STORMWATER	3	60.00%	SWO STORMWATER (END OF SWAYNE DRIVE NE)
SPDITCH1	1	60.00%	SMITH PRAIRIE DITCH 1
SL0.1	3	56.67%	SLEEP CREEK @ MOUTH
WD6.9	3	56.48%	WOODARD CREEK @ BIKE PATH
W RM 3.8	2	55.79%	WOODLAND CREEK (RM 3.8)
13A150D	1	53.33%	Deschutes R nr Rainier
WL3.4	4	50.61%	WOODARD CREEK @ 36TH AVE
WD6.2	3	50.00%	WOODARD CREEK @ ENSIGN RD
WL2.25T	3	50.00%	EAGLE CREEK
WL2.6	3	50.00%	WOODLAND CREEK @ 21ST COURT NE
WL1.9T	1	45.45%	FOX CREEK
SCR	3	44.63%	SWIFT CREEK
13A060D	3	44.27%	DESCHUTES RIVER AT E ST BRIDGE
CC0.2	3	44.05%	COLLEGE CREEK BEHIND TOP FOODS
W RM 3.7	5	43.06%	WOODLAND CREEK (RM 3.7)
WL2.9	3	40.91%	WOODLAND CREEK @ DRAHAM RD
13A060E	2	38.90%	DESCHUTES RIVER AT E ST BRIDGE
WL3.1	3	34.85%	WOODLAND CREEK D/S OF I-5

Table A5: Lentic Site Locations WRIA 13

Site_ID	Count	Over All	Location
MCITH11	3	100.00%	MCINTOSH Lake/Pond/Reservoir
BLATH11	5	99.43%	Black Lake/Pond/Reservoir
LONTH11	4	91.13%	LONG Lake/Pond/Reservoir
CHATH11	4	90.66%	CHAMBERS Lake/Pond/Reservoir
OFFTH11	5	88.32%	OFFFUT Lake/Pond/Reservoir
PATTH21	4	85.24%	PATTISON (SOUTH ARM) Lake/Pond/Reservoir
LAWTH11	4	84.01%	LAWRENCE Lake/Pond/Reservoir
PATTH11	5	67.05%	PATTISON (NORTH ARM) Lake/Pond/Reservoir
MUNTH11	3	62.23%	MUNN Lake/Pond/Reservoir
HICTH11	4	60.26%	HICKS Lake/Pond/Reservoir
WARTH11	5	46.92%	WARD Lake/Pond/Reservoir