EFFECT OF WINTER STORM ON WATER QUALITY AND FISH TOXICITY

THE DUWAMISH AND NISQUALLY RIVERS

by

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ABSTRACT

Effect of Winter Storms on Water Quality and Fish Toxicity
The Duwamish and Nisqually Rivers

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The Duwamish river receives urban runoff, while the Nisqually river receives agricultural runoff. The Duwamish watershed has diverse industrial activities, which increase pollution level in the river and has impact on water quality parameters. Agricultural farms and lands around the Nisqually watershed increase pollution of river basin from agricultural activities and facilities. Fecal coliform bacteria, ammonia nitrogen, nitrate-nitrite nitrogen, water temperature, dissolved oxygen, water turbidity, pH level and heavy metals (dissolved copper and lead) were analyzed, in order to see health risk to fish in these river basins – specifically in salmon. The Washington State Department of Ecology monitors the Duwamish river site at Tukwila since 1990 and the Nisqually river site at Nisqually since 1978. There were some days when water quality parameters (fecal coliform bacteria and water temperature) exceeded water quality criteria and could cause fish toxicity. The research shows that pollution level is greater in winter than in summer, due to stormwater runoff in both rivers, and the Duwamish river is more polluted than Nisqually river, presumable because of the urban runoff in the Duwamish watershed. The Department of Ecology, Department of Transportation and other state and local agencies are working on reducing pollution level in the Duwamish and Nisqually rivers, in order to protect fish wildlife and biodiversity.

Chapter I

INTRODUCTION

This thesis analyzes and compares water quality parameters and chemical concentrations in the Duwamish river at Tukwila (water sample station 09A070[1]) and Nisqually river at Nisqually (water sample station 11A080[2]) during the winter and summer seasons. The two rivers are located in the same geographic area of Northwestern United States, in Washington State, but the Duwamish River has an urban runoff, while the Nisqually River has a non-urban runoff.

The drainage area for the Duwamish river at water resources inventory resources area (WRIA) #9 is approximately 372,358 acres, which is located in King County. The watershed is divided in upper and lower parts. The upper part is mountainous, while the lower one is part of the Puget lowlands. The main land uses of the Duwamish watershed are forestry (58%) and urban (18%) related uses. (Ecology, 2006, WRI #9). The main species that inhabit this river basin are salmonids (Chinook, coho and chum), steelhead trout and shellfish. (Green-Duwamish Watershed, Initial Assessment, 1995)

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[1] Water resources inventory area 09
[2] Water resources inventory area 11

The drainage area of the Nisqually river is approximately 491,258 acres. The land in the Nisqually basin is mainly forested (75%) and includes some Agricultural use (5%). Salmonid and shellfish are the main species that inhabit the Nisqually watershed (http://www.ecy.wa.gov/pubs/0610039/11.pdf, 2007).

The water quality of the rivers depends on the type and the quantity of runoff that in turn depend on land use and precipitation patterns. It is expected that the higher the precipitation the higher the volume of runoff to the river. Since precipitation follows seasonal patterns, it is also expected that the amount of precipitation and therefore stormwater runoff is greater during the winter in Washington state than in summer. Water quality is critical for the successful spawning, rearing and migration of salmons, salmonids and shellfish in the Duwamish and Nisqually rivers. Washington State has set water quality standards for fresh water, including rivers. At any time water quality parameters and chemical concentrations in the Duwamish and Nisqually rivers should meet State standards.

According to my hypothesis, stormwater runoff increases the amount of chemicals, toxins and microbiological organisms in the river. The northern Washington State has high level of storms during the winter season. Rain storms increase the amount of stormwater runoff during the winter season. According to this hypothesis, concentration of chemicals, toxins and biological organisms in the Duwamish and Nisqually rivers should be increased during the winter storms.

In order to see whether stormwater runoff increases water pollution, I compare winter water quality parameters and chemical concentrations to those of summer.

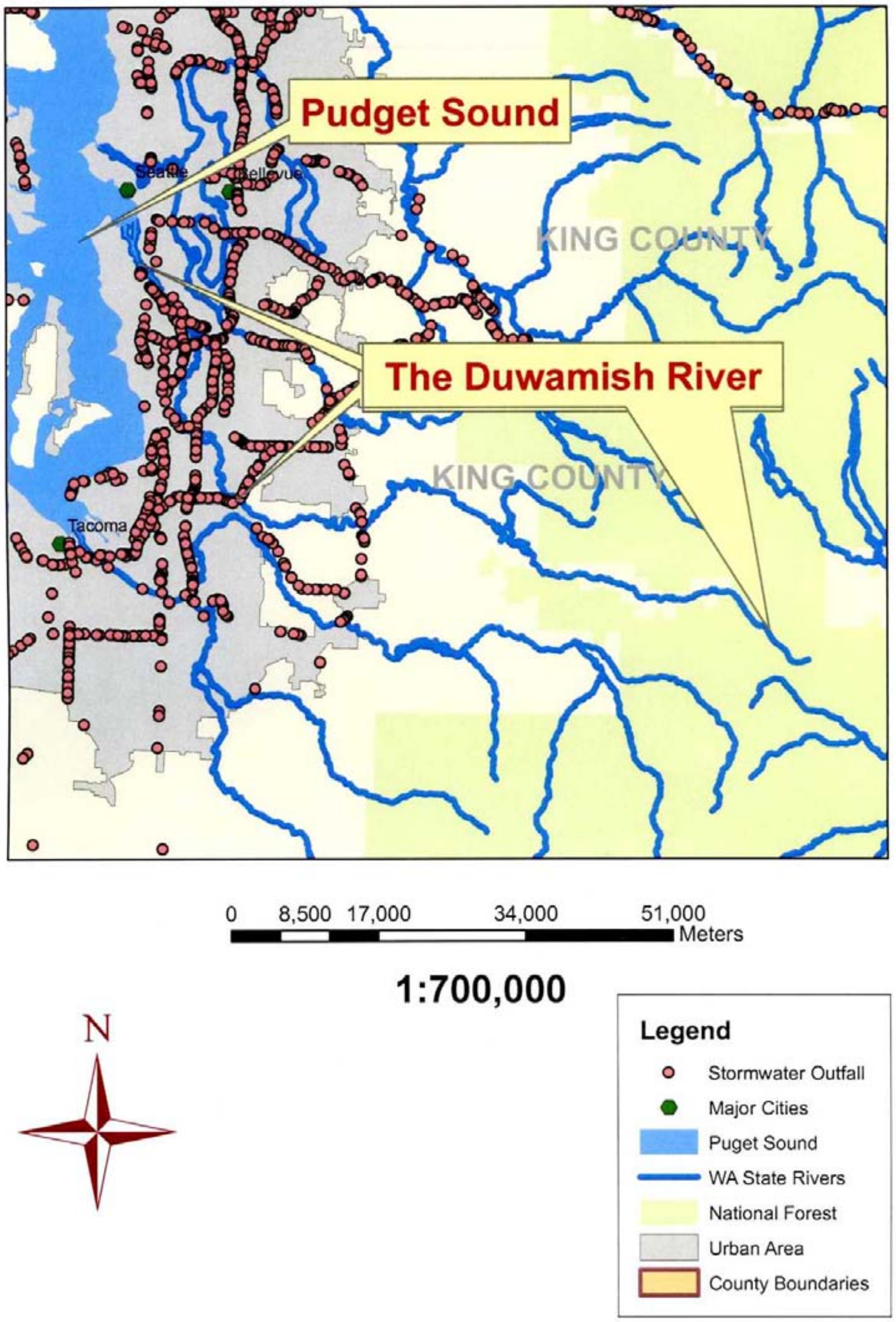
Water quality in the two rivers is evaluated qualitatively and quantitatively. The types of pollutants are described and compared to test whether pollution level of the Duwamish River during the winter is higher than in summer. In addition, statistical tests (linear regression and t-pair test) are performed to quantitatively compare the concentrations of the pollutants in the two rivers and test whether urban runoff significantly affects water pollution compared to non-urban runoff.

I. a. The Green-Duwamish River, Geography and History

Urbanization, industrialization and an agricultural development are the main factors, affecting water quality. The Green Duwamish River is one of the most polluted rivers in the Northern part of Washington State. The main tributaries of the Green-Duwamish River are Black River, Newakum Creek, Crisp Creek, Mill Creek, Springbrook Creek, Soos Creek, Jenkins and Covington Creeks. The size of the Green River watershed is 492 square miles, with 65 miles length from Elliot Bay to

Howard Handson Dam. Two dams have been built: Tacoma Water Supply Division Dam in 1911 and Howard Hanson Dam in 1962. The salmon species present in this river are Chinook, chum, coho, and winter steelhead (http://dnr.metrokc.gov/wlr/watersheds/green.htm). The Green river is divided in three parts: Upper Green river, Middle Green River and Lower Green River. The lower Green River is the most polluted part of the whole Green Duwamish River. It is the most urbanized and industrialized region. The tributaries Auburn, Mill, Midway Creek and Mullen Slough are contributing pollution in the Lower Green River. (Kraft T., 2004)

THE DUWAMISH RIVER



Pollution of this river basin has started from the 1890s, when the City of Seattle began construction of sewage systems. The sewage system and stormwater runoff were discharged into the Duwamish River, Elliot Bay and Puget Sound (http://www.ldwg.org/history.htm). It is also important to mention that construction of the port in Seattle in 1911 increased pollution level of the river basin. Increased concentration of toxins in the river made the Washington State Pollution Control Commission to publish reports in 1945 about the investigations of metals, oils, sewage and industrial waste into the Green-Duwamish River.

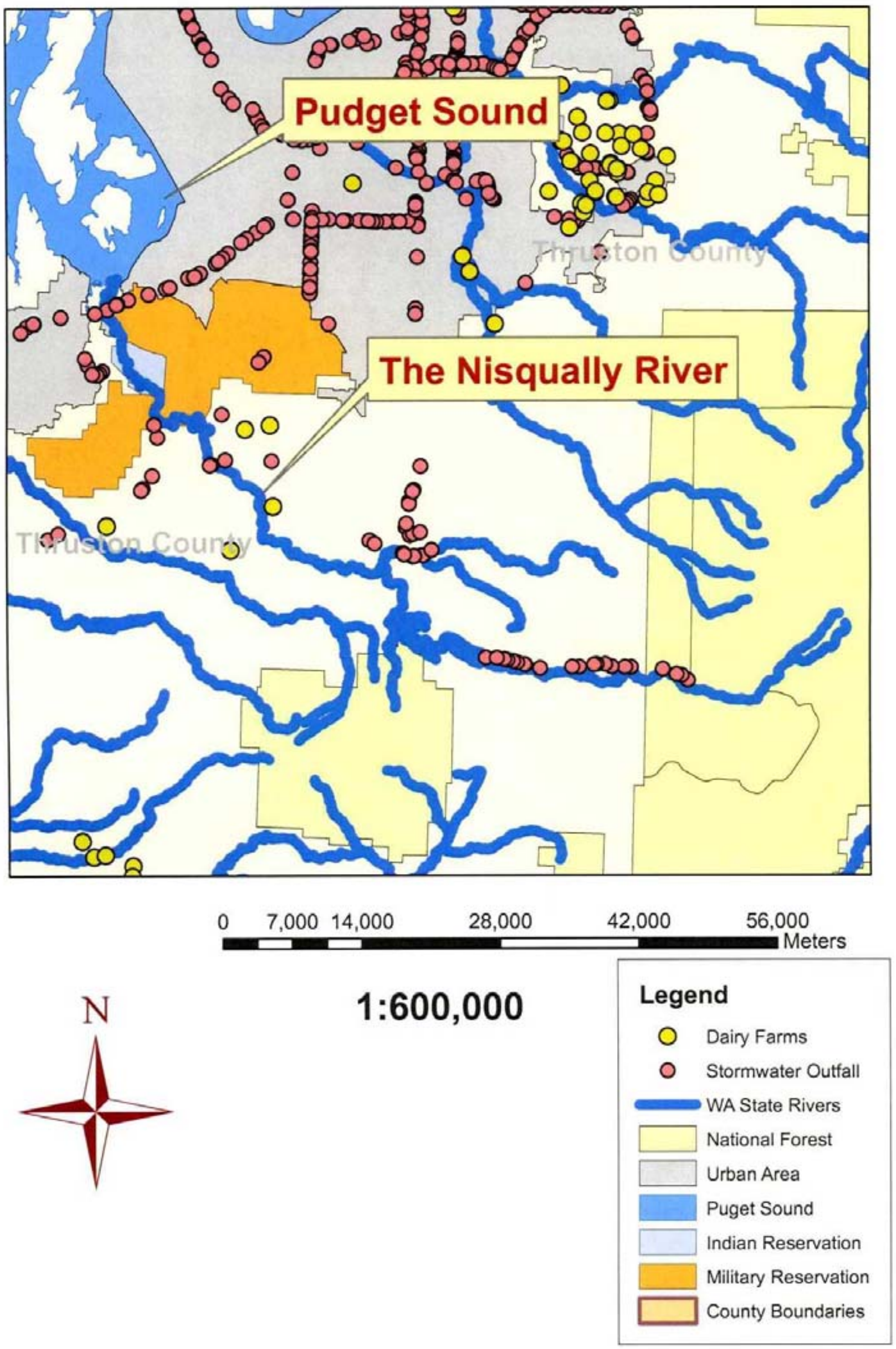
In 2001 the U.S. Environmental Protection Agency (EPA) listed the Lower Duwamish River in the federal Superfund site list (a list of the most toxic contaminated sites in the country) (http://www.duwamishcleanup.org/). According to Duwamish Cleanup Coalition, Duwamish river crab and fish in 1998 had seven times more cancer-causing chemicals than fish from clean site. Among the pollutants found in salmon at the Duwamish river superfund site, there were PCBs, heavy metals, pesticides, sewage, and other toxins. These pollutants found in the Duwamish river increase risk of human health and well-being, through consumption of food species from the river, as well as the health of fish and wildlife (http://www.duwamishcleanup.org/index.php?page). Pollution of the Duwamish River affects mainly local society, inhabitants and tribes, in many levels. High level of toxicity in the fish and crabs affects human health. At the same time it affects the development of the economic sector. For local tribes fishing is a source of income. Minimizing recreational and fishing activities influence on the local inhabitants income. At the same time it is important to mention that there are several of non-English speaking communities living and working around the lower Duwamish river basin and close to the Port of Seattle. Low level of information regarding to the Duwamish river pollution and effect on human and environmental health, keeps them from effectively protecting themselves and their families' health, living and working environment.

The contributors and sources of pollution of Duwamish River are: Boeing, the City of Seattle, King Country, and the Port of Seattle. Stormwater runoff, which contributes heavy metals, oil and grease from the streets, arsenic in cement materials, industrial and domestic waste have a long-term effect on the river pollution (http://www.duwamishcleanup.org/index.php?page=who_is_responsible).

I. b. The Nisqually River, Geography and History

Compared to the Duwamish River, the Nisqually River is one of the most pristine rivers in the Washington State (http://www.nisquallyriver.org). The Nisqually River has its source at the Nisqually Glacier on Mount Rainier. It flows 78 miles through forests and mountains. It flows through the Fort Lewis Military Reservation and the Nisqually Indian Reservation and enters into the Puget Sound (http://www.outstandingrivers.org/rivers/nisqually_river/).

THE NISQUALLY RIVER



The lower Nisqually River is a transport corridor for anadromous salmonids and is a place for spawning for chum, chinook, coho and steelhead habitats (Ecology, 2005).

Chapter II

WASHINGTON STATE WATER QUALITY STANDARDS

Pollution of water bodies derived from storm water is called non-point sources (NPS) pollution. Atmospheric deposition, sediment flow from improperly managed construction sites, forest lands and eroding stream banks in addition of the above are the sources of NPS pollution (Water Quality Standards for Surface Waters of the State of Washington, 2006, http://www.epa.gov/owow /nps/qa.html). According to “Water Quality Standards for Surface Waters of the State of Washington” (WQSSWSW) (2006) storm water is defined as “the portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, pipes, and other features of a storm water drainage system into a defined surface water body, or a constructed infiltration facility”.

NPS pollution has a harmful effect on the ecosystem of the Duwamish and Nisqually river basins. The purpose of the chapter 173-201A WAC of WQSSWSW is to establish water quality standards for fecal coliform bacteria, dissolved oxygen, water temperature, water pH level and water turbidity for surface waters of Washington State consistent with public health and protection of fish and wildlife. The surface waters are protected by designated uses and criteria (Water Quality Standards for Surface Waters of the State of Washington, 2006).

The following chapters include a qualitative and quantitative analysis of water quality parameters such as water temperature, pH, dissolved oxygen, turbidity, ammonia nitrogen, nitrate-nitrite nitrogen, fecal coliform bacteria, and concentration of metals: dissolved copper and lead. This chapter includes definitions of the abovementioned water quality parameters, Washington State water quality standards, sampling procedures and descriptions of their effects on water quality and fish.

The sampling procedure is determined by the Unites States Environmental Protection Agency (EPA). Washington State Department of Ecology samples Washington rivers monthly.

II. a Dissolved Oxygen

Dissolved Oxygen (DO) is oxygen dissolved in water. It is the main source of oxygen for fish and aquatic life. Fish absorbs oxygen directly from water through the gills. The sources of oxygen in water are: wind and wave action, direct diffusion from the atmosphere and photosynthesis. Photosynthesis is one of the most important sources of oxygen in the aquatic environment. The level of oxygen during the night is lower than during the day, which is explained by the absence of photosynthesis during the night and the increasing respiration by fish and plants (photosynthesis occurs, when sunlight shines on the plant in the water, which is during the day time) (http://edis.ifas.ufl.edu).

The level of DO varies in response to changes of water temperature and atmospheric pressure. The higher the water temperature the lower is the solubility of oxygen in water. Oxygen depletion (lack of oxygen in the water) can occur in every season. However, summer is the season when oxygen depletion (OD) occurs more often than in any other three seasons. Cool water is more capable to hold oxygen than warm water. The water with 7ºC temperature can hold 11.9 mg/L DO, while warmer water (32º C) can hold only 7.4 mg/L DO (WSWQS, 2006). In the warm water, the metabolism in fish increases, which increases oxygen demand as well. Another reason of high level of DO is atmospheric pressure. The higher the atmospheric pressure the higher is concentration of DO. Atmospheric pressure increases oxygen solubility in water. DO level in the surface waters can be decreased with higher concentrations of organic and inorganic materials, chemicals and toxins (http://edis.ifas.ufl.edu).

DO level in the water determines aquatic life's wellbeing. When oxygen consumption exceeds oxygen production, oxygen depletion occurs (http://edis.ifas.ufl.edu). Oxygen depletion (OD) may cause fish mortality. According to 2006 Washington State Water Quality Standards, minimum DO level in the surface waters should be in the range 6.5mg/L - 9.5 mg/L.

Fish mortality in surface waters occurs when the level of DO concentration is less than 2mg/L. The larger the fish the more affected by low level of DO it is than smaller ones. In the Duwamish and Nisqually rivers DO level was never observed as low as 2mg/L.

The 1-Day minimum DO required for aquatic life categories depends on the species and varies between 6.5mg/L to 9.5 mg/L (Table 1.)

Table 1. Aquatic Life Dissolved Oxygen Criteria in Fresh Water

Category	**Lowest 1-Day Minimum**
Char Spawning and rearing	9.5 mg/L
Core Summer Salmonid Habitat	9.5mg/L
Salmonid Spawning, Rearing, and Migration	8.0mg/L
Salmonid Rearing and Migration Only	6.5 mg/L
Non-anadromous Interior Redband Trout	8.0 mg/L
Indigenous Warm Water Species	6.5 mg/L

Source: Water Quality Standards for Surface Waters of the State of Washington, 2006

DO sampling procedure. The water samples for determining DO level in the water are taken in the thalweg (the middle part of the river, channel) (Washington State Water Quality Standards, 2006).

II. b. Water Temperature

Water Temperature is another main water parameter, which determines surface water quality level. Temperature is different between lowland streams and mountain rivers. Lowland streams are warmer, while mountain streams are cooler. High temperature can cause oxygen depletion in river, which could be followed by fish mortality (http://www.state.ky.us/nrepc/water/wcpno.htm).

The temperature in the surface water can be increased naturally (increasing atmospheric temperature) and by humankind activities, by increasing non-point source (NPS) pollution (Water Quality Standards for Surface Waters of the State of Washington, 2006). High water temperature affects fish embryos. Lethality of embryos can occur, when 1-DMax[3] temperature is greater than 17.5ºC. For adult salmons migration 1-DMax temperature should not be greater than 22ºC (WQSSWSW, 2006). Metabolic changes of biological communities in rivers and streams depend on water temperature. Water discharge, depth, season, time of day, stream segment, solar radiation and human activities determine water

[3] **"1-DMax"** or **"1-day maximum temperature"** is the highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less. (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*

temperature. Chapter 173-201A WAC of WQSSWSW (2006) sets a 7-DADMax[4] temperature, in order to protect fish and wildlife, and have sufficient level of fish spawning, rearing and migration in the Washington State rivers. The highest tolerated temperature is different for different species (Table 2.).

Table 2. Aquatic Life Temperature Criteria in Fresh Water

Category	**Highest 7-DADMax**
Char Spawning	9ºC
Char Spawning and rearing	12ºC
Salmon and Trout Spawning	13ºC
Core Summer Salmonid Habitat	16ºC
Salmonid Spawning, Rearing, and Migration	17.5ºC
Salmonid Rearing and Migration Only	17.5ºC
Non-anadromous Interior Redband Trout	18ºC
Indigenous Warm Water Species	20ºC

Source: Water Quality Standards for Surface Waters of the State of Washington, 2006

[4] **"7-DADMax"** or **"7-day average of the daily maximum temperatures"** is the arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days prior and the three days after that date. (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*

Sapling procedure for Temperature. The samples for determining water temperature should be taken from the well mixed water in the rivers and streams, and not from the shallow part of the surface water and not from the edge of the river (WSWQS, 2006. (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*

II. c. Water pH Level

pH level measures hydrogen ion concentration in water. The measure of the river water pH shows how acidic or basic the water is (http://www.grc.nasa.gov/WWW/K-12/fenlewis/Waterquality.html). pH changes in the river influences on water quality and water chemistry, which has an effect on fish health (http://www.fishdoc.co.uk/water/pH.htm) Water pH level ranges from 0 to 14. The highest pH unit is 14, which means the water is highly basic (alkaline). The neutral level of pH is 7. The lower the pH the higher the acidity, so the closer to 0 the pH is the more acidic it is. The changes of each pH unit are changes in the hydrogen ion concentration relative to the hydroxyl ion concentration: the more hydrogen ions the more acidic and the more hydroxyl ions the more alkaline or basic. High or low levels of pH makes river inhospitable for fish and aquatic life. The pH level in the fresh water basins should be within the neutral range from 6.5 to 8.5 for effective fish spawning and rearing

(Table 3.) (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*.

Table 3. Aquatic Life pH Criteria in Fresh Water

Category	**pH units**
Char Spawning and rearing	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.2 units.
Core Summer Salmonid Habitat	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.2 units.
Salmonid Spawning, Rearing, and Migration	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.5 units.
Salmonid Rearing and Migration Only	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.5 units.
Non-anadromous Interior Redband Trout	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.5 units.
Indigenous Warm Water Species	Between 6.5 and 8.5, with a human-caused variation within the above range of less than 0.5 units.

Source: Water Quality Standards for Surface Waters of the State of Washington, 2006

Sapling procedure for pH. Water samples for pH are collected by the DO sample bucket. The probe of the pH meter is placed in the water sample. The measurements should be reported on the Field Data Report Form (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*.

II. d. Fecal Coliform Bacteria

Fecal Coliform (FC) bacteria refer to that portion of the coliform group of bacteria which presents in the intestinal tracts and feces of warm-blooded animals. FC bacteria grow on warm temperature and are produced by the fecal material of warm-blooded animals. Bacteria occur in the water through domestic sewage (http://www.state.ky.us/nrepc/water/wcpfcol.htm).

In recreational and fresh waters, the FC bacteria must not exceed a geometric mean[5] value of 50 colonies/100 ml in the extraordinary primary contact recreation (Table 5). While in the primary contact recreation category, it must not exceed a geometric mean value of 100 colonies/100ml. For secondary contact recreation FC bacteria must not exceed a geometric mean value of 200 colonies/100 mL, (Table 4) *(Water Quality Standards for Surface Waters of the State of Washington, Washington State Department of Ecology, 2006).*

[5] "Geometric mean" means either the n^{th} root of a product of n factors, or the antilogarithm of the arithmetic mean of the logarithms of the individual sample values

Table 4. Water Contact Recreation Bacteria Criteria in Fresh Water

Category	Bacteria Indicator
Extraordinary Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.
Primary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies /100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200 colonies /100 mL.
Secondary Contact Recreation	Fecal coliform organism levels must not exceed a geometric mean value of 200 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 400 colonies /100 mL.

Source: Water Quality Standards for Surface Waters of the State of Washington, 2006

Sampling procedure for Fecal Coliform bacteria. The detection limit of FCB is 1 colony per 100 mL water. A 250 mL autoclaved bacterial sampler bottle and fecal coliform sampler is used to determine amount of FCB. After collecting sample for FCB, the sample should be placed in the cooler in ice and shipped to Lab for analysis (*Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)*.

II. e. Water Turbidity

Water Turbidity is another criterion of aquatic life, which is measured in nephelometric turbidity units (NTUs). Turbidity is the amount of particulate matter suspended in water. Suspended soils that cause turbidity are: clay, silt, organic and inorganic matter, microscopic organisms, plankton and soluble colored organic compounds. High level of turbidity makes the water cloudy, which has a negative effect on fish spawning and rearing. Turbidity measures the scattering effect that suspended matter has on light. Rain storms and therefore storm water runoff (particles from the land are washed into the river) increase water turbidity in rivers (http://ga2.er.usgs.gov/bacteria/helpturbidity.cfm).

According to the Department of Ecology Water Quality Standards for Surface Waters of Washington State 2006, turbidity level in fresh waters should not exceed the background of 50 NTU by more than 5-10 NTU depending on the species (Table 5).

Table 5. Aquatic Life Turbidity Criteria in Fresh Water

Category	NTUs (turbidity should not exceed)
Char Spawning and rearing	5 NTU over background when the background is 50 NTU or less
Core Summer Salmonid Habitat	5 NTU over background when the background is 50 NTU or less
Salmonid Spawning, Rearing, and Migration	5 NTU over background when the background is 50 NTU or less
Salmonid Rearing and Migration Only	10 NTU over background when the background is 50 NTU or less
Non-anadromous Interior Redband Trout	5 NTU over background when the background is 50 NTU or less
Indigenous Warm Water Species	10 NTU over background when the background is 50 NTU or less

Source: Water Quality Standards for Surface Waters of the State of Washington, 2006

According to the chapter 173-201A-200 WAC of Water Quality Standards for Surface Waters of the State of Washington (2006) turbidity criteria can be modified after in-water constructions, which result in the disturbance of in-place sediments.

II. f. Nitrate, Nitrite and Nitrogen

Nitrogen is one of the most widely distributed chemical elements in the world. 80% of air contains nitrogen. Nitrogen can be organic and inorganic. Inorganic nitrogen can exist as nitrate NO^{3-}, nitrite NO^{2-}, ammonia NH^{3+} or molecular gas N_2. The main sources of nitrogen in rivers are septic tanks, municipal and industrial wastewater, animal waste and car exhausts. Nitrites are easily converted to nitrates in water by bacteria.

Nitrates reduce DO level in rivers, which cause oxygen depletion. Nitrites have effect on fish by developing “brown blood disease” (http://www.state.ky.us/nrepc/water/wcpno.htm). Nitrite enters into the fish’s bloodstream system through gills. Hemoglobin combines with nitrite and forms methemoglobin. Methemoglobin blocks transportation of oxygen in the blood and turns blood into chocolate-brown color. When there is lack of oxygen in the body, fish starts gasping (http://msucares.com/pubs/infosheets/is1390.htm). In humans, nitrates also react with hemoglobin in blood cells and produce methemoglobin. The “Blue baby” disease or methemoglobinemia is a serious disease in babies, which is developed by producing methemoglobin. The nitrate level above 0.5 mg/l, and nitrite and nitrogen levels above 90mg/l has toxic effect on fish (http://www.state.ky.us/nrepc/water/wcpno.htm).

Nitrates in rivers occur through insufficiently and inefficiently treated waste-waters, and ineffective filtration systems. Nitrite is broken down to nitrate by bacteria. If nitrite production exceeds conversion of nitrite to nitrate, fish in the river are at risk for brown blood disease (http://msucares.com/pubs/infosheets/is1390.htm) .

Sampling procedure for Nutrients. Nutrients include nitrogen and phosphorus. The detection limit for ammonia and nitrate-nitrite nitrogen is 0.01 mg/. After taking water sample, the bottle with water sample is labeled, placed in the cooler and shipped to Lab *(Stream Sampling Protocols for the Environmental Monitoring and Trends Section, 2001)***.**

II. g. Metals: Dissolved Copper and Lead

The concentration level of metals in the Duwamish river at 09A080 water sample station was sampled in 2002-2003 water years (Table 6) by the Washington State department of Ecology. In the Nisqually river at 11A070 water sample station, metals were sampled in 1998-1999, 2001-2002 (Table 7) water sample years.

Table 6. Concentration of Dissolved Copper and Lead in the Duwamish River

Sampling date	Dissolved Cu (ug/L)	Dissolved Pb (ug/L)
12/11/2002	1.11	0.244
2/24/2003	0.48	0.04
6/16/2003	0.43	0.036
8/18/2003	0.36	N/D*

Table 7. Concentration of Dissolved Copper and Lead in the Nisqually River

Sampling date	Dissolved Cu (ug/L)	Dissolved Pb (ug/L)
12/13/1998	2.3	0.1
2/23/1999	1	0.06
6/28/1999	0.4	N/D
12/11/2001	1.1	0.05
2/19/2002	0.9	N/D
6/25/2002	0.4	N/D
8/27/2002	0.6	N/D

Chapter III

METHODOLOGY

III. a. Data sources

III.a.a Water quality data

The water quality monitoring data for this thesis were downloaded from the Washington State Department of Ecology's web-site: http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=final_data&scrolly=174&sta=09A080&docextension=.xls&docextension=.xls for the Duwamish river at Tukwila at 09A080 water sample station and http://www.ecy.wa.gov/apps/watersheds/riv/station.asp?theyear=&tab=final_data&scrolly=579&wria=11&sta=11A070 for the Nisqually river at Nisqually at 11A070 water sample station in March, 2006.

The water quality monitoring data on the Duwamish river were taken at Tukwila, at the 09A080 water sample station. The Duwamish river at Tukwila is considered a class A water category (excellent water category).

The Nisqually river water quality monitoring data were taken at Nisqually, at the 11A070 water sample station. The Nisqually river is also classified as water quality category A.

III. a. b.Precipitation data

Precipitation data for the Duwamish and Nisqually river basins, was downloaded from King County's web-site at http://dnr.metrokc.gov/wlr/waterres/hydrology/DataReport.aspx , in April, 2007.

Precipitation data for the region were recorded at the Sea-Tac airport precipitation monitoring station at the site Panther Creek precipitation gauge, with a site code 03u. Precipitation records from the gauge at the site Tukwila I&I Rain Gage with a site code TUKW would have been more representative of the Duwamish river because this site is closer to water sample station 09A080 than Panther Creek precipitation gauge. However, the Tukwila I&I Rain Gage gauge was installed only in October 1st, 2002 and historical precipitation data from this station is only available since this day http://dnr.metrokc.gov/wlr/waterres/hydrology/DataReport.aspx .

To avoid bias in precipitation data and to see whether they could be used as a representative precipitation data for the Tukwila area, I compared precipitation data at the site Panther Creek precipitation gauge to Tukwila precipitation gauge for the period since October 2002 (the Tukwila gauge was established in October 2002) (Figure 1).

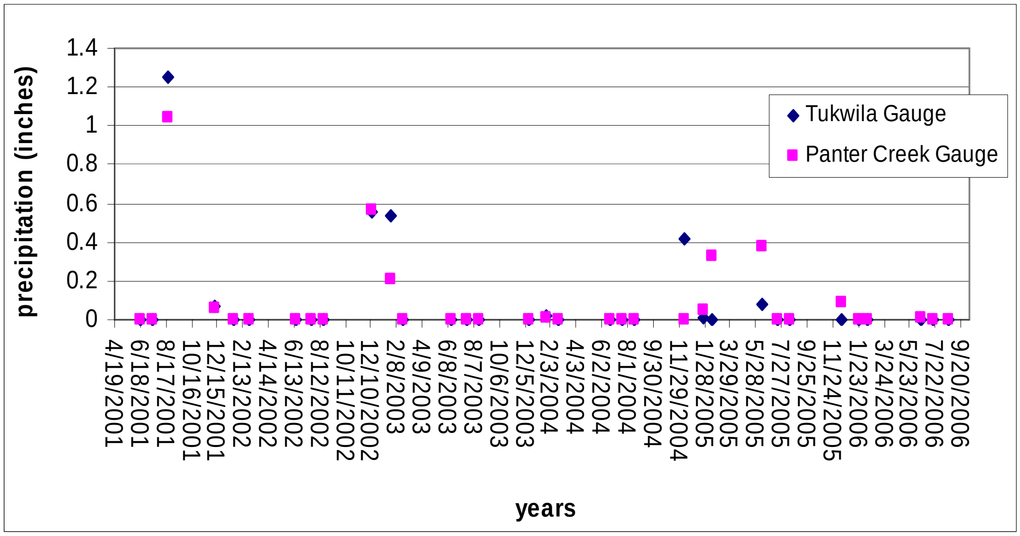


Figure 1. Precipitation Data at Tukwila and Panter Creek Gauges (2001-2006). The precipitation data are taken in the same days when water was sampled at the Duwamish River water sample station.

The precipitation data at the Tukwila site matches closely those at the Panter creek site. In some cases there were small differences observed. For example, in January 24, 2001 precipitation at Tukwila Gauge was 0.06 inches, while at Panter Creek Gauge it was 0.12 inches. Another small difference is recorded in August 22, 2001. Precipitation was 0.24 inches greater at Tukwila Gauge (1.25 inches) than in Panter Creek gauge (1.04 inches). In January 27, 2003 there was difference in precipitation between these two gauges, with a difference of 0.23 inches (0.54 inches precipitation at Tuwkila gauge and 0.21 inches of precipitation at Panter Creek gauge). Another big difference occurred in December 13, 2004. Precipitation at Tukwila gauge was 0.42 inches, while at Panter Creek was no precipitation. In February 14, 2005, 0.33 inches of precipitation was recorded at Panter creek gauge, while there was no precipitation at Tukwila gauge. More differences of precipitation between these two gauges were observed in June 13, 2005 (difference 0.3 inches) and in December 14, 2005 (0.09 inches of precipitation at Panter Creek Gauge and no precipitation at Tukwila gauge). There were no more significant differences in precipitation data between these two gauges. Observation on precipitation data at Tukwila and Panter Creek gauges shows that there are some small precipitation differences between these two gauges, but not significant. Small difference in precipitation does not affect the linear regression tests. Therefore the precipitation data obtained from the Panther Creek gauge is a good approximation to precipitation at the Tukwila area.

The water sample station 11A080 in the Nisqually river is located in King county as well. There is no available long-term historical precipitation record for this gauge. Because of that and because the 11A070 water sample station and Panter Creek precipitation gauge are located in the same county and are geographically in close proximity as it relates to weather phenomena, I used the historical precipitation data from Panter Creek as a surrogate for the precipitation at the Nisqually river. The Panter Creek gauge started operating from 1988.

III.b. Data Analysis

Water sampling on the Tukwila station of the Duwamish river has started since 1990 by the Washington State Department of Ecology. I used water sample data from December 1990 to August 2006. To compare the level of winter water quality criteria to summer, I calculated averages of winter months (December, January and February) and summer months (June, July, August) for water DO, pH, temperature, turbidity, FC bacteria, ammonia nitrogen and nitrate-nitrite nitrogen.

The water quality monitoring data for the Duwamish river at Tukwila had missing data for DO in July 2000 (was not sampled in this month). To obtain an estimate for the missed data of DO, I calculated averages of DO in months of July from 1991 to 2006 and put the received amount in July 2000.

I used water sample data from December 1977 to August 2006. The water quality monitoring data for the Nisqually river had missing data for turbidity in July and August 1985, and in August 1992, temperature in January 1979, FC bacteria - in December 1990, August 1986 and June 1988, ammonia nitrogen in June 1988, and DO in January 1991 and January 1995. To obtain an estimate of missing data I calculated averages by months and plugged into the missed months.

To compare some of the Duwamish river water quality parameters (FC bacteria, ammonia nitrogen, nitrate-nitrite nitrogen and DO) to the same water quality parameters of the Nisqually river, these two rivers were compared to each other (for each year) with paired t-test.

Chapter IV

RESULTS

To test the hypothesis that stormwater runoff increases pollution level in the river I used linear regression and to test whether water quality parameters are greater in winter than in summer, I used the paired t-test. To compare the Duwamish water quality (for each year) to the Nisqually water quality, I used the paired t-test.

To find whether stormwater runoff increases the number of Fecal Coliform (FC) bacteria, I used linear regression, where precipitation was the independent value and number of FC bacteria was the depended. Linear regression on FC bacteria in the Duwamish river at water sample station 09A080, shows that there is some but not highly significant evidence (p= 0.04701, t=2.01, R^2=0.041 with the slope b1=137) to infer that increase in precipitation (that there is correlation between precipitation and FC bacteria), increases the number of FC bacteria in the river basin. Linear regression on FC bacteria for the Nisqually river at the water sample station 11A070, shows that there is not enough statistical evidence (p=0.453, t=0.753, $R^{2=}$ 0.005 with a slope b1=41) to infer that there is correlation between precipitation and number of FC bacteria in the Nisqually river.

To compare other water quality parameters (ammonia nitrogen, nitrate-nitrite nitrogen, DO, pH, temperature and turbidity) in the Duwamish and Nisqually rivers between winter and summer, the differences between the two seasons by years were examined with paired t-tests.

These tests showed that there is significant evidence to infer that the water quality parameters nitrate-nitrite nitrogen, DO, pH, turbidity are greater in winter than in summer and that, as expected, water temperature is lower in winter than in summer in the Duwamish river. However, there was not significant evidence to infer that ammonia nitrogen levels are greater in winter than in summer. In the Nisqually river, the tests showed that there is significant evidence to infer that the water quality parameters ammonia nitrogen, nitrate-nitrite nitrogen, DO, pH, turbidity are all greater in winter than in summer and, as expected, water temperature is lower in winter than in summer (Table 8).

Table 8. Differences in water quality parameters between summer and winter: paired T-tests for the Duwamish and Nisqually Rivers

	The Duwamish River		The Nisqually River	
	t-stat	**p-value**	**t-stat**	**p-value**
FC Bacteria	0.402	0.3465	1.53	0.067
Ammonia nitrogen	-0.2284	0.4114	4.508	<0.001
Nitrate-nitrite nitrogen	11.4636	<0.001	19.0631	<0.001
DO	23.4129	<0.001	28.2946	<0.001
pH Level	0.0292	-2.0474	<0.001	- 6.371
Water Temperature	<0.001	-38.669	<0.001	-6.446
Turbidity	0.001	3.57	0.005	2.697

According to my hypothesis, high amount of precipitation in winter increases the number of FC bacteria, ammonia nitrogen, nitrate-nitrite nitrogen, pH, DO, water turbidity in the Duwamish and Nisqually rivers. In the Washington state more rain storms are observed in winter than in summer. Because of that, storm water runoff is greater in winter than in summer. Precipitation during the water sampling days from 1990 to 2006 in the Duwamish river at Tukwila is approximately 5.68 inches and 2.08 inches in summer (Figure 2.). As for Nisqually river precipitation during the winter from 1988 to 2006 totally was 6.64 inches and 3.03 inches in summer (Figure 3).

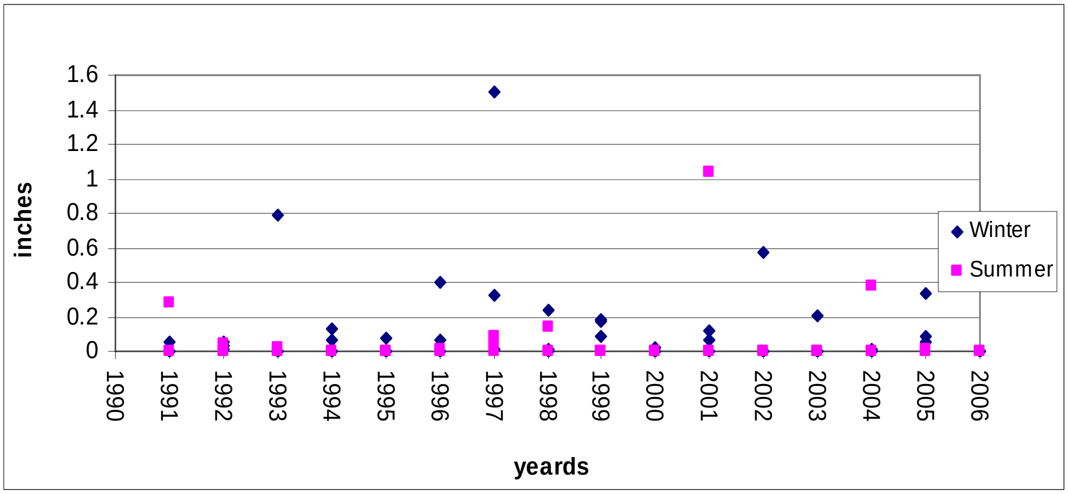


Figure 2. Precipitation Data at The Panter Creek Gauge for the Duwamish River (1990-2006). The data are given seasonally, sampled once in a month.

This chart represents season total precipitation at the Panter Creek Gauge (from 1990 to 2006) for those days when the water was sampled in the Duwamish river at Tukwila water sample station - 09A080.

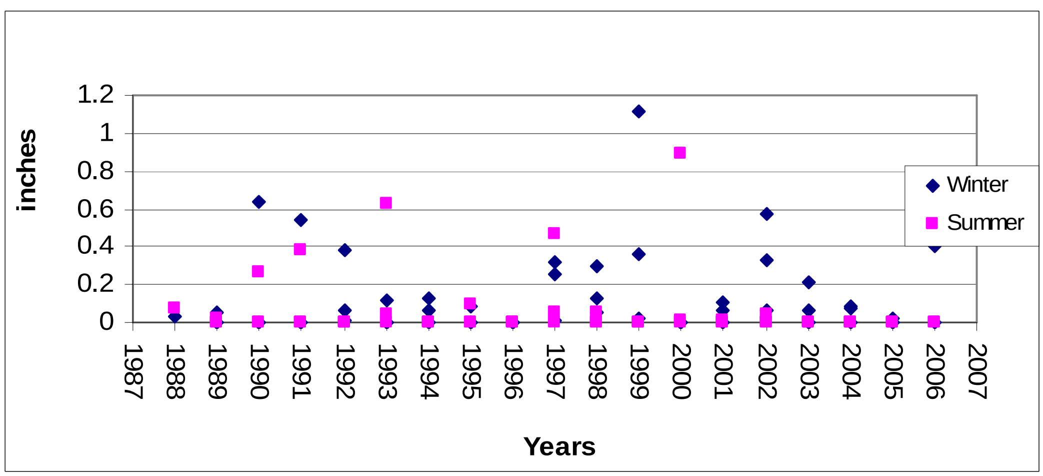


Figure 3. Precipitation Data at the Panter Creek Gauge for the Nisqually River (19988-2006). The data are given seasonally, sampled once in a month.

This chart represents precipitation data at the Panter Creek Gauge (from 1988 to 2006) in the specific water sampling days in the Nisqually river at Nisqually water sample station - 11A070.

IV. a. FC Bacteria

The linear Regression on FC bacteria in the Duwamish River at 09A080 (at Tukwila) water sample station shows that there is some but not strong evidence to infer that number of FC bacteria increases with increased precipitation in the Duwamish river basin at 09A080 water sample station (slope=133.44, $t = 2.0126$, $p = 0.04701$, $R^2=0.041$). Linear regression on FC bacteria shows that there is correlation between precipitation and FC bacteria in the Duwamish river. Paired t-test shows that there is not enough evidence to infer that number of FC bacteria is greater (Figure 4) in winter than in summer ($t=0.4024$, $p=0.3465$).

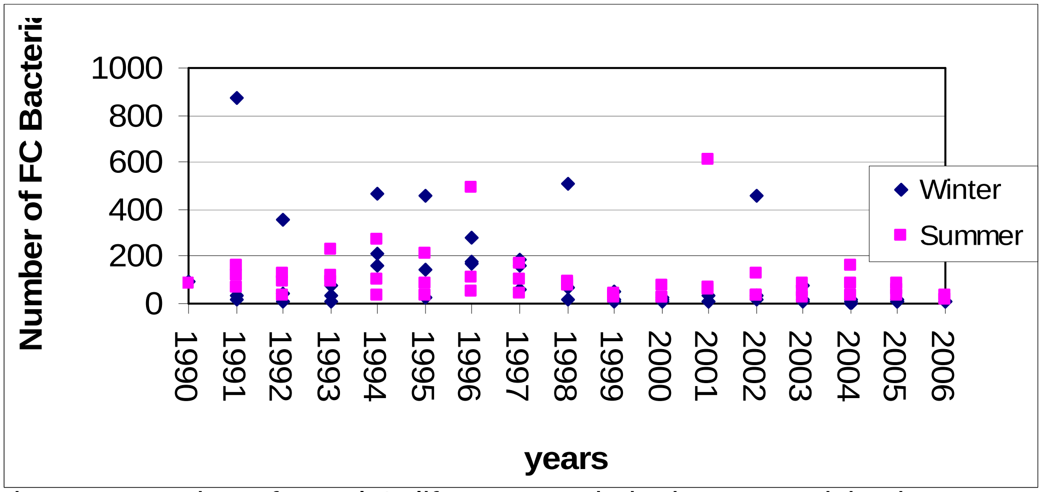


Figure 4. Number of Fecal Coliform Bacteria in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Samples done once in a month, three times in a season.

The highest amount of FC bacteria in the Duwamish river at Tukwila water sample station was observed on the following 5 occasions. The first three occurred on days with no precipitation: about 870 FC bacteria /100ml on 2/20/1991; 470 FC bacteria/100ml on 12/19/1995; 490 FC Bacteria on 6/18/1997. The other two occurred on days of low precipitation: on 1/20/1998 510 FC bacteria was counted in the water and precipitation was 0.01 inches. On 8/22/01, 610 FC bacteria was detected in water sample, with 1.04 inches of precipitation.

As for the Nisqually river, the linear Regression on FC bacteria at 11A070 (at Nisqually) water sample station shows that there is not enough evidence to infer that number of FC bacteria increases by increasing precipitation and stormwater runoff (slope=41.75, t =0.75, p=0.45, R^2=0.041). Linear regression on FC bacteria shows that precipitation and therefore stormwater runoff does not increase amount of FC bacteria in the river. In other words there is no significant linear relationship between precipitation and FC bacteria in the Nisqually river.

The t-pair test on Fecal Coliform bacteria in the Nisqually River at 11A070 (at Nisqually) shows that number of FC bacteria is not significantly greater (figure 5) in winter than in summer (t=1.539, p= 0.067) in the Nisqually River basin at Nisqually water sample station.

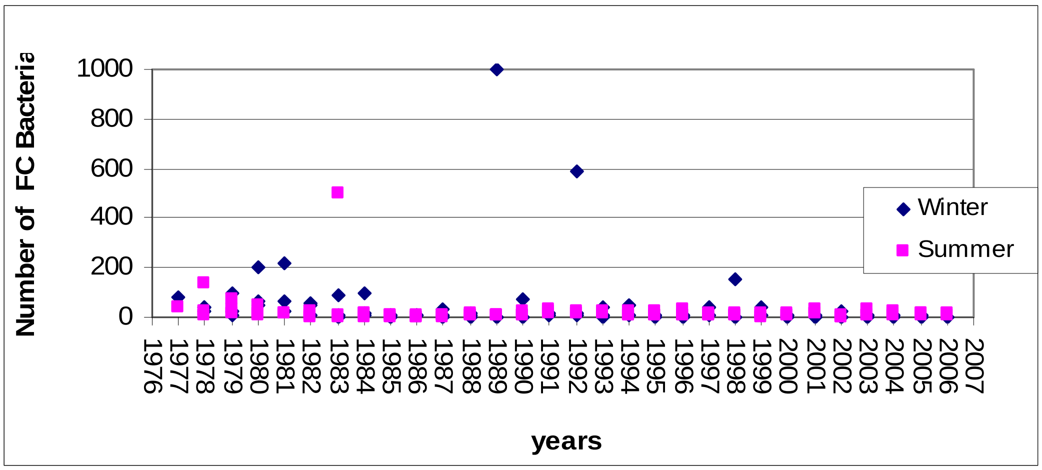


Figure 5. Number of Fecal Coliform Bacteria in the Nisqually River at Nisqually in Winter and in Summer (1979-2006). Samples done once in a month, three times in a season.

The highest amount of FC bacteria in the Duwamish river at Tukwila water sample station was observed in 12/20/1989 for about 1000 FC bacteria and with no precipitation in this day, 1/29/1992 with 590 FC bacteria with a daily precipitation of 0.38 inches. Another high amount of FC was recorded in 7/13/1983. There is no precipitation record for this day.

IV. b. Ammonia Nitrogen

The paired t-test on Ammonia Nitrogen in the Duwamish River at 09A080 water sample station shows that there is not enough evidence to infer that level of Ammonia Nitrogen in winter is greater than in summer (Figure 6) in the Duwamish river basin at Tukwila water sample station ($t = -0.2284$, $p= 0.4112$).

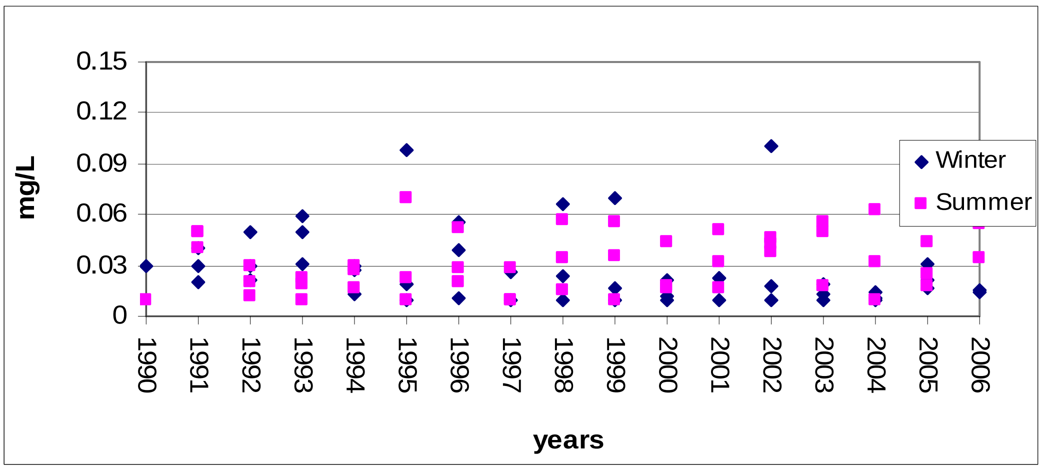


Figure 6. Concentration of Ammonia Nitrogen in the Duwamish River at Tukwila in Winter and n Summer (1990-2006). Samples done once in a month, three times in a season.

The highest concentration levels of ammonia nitrogen in the Duwamish river at 11A070 water sample station is observed in 12/19/1995 0.098mg/L with no precipitation in this day and 0.152 mg/L in 12/16/1997 with precipitation of 1.5 inches (Figure 2.)

The paired t-test on Ammonia Nitrogen in the Nisqually River at 11A070 at 09A080 water sample station shows that there is significant evidence to infer that level of Ammonia Nitrogen in winter is greater than in summer (Figure 7) in the Nisqually river basin at Nisqually water sample station (t = 4.5088, p<0.001).

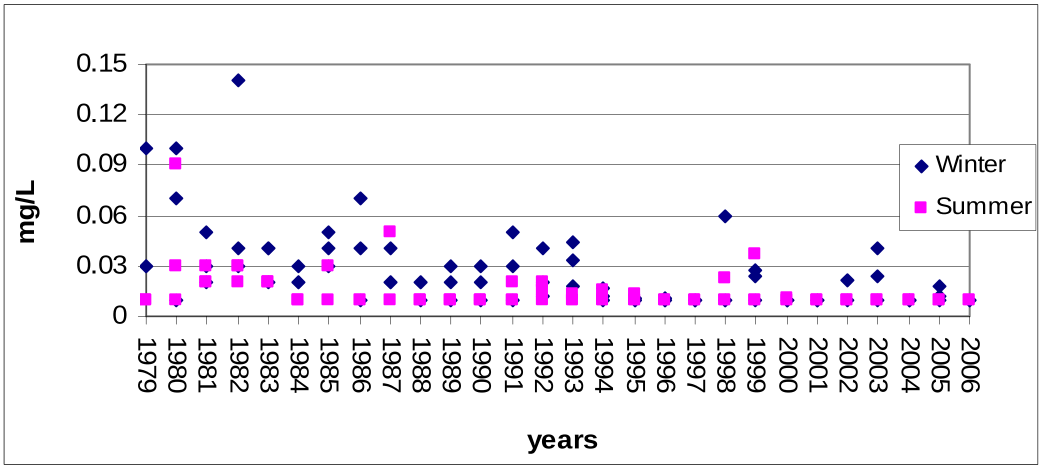


Figure 7. Concentration of Ammonia Nitrogen in the Nisqually River at Nisqually in Winter and n Summer (1979-2006). Samples done once in a month, three times in a season.

The highest concentration levels of ammonia nitrogen in the Nisqually river were 0.14 mg/L in 1/14/1982. There are no records for precipitation on this exact day at Panter Creek gauge.

IV. c. Nitrate-Nitrite Nitrogen

The paired t-test on Nitrate-Nitrite-Nitrogen in the Duwamish River at 09A080 water sample station shows that there is overwhelming evidence to infer that level of Nitrate+Nitrite-Nitrogen in winter is greater than in summer (Figure 8) in the Duwamish river basin at Tukwila water sample station (t = 11.4636, p<0.001).

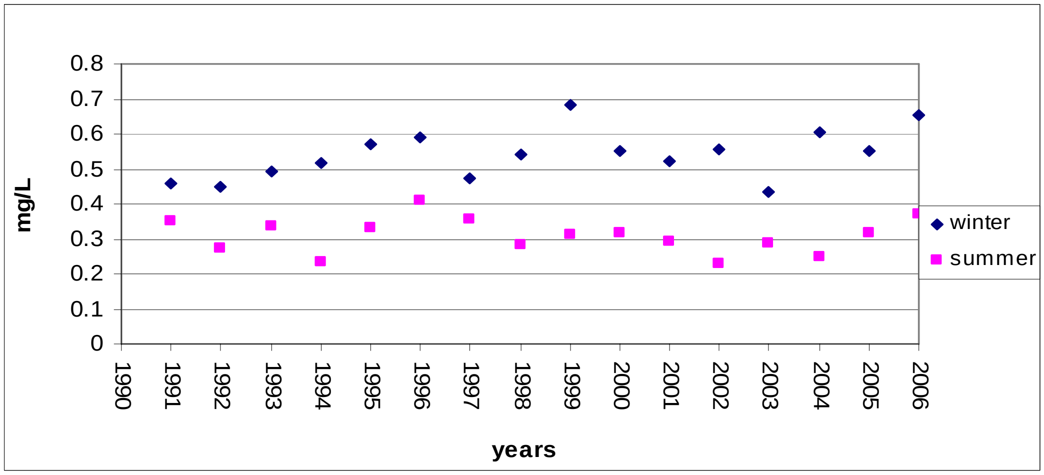


Figure 8. Nitrate-Nitrite Nitrogen in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Samples done once in a month, three times in a season.

The highest concentration levels of Nitrate-Nitrite nitrogen in the Duwamish river at Tukwila was observed in winter, 0.778 mg/L in 2/17/1999, with a precipitation of 0.09 inches in this day. 0.664mg/L of Nitrate-nitrite nitrogen was observed in 1/19/200 and precipitation was 0.02 inches. 0.608 mg/L was in 1/24/2001 with precipitation of 0.12 inches (Figure 2). There is an overall difference between winter and summer but it is not directly related to precipitation level.

The paired t-test on Nitrate-Nitrite Nitrogen in the Nisqually River at 11A070 at 09A080 water sample station shows that there is significant evidence to infer that level of Nitrate-Nitrite Nitrogen in winter is greater than in summer (Figure 9) in the Nisqually river basin at Nisqually water sample station ($t = 19.0631$, $p<0.001$).

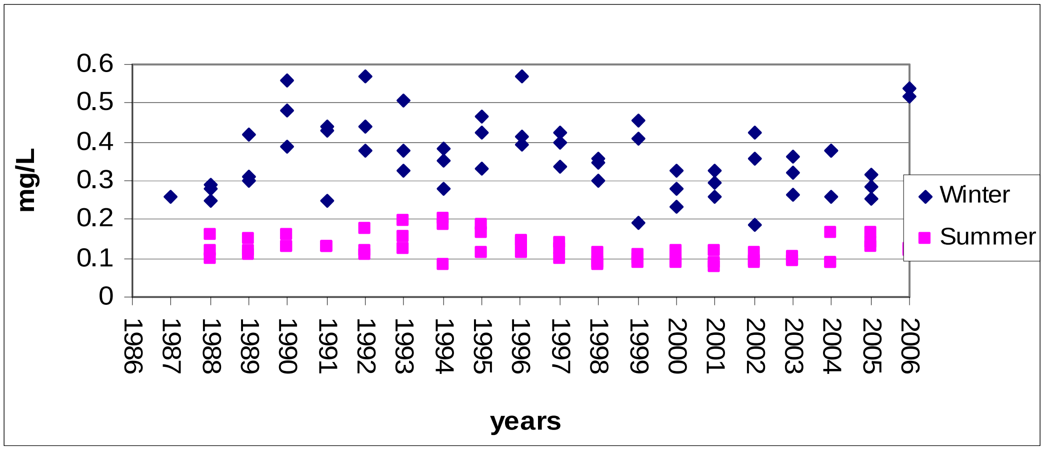


Figure 9. Nitrate-Nitrite Nitrogen in the Nisqually River at Nisqually in Winter and in Summer (1986-2006). Samples done once in a month, three times in a season.

The highest concentration levels of Nitrate-Nitrite nitrogen in the Nisqually river at Nisqually was recorded in winter, 0.508 mg/L in 1/26/1993, with a precipitation of 0.12 inches in this day. 0.569mg/L of Nitrate-nitrite nitrogen was recorded in 12/27/1996 with no precipitation in this particular day. 0.515 mg/L was in 2/13/2006 with precipitation of 0.04 inches (Figure 3).

IV. d. Dissolved Oxygen

The paired t-test on DO in the Duwamish River at 09A080 water sample station shows that there is overwhelming evidence to infer that level of DO in winter is greater than in summer (Figure 10) in the Duwamish river basin at Tukwila water sample station ($t = 23.4129$, $p<0.001$).

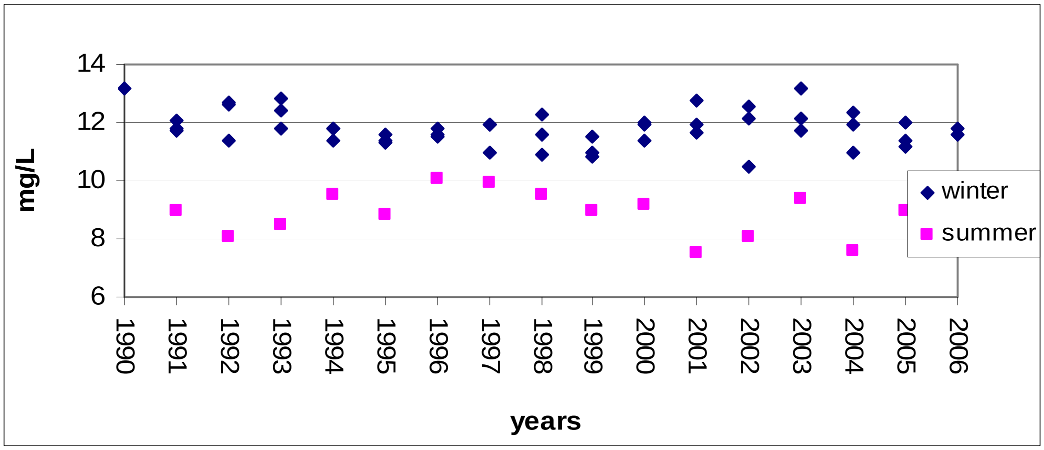


Figure 10. Dissolved Oxygen Level in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Sampled once in a month, three times in a season.

The highest levels of DO were recorded in 12/12/1990 - 13.2 mg/L and 13.19 mg/L in 2/24/2003. In these days water temperature were 6.1 °C and 4.7 °C.

The paired t-test on DO in the Nisqually River at 11A070 water sample station shows that there is overwhelming evidence to infer that level of DO in winter is greater than in summer (Figure 11) in the Nisqually river basin at Nisqually water sample station ($t = 18.2945$, $p<0.001$).

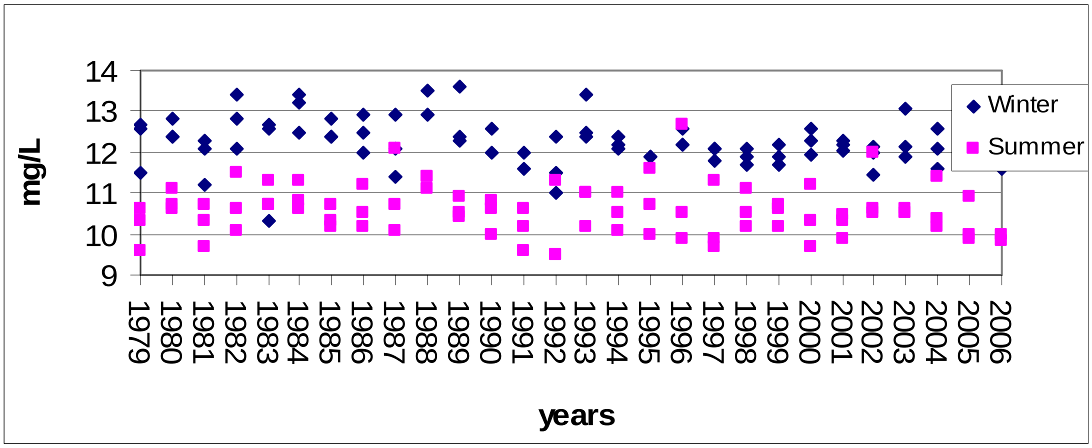


Figure 11. Dissolved Oxygen Level in the Nisqually River at Nisqually in Winter and in Summer (1979-2006). Sampled once in a month, three times in a season.

The highest levels of DO were recorded in 12/19/1990 – 14.1 mg/L, 13.4 mg/L –in 2/23/1993. In these days water temperature were 2.7 °C and 3.8 °C.

IV. e. pH level

The paired t-test on pH in the Duwamish River at 09A080 water sample station gives t = -2.0474, t value with a negative sign, and infers that there is evidence to infer that pH level is greater in summer than in winter (Figure 12) in the Duwamish river basin at Tukwila water sample station ($t = -2.0474$, $p = 0.0293$).

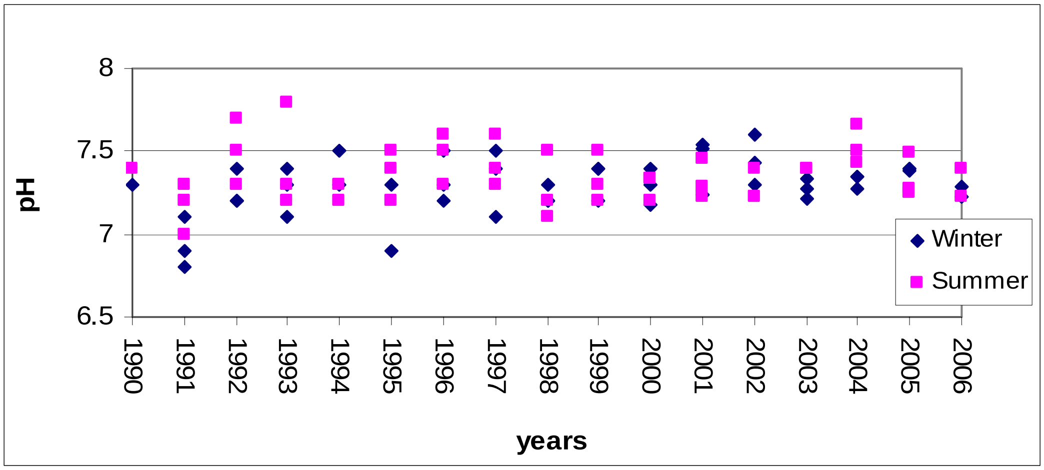


Figure 12. pH level in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Sampled once in a month, three times in a season.

The paired t-test on pH in the Nisqually River at 11A070 at 09A080 water sample station shows that there is overwhelming statistical evidence to infer that level of pH in winter is lower than in summer (Figure 13) in the Nisqually river basin at Nisqually water sample station (t = -6.3716, p<0.001).

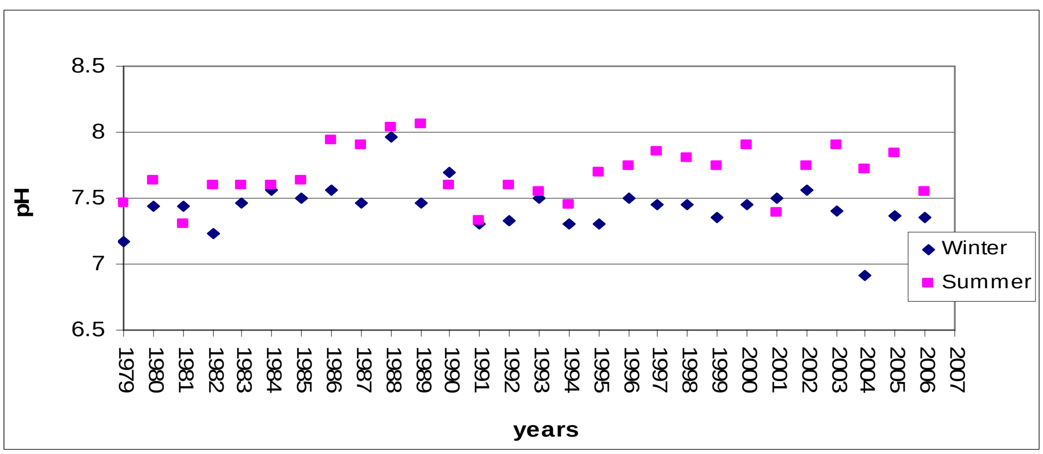


Figure 13. pH level in the Nisqually River at Nisqually in Winter and in Summer (1979-2006). Sampled once in a month, three times in a season.

The higher pH levels were observed more in summer than in winter. In 8/26/1987 pH level was 8.3, in 12/29/1987 - pH was 8.5 and in 6/29/1988 – 8.4.

IV. f. Water Temperature

The paired t-test on water temperature in the Duwamish River at 09A080 water sample station shows that there is overwhelming evidence to infer that water temperature in summer is greater than in winter (Figure 14) in the Duwamish river basin at Tukwila water sample station (t =-38.6691, p<0.001).

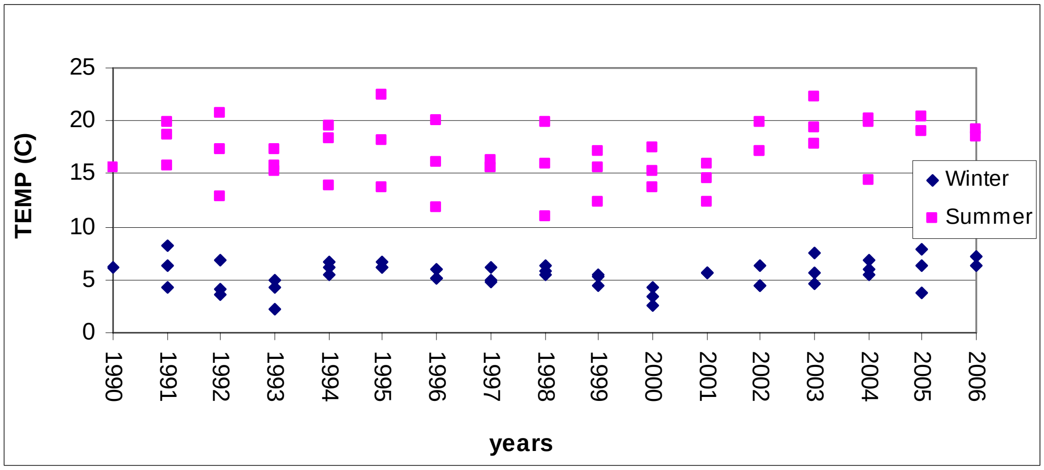


Figure 14. Water Temperature in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Sampled once in a month, three times in a season.

The temperature differences in winter and summer are mainly explained by differences of air temperature in winter and summer.

The paired t-test on water temperature in the Nisqually River at 11A070 water sample station shows that there is overwhelming evidence to infer that water temperature in winter is greater than in summer (Figure 15) in the Nisqually river basin at Nisqually water sample station (t = -6.446071884, p<0.001).

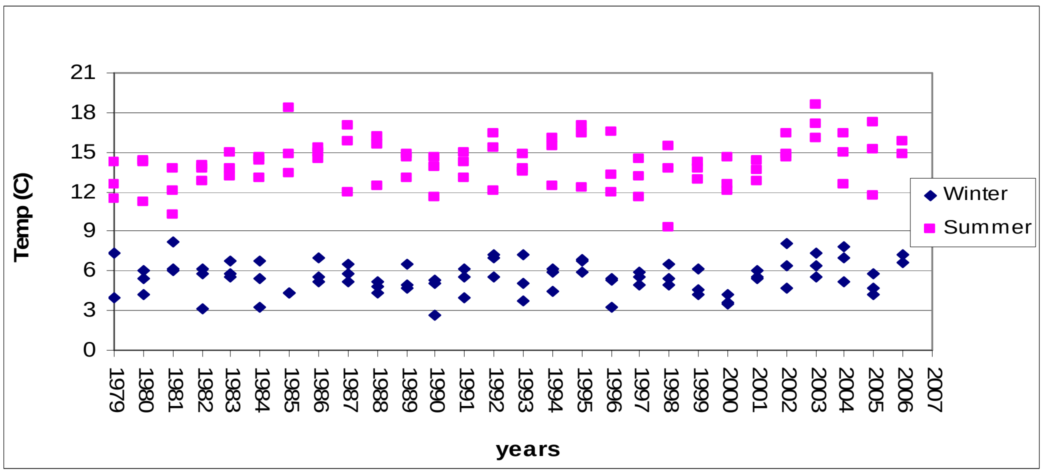


Figure 15. Water Temperature in the Nisqually River at Nisqually in Winter and in Summer (1978-2006). Sampled once in a month, three times in a season.

IV. g. Water Turbidity

The paired t-test on water turbidity in the Duwamish River at 09A080 water sample station shows that there is significant evidence to infer that water turbidity in winter is greater than in summer (Figure 16) in the Duwamish river basin at Tukwila water sample station (t =3.5708, p = 0.00139).

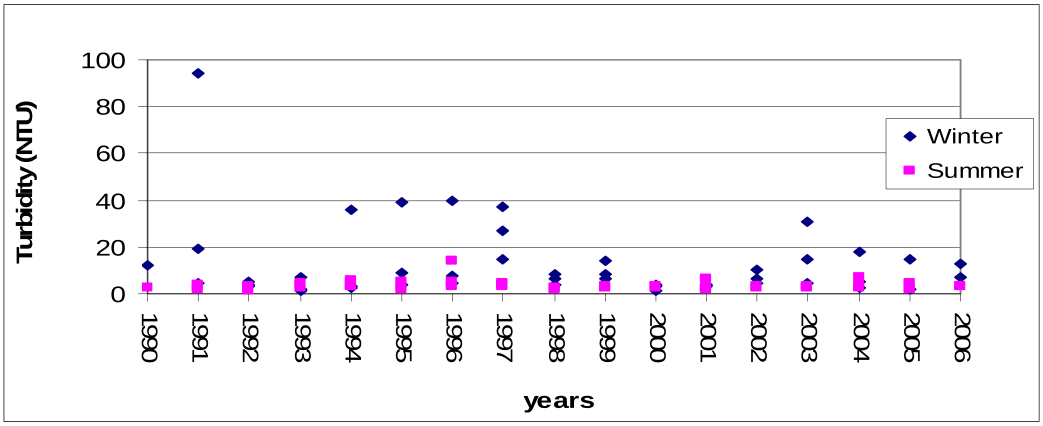


Figure 16. Water Turbidity in the Duwamish River at Tukwila in Winter and in Summer (1990-2006). Sampled once in a month, three times in a season.

As it is seen from figure 13, turbidity was greater in winter than in summer. It reached its peak (94 NTU) in 2/20/1991, with no precipitation on this or previous days. Higher level of turbidity in winter than in summer is explained by greater water flow in winter than in summer, which is due to more precipitation and storm water runoff in winter.

The paired t-test on water turbidity in the Nisqually River at 11A070 water sample station shows that there is significant evidence to infer that water turbidity in winter is greater than in summer (Figure 17) in the Nisqually river basin at Nisqually water sample station ($t = 2.6977$, $p = 0.0058$).

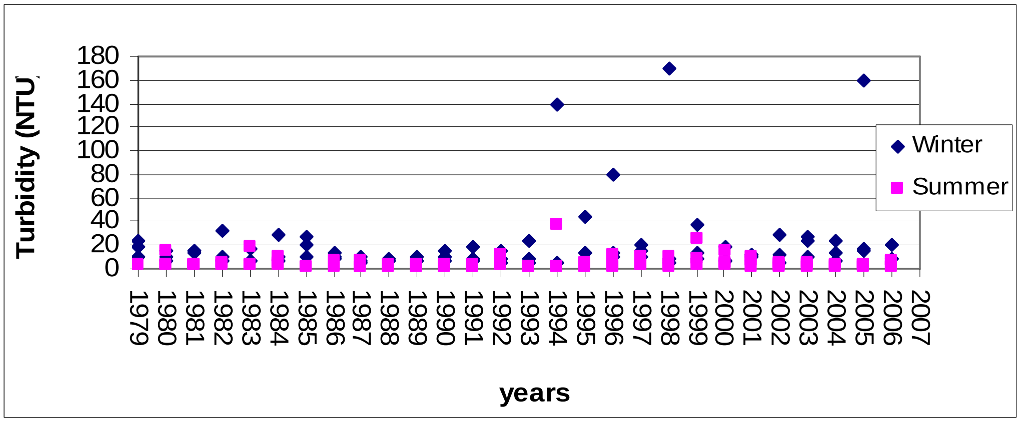


Figure 16. Water Turbidity in the Nisqually River at Nisqually in Winter and in Summer (1978-2006). Sampled once in a month, three times in a season.

As in the Duwamish river so in the Nisqually river higher level of turbidity is observed in winter compare to summer (Figure 17). The highest turbidity in the Nisqually river were 140 NTU 12/21/1994 with zero precipitation in this specific day, 170 NTU 12/28/1998, no precipitation was recorded in this day and 160 NTU 1/25/2005, with 0.07 inches of precipitation,

IV. h. Dissolved Copper and Dissolved Lead

The Maximum Contaminant Level (MCL) of dissolved copper (Cu) and lead (Pb) in the fresh waters is calculated by considering water hardness (Table 9) (Ecology, Johnson A., 1994, http://www.ecy.wa.gov/pubs/9458.pdf, Toxin Substances, WAC 173-201A-240).

The criteria for dissolved Cu and Pb for the Washington state waters is computed as a function of the relative water hardness. The capacity of the water to bind elemenstal copper and transform to a less toxic state to fish depends on water hardness. The higher hardness of the water, the higher capacity of water to bind elemental copper. (http://www.eho.wa.gov/searchdocuments/1997%20Archive/pchb%2096-193%20summary%20judgment.htm).

Table 9. Equations for Calculating Chronic and Acute Criteria for Copper and Lead

	Chronic Criteria	Acute Criteria
Copper	$\leq (0.862)(e^{(0.8545[\ln(\text{hardness})]-1.465)})$	$\leq (0.862)(e^{(0.9422[\ln(\text{hardness})]-1.464)})$
Lead	$\leq (0.687)(e^{(1.273[\ln(\text{hardness})]-4.705)})$	$\leq (0.687)(e^{(1.273[\ln(\text{hardness})]-1.460)})$

Source: Ecology, 1994, Johnson A.

In the Duwamish river at Tukwila, water sample station 09A080, concentration level of metals were sampled four times during the 2002-2003 water year (twice in Winter 12/11/2002 and 2/24/2003, and twice in summer 6/16/2003 and 8/18/2003) by the Washington State Department of Ecology. The concentrations of dissolved copper in winter were 1.11ug/L and 0.48ug/L. The concentration levels of dissolved lead in winter were 0.244ug/L and 0.04ug/L. In summer 2003 the concentrations of dissolved copper were 0.43ug/L and 0.36ug/L. Dissolved lead in summer (6/16/2003) were 0.036ug/L. In 8/18/2003 dissolved lead was not determined. The hardness in winter was 48.4mg/L and 18.5mg/L, and 40.6mg/L and 49.3mg/L in summer. The table 10 summaries the water quality criteria of dissolved copper and lead at given water hardness. The values of dissolved copper and lead are within normal range.

Table 10. Water Quality Criteria of Dissolved Copper and Lead in the Duwamish River at Tukwila

	Hardness mg/L	Chronic Toxicity (Dis. Cu)	Acute Toxicity (Dis. Cu)	Concentration of Dis. Cu (ug/L) in the river	Chronic Tox. (Dis. Pb)	Acute Tox. (Dis. Pb)	Conc. of Dis. Pb (ug/L) in the river
12/11/2002	48.4	5.48	7.7	1.11	6.3	22.3	0.244
2/24/2003	18.5	2.4	3.4	0.48	2.25	6.5	0.04
6/16/2003	40.6	4.7	6.5	0.43	0.69	17.8	0.036
8/18/2003	49.3	6.9	7.8	0.36	6.3	22.7	N/D*

In order to determine the metals criteria in the river, I used equations given in the Table 2. Dissolved copper and lead at 48.4 mg/L, 18.5 mg/L, 40.6mg/L and 49.3 mg/L hardness should not exceed 5.48 ug/L, 2.4 ug/L, 4.7 ug/L, 6.9 ug/L, respectively, and for lead water quality criteria at the same hardness is 6.3 ug/L, 2.25 ug/L, 0.69 ug/L and 22.7 ug/L, respectively. According to this calculation lead and copper did not exceed water quality criteria in the Duwamish river at water sample 09A080 during the specific water sample days in 2002-2003.

The concentration levels of both metals, dissolved copper and lead, in the Duwamish river, are greater in winter than in summer (Table 11), which is explained by increased urban runoff in winter than in summer.

In the Nisqually river at the water sample station 11A070 concentration level of metals in the river were sampled in 1998-1999 (twice in winter and once in summer) and 2001-2002 (twice in winter and twice in summer) water years. (Table 11).

Table 11. Water Quality Criteria of Dissolved Copper and Lead in the Nisqually River at Nisqually

Date	Hardness (mg/L)	Chronic Criteria (Dis. Cu)	Acute Criteria (Dis. Cu)	Concentration of Dis. Cu (ug/L) in the river	Chronic Criteria (Dis. Pb)	Acute Criteria (Dis. Pb)	Conc. of Dis. Pb (ug/L) in the river
12/13/1998	31	3.7	5.1	2.3	5.2	7.4	0.1
2/23/1999	23	2.9	3.8	1	4.46	6.69	0.06
6/28/1999	20	6.1	3.4	0.4	4.11	6.34	N/D
12/11/2001	23.9	5.16	3.96	1.1	4.6	6.78	0.05
2/19/2002	25.8	3.2	4.26	0.9	4.7	6.97	N/D
6/25/2002	24.4	3.05	4.04	0.4	4.6	6.83	N/D
8/27/2002	24	3.01	3.98	0.6	4.56	6.79	N/D

The metals criteria levels for the Nisqually river at 11A070 water sample station were calculated by the same equations as for the Duwamish river. The calculations show that dissolved copper and dissolved lead, at 23.9 mg/L, 25.8 mg/L, 24.4mg/L, 24 mg/L, 31mg/L, 23 mg/L, and 20 mg/L hardness, should not exceed 3.7 ug/L, 2.9ug/L, 6.1 ug/L, 5.16 ug/L, 3.2 ug/L, 3.05 ug/L, 3.01 ug/L for dissolved copper, and 5.2 ug/L, 4.46 ug/L, 4.11 ug/L, 4.6 ug/L, 4.7 ug/L, 4.6 ug/L and 6.8 ug/L for dissolved lead. The concentration of copper and lead in the Nisqually river at 11A070 water sample station during the specific water sample days meet water quality criteria.

Dissolved copper and lead in the Nisqually river in 1998-1999 and 2001-2002 winters are greater than in summer (Table 11) which is also due to increased urban runoff in wet season (winter).

The negative health effect on fish from copper and lead would occur when these metals did not meet water quality criteria. But there is no evidence to infer that there was any ecological risk to fish in the Duwamish and Nisqually rivers in the abovementioned water sample years.

IV. i. Comparing the Duwamish River Urban Runoff to the Nisqually River Non-urban Runoff

Urban runoff increases pollution of river basin more than non-urban runoff. The Duwamish river, which has urban runoff, has more pollution compared to the Nisqually river. Specifically Duwamish river shows higher overall levels of FC bacteria (Figure 18), Ammonia Nitrogen (Figure 19), Nitrate/Nitrite Nitrogen (Figure 20), and lower Dissolved Oxygen levels (Figure 21).

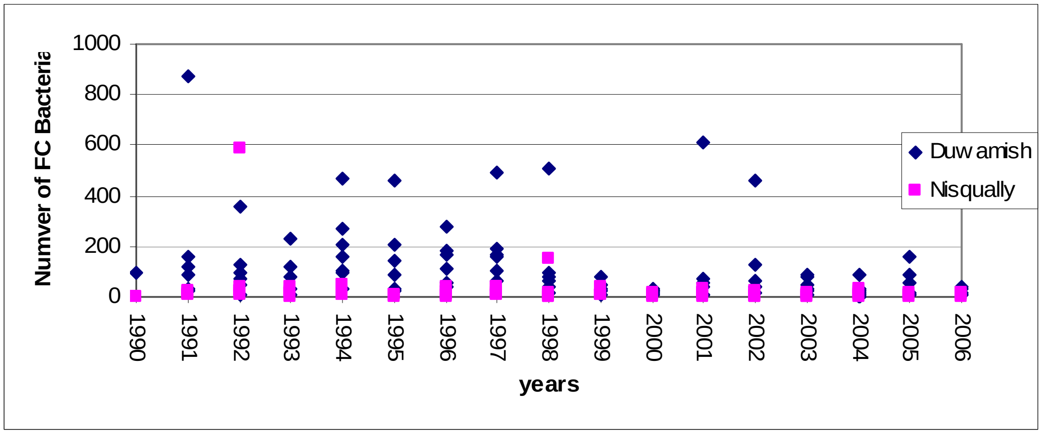


Figure 18. Comparing Number of FC Bacteria in the Duwamish river to the Nisqually river. Sampled once in a month, three times in a season.

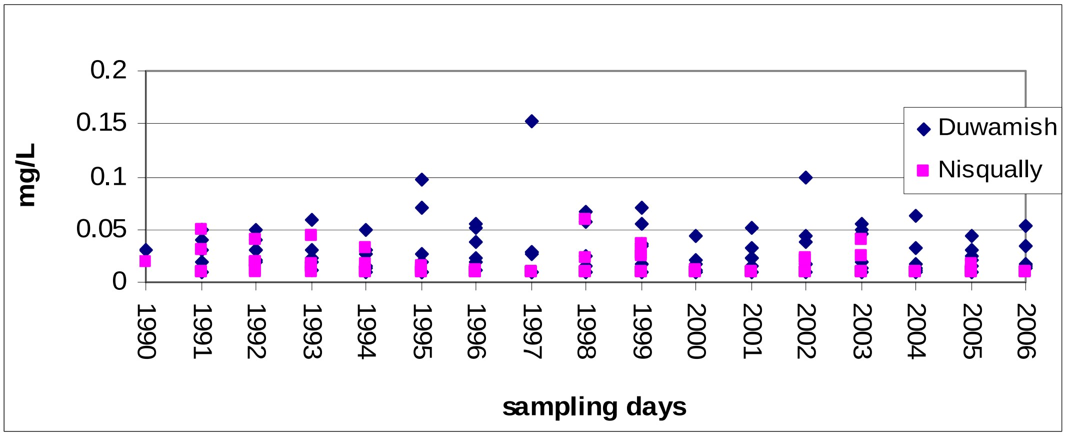


Figure 19. Comparing Ammonia Nitrogen in the Duwamish river to the Nisqually river. Sampled once in a month, three times in a season.

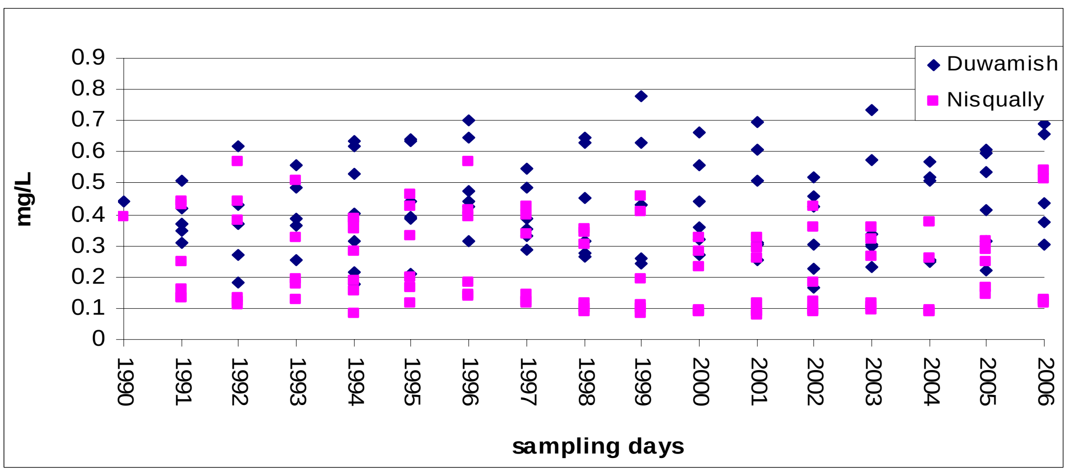


Figure 20. Comparing Nitrate-Nitrite Nitrogen in the Duwamish river to the Nisqually river. Sampled once in a month, three times in a season.

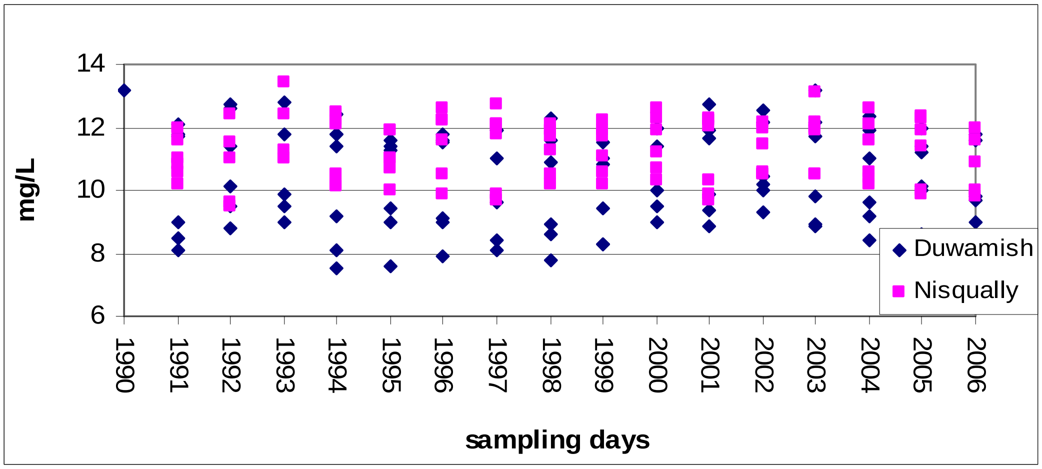


Figure 21. Comparing Dissolved Oxygen Level in the Duwamish river to the Nisqually river. Sampled once in a month, three times in a season.

Number of FC bacteria, ammonia nitrogen and nitrate-nitrite nitrogen in the Duwamish river are significantly higher than in the Nisqually river (for FC bacteria: t-value=0.05, p-values<0.002; ammonia nitrogen: t-value=6.6, p-value<0.001; nitrate-nitrite nitrogen: t-value=15.67, p-value<0.001; dissolved oxygen: t-value=-9.12, p-value<0.001). It was expected that dissolved oxygen level would be greater in the Nisqually river than in the Duwamish river (Table12), which is due to less urban runoff. FC bacteria, ammonia nitrogen and nitrate-nitrite nitrogen has effect on water quality parameters and therefore on DO level.

Table 12. Statistical Values of T-Test, Comparing the Duwamish and Nisqually Rivers Water pollutant and Quality Parameters

	t-value	p-value	mean (Duwamish river)±SD	mean (Nisqually river)±SD
FC Bacteria	5.05	<0.001	108±147.49	20±61.39
Ammonia Nitrogen	6.606	<0.001	0.03±0.02	0.014±0.009
Nitrate-Nitrite Nitrogen	15.67	<0.001	0.42±0.15	0.24±0.13
Dissolved Oxygen	-9.12	<0.001	10.43±1.53	11.29±0.99

Chapter V

DISCUSSIONS

According to Washington State Department of Ecology's water quality data, sampled from 1990 to 2006 in the Duwamish River at Tukwila, 09A080 water sample station, the annual DO level ranges between 7.6 mg/L and 13.2mg/L. DO level was never less than 7.5 mg/L during the sampling from 1990 to 2006 water sampling years. In the Nisqually River at 11A070 water sample station at Nisqually the annual DO level is between 9.1 mg/L and 14.1 mg/L. DO level was never less than 9.1 mg/L during the water sampling from 1977 to 2006. According to these data DO levels in the Duwamish and Nisqually rivers are within the range of Washington State water quality standards. There is no expected negative effect on fish in these rivers.

The water temperature from 1991 to 2006 in the Duwamish River at Tukwila is between 2.2 ºC and 6.8 ºC in winter and between 10.9 º C and 22.3 º C in summer. The water temperature exceeded water quality criteria 4 times in summer. In August 19, 1992, water temperature was 20.8 ºC, in July 19, 1995 – 22.4 ºC, in July 21, 2003 – 22.3 º and August 15, 2005 was 20.4 º. In the Nisqually River at Nisqually water sample station the water temperature in winter ranges between 3.2 ºC and 7.9 ºC. The range of water temperature in summer is between 9.3 and 18.3 ºC. There are no instances of exceeding the 7-DMax levels of temperature in the Nisqually river. The calculation of average water temperature in the Nisqually river is based on data collected from 1978 to 2006.

According to Bernhardt (1981) the upstream migration of Chinook salmon and summer steal head is in summer (June, July and August). Winter steelhead migrates upstream during the winter. Water temperature in the Duwamish and Nisqually rivers in winter satisfies the migration pass for summer steelheads and salmonids. The coho, chum and winter steelhead start spawning in winter. According to WSWQS (2006) water temperature in winter for spawning should be 9ºC-13ºC (depends on species). The river basins water temperature does not exceed water quality standard level for this activity. This means that water temperature in the Duwamish and Nisqually rivers gives a sufficient spawning place to coho, chum and winter steamheads. Summer Chinook rearing is in winter, coho and winter steelhead is rearing during the whole year and summer steelhead rearing is during the summer. According to WSWQS (2006) the water temperature in summer should not exceed 17ºC for a productive rearing. The Duwamish and Nisqually rivers satisfy Washington State water quality standards. There were some days that water temperatures in the Duwamish river were greater than acceptance level. Overall water temperature is not expected to have negative effect on fish migration, spawning and rearing in the Duwamish and Nisqually rivers.

High acidity or alkalinity has direct physical damage on fish skin, gills and eyes. Prolonged toxicity and exposure to extreme pH levels increase mucus production and epithelial hyperplasia (makes skin and gill epithelia thicker), and cause stress in fish. Such kind of health problems in fish can be followed by fish mortality. Fish maintains its own internal pH. Extreme external (water) pH affects fish's internal (blood) pH level, which causes acidosis or alkalosis of the blood (too low and too high pH respectively). Fluctuation of blood pH in fish can cause fish mortality in the river basin. Several factors have an effect on pH level changes in river (http://www.fishdoc.co.uk/water/pH.htm). Creating additional hydrogen or hydroxyl ions, changes the pH level by added or dissolved compounds in water. Cement and concrete make water more alkaline. Photosynthesis plays one of the main roles in changing pH level. Plants and animals respiration process excretes carbon dioxide in the water. By photosynthesis, plants remove carbon dioxide and water becomes more alkaline. The higher photosynthesis (more sunshine during the day and algae in the water) the higher alkalinity of water is. According to these two processes in the water, respiration and photosynthesis, the alkalinity and acidity of water depends on day and night time cycle. During the day time photosynthesis increases water alkalinity and during the night not having photosynthesis and high respiration level increases acidity of water. High level of pH increases the toxicity of some chemicals. The higher pH is the more toxic ammonia is. Potassium permanganate is more toxic at high pH, while chloramines-T is more dangerous at low pH (http://www.fishdoc.co.uk/water/pH.htm).

The pH levels in the Duwamish river at Tukwila is between 6.8 and 7.6 and in the Nisqually river at Nisqually between 6.6 and 8.5. Compare to Table 4, the pH levels of these river basins are sufficient for fish spawning, rearing and migration.

Pollution level in rivers in winter is significantly greater than in summer. Observations show that concentrations of copper and lead in the Duwamish and Nisqually rivers are greater in winter than is summer. At the same time water quality parameters: DO, turbidity, nitrate, nitrite-nitrate nitrogen and pH are greater in winter than in summer. The observed concentrations of copper and lead are not expected to have harmful effects on fish of these two rivers. The Duwamish and Nisqually rivers are in the water class A (excellent water category). To consider these rivers for class AA (extraordinary water category), more clean up projects and TMDL studies should be implemented in these river basins. The main pollutants for these basins are FC bacteria and ammonia nitrogen. Water quality parameters (temperature and DO) did not meet water quality standards several times during the specific water sample days. In summer water temperature exceeded water quality criteria in specific days in the Duwamish and Nisqually rivers.

The number of FC bacteria in the Duwamish River at 09A080 water sample station did not meet secondary contact recreational water quality criteria 13 times From these, the highest exceeding levels were observed in February 1992, August 1994, December 1994, December 1995, February 1996, June 1997, January 1998, August 2001 and December 2002. The highest amount of FC bacteria was 870/100ml–in February 20, 1991. In the Nisqually river at 11A070 water sample station the number of FC bacteria did not meet secondary contact recreational water quality criteria 4 times. In December 1981 the number of FC bacteria was 220/100ml, in July 1983 was 500/100ml, in December 1992 it was 1000/100ml and 590/100ml in January. High level of FC bacteria affects water pH balance and depletes oxygen in the water. Sewage also contains nitrogen and phosphorus, which in the rivers and surface waters acts as a fertilizer for aquatic plants and algae. Therefore in addition to FC bacteria sewage also increases photosynthesis during the day and leads to depletion of oxygen during the night (http://www.ecy.wa.gov/pubs/0210010.pdf).

The water turbidity in the Duwamish river at Tukwila exceeded water quality criteria once in February 20, 1991 (94.5NTU) during the whole 1990-2006 water sample years. In the Nisqually river water turbidity did not meet water quality criteria 5 times during the water sampling 1978-2006 years. The highest number was 170 and 160 NTU, sampled in December 28,1998 and January 25, 2005. In both of these rivers, high numbers of water turbidity were sampled during the winter, which is explained by more precipitation. Increasing water runoff into the rivers, increases flow of clay, silt, organic and inorganic matters, microscopic organisms, plankton and soluble colored organic compounds in the river.

The average amount of ammonia nitrogen and nitrate-nitrite nitrogen in the Duwamish River at station 09A080 in winter is 0.03mg/L and 0.54mg/L respectively, while in summer the average amount of ammonia nitrogen and nitrite-nitrate nitrogen is 0.031mg/L and 0.307mg/L respectively. In the Nisqually river at 11A070 water sample station average amounts of ammonia nitrogen and nitrite-nitrate nitrogen in winter is 0.02mg/L and 0.37mg/L vs. 0.01mg/L and 0.12mg/L in summer. The higher concentration of nitrates in winter than in summer is explained by agricultural runoff and increased amount of rain storm during the winter season.

Nitrite is less toxic than ammonia. Nitrite level over 0.1mg/L in the fresh water is considered as unacceptable, while nitrate level in the fresh water should not exceed 50mg/L (http://www.fishdoc.co.uk/water/nitrite.htm). Ammonia causes damage in fish at level of 0.1mg/L. In higher alkalinity of water there is more ammonia present, while at acidic level of pH more ammonium (NH^{4+}) is present, which is less toxic than ammonia. Ammonia more than 0.1mg/L in fresh water causes the destruction of mucus membranes in the fish and damages gills. At 0.1mg/L nitrite level symptoms of fish nitrite poisoning includes gasping and fast gill movement. These symptoms occur during the low level of DO as well. Higher level of nitrite can be followed by fish mortality and brown blood disease in fish. Nitrate is less harmless to fish than both nitrite and ammonia (http://www.thetropicaltank.co.uk/cycling2.htm). High level of nitrate might have long-term effect on fish's growth and reproduction. Salty water, sodium chloride in the water, works as a treatment from the actual toxicity of nitrate. Fish gills take up chloride ions, which protect fish against the nitrate poisoning (http://www.fishdoc.co.uk/water/nitrite.htm) .

Ammonia cause damage in the fish at level over 0.1mg/L. In the Duwamish river the average level of nitrate in winter is 0.03mg/L and 0.031mg/L in summer. In June 22,1994 the level of ammonia nitrogen was above the acceptance level (0.152mg/L). All other times ammonia nitrogen was below the standard level.

Chapter VI

CONCLUSSIONS AND RECOMMENDATIONS

Water sampling in Washington rivers are done once a month during the water sampling year. When the sample showed 1000 FC bacteria in the Nisqually river in 12/20/1989 no new samples were taken in the same month. Washington State should sample water more than once in the month on exceptional occasions, if water does not meet water quality standards and exceeding level is much higher than water quality criteria.

The urbanized area of the Duwamish watershed increases risk of river pollution. Developing watershed runoff water quantity and quality models will minimize flow of FC bacteria, nitrogen and metals into the river. This by itself will reduce ecological and environmental risk to aquatic life and people (recreational activities). Developing regional stakeholders' and public's awareness programs will increase protection of watershed by minimizing pollution level through human activities.

During the water sampling high level of FC bacteria and ammonia nitrogen were observed in the Duwamish river. In order to minimize pollution in the Duwamish river, stormwater runoff should be monitored and managed. High level of infiltration systems in urbanized areas in the Duwamish watershed should be installed. Dumping oil and grease from the industrial sector should be eliminated. More clean up projects should be implemented for the Duwamish river basin.

Concentration of metals and nitrogen in the Duwamish river should be monitored and reduced. Increased level of nitrogen has negative effect on DO level in water (cause oxygen depletion in rivers).

In 1996 the Nisqually river was listed in 303(d) list[6] (do not meet water quality standards for Fecal Coliform bacteria), Total Maximum Daily Loads (TMDL)[7] study conducted from March 2002 to September 2003 for the Nisqually river showed improved trends and met FC bacteria water quality standards (Ecology, 2007). Repairing on-site sewage systems and managing loads of FC bacteria from the animal farms in the Nisqually river are the main approaches to reduce flow of FC bacteria into the river. The Pierce County Department of Community Services Housing Programs, Nisqually Tribe, Thurston Conservation District , Tacoma-Pierce County Health Department and Washington State Department of Transportation are working together to reduce risk of river pollution from the FC bacteria.

The Tacoma-Pierce County Health Department is developing on-site sewage system management plan to identify type of on-site sewage systems in Pierce County, enforce maintenance of these systems, and reduce and eliminate potential health risks from these sewage systems in the Nisqually water basin. Evidence of pet feces occurred during the TMDL study. The Washington State Department of Transportation started

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[6] **List for water bodies, which do not meet water quality standards**

[7] TMDL identifies how much pollution needs to be reduced to achieve clean water. (Ecology, 2007)

managing pet waste for the Nisqually basin area. The Nisqually Tribe is planning to manage the removal of animal farms (located very close to watershed) from the Nisqually watershed area.

Landowners' awareness programs are planned by the Thurston Conservation District to develop conservation and restoration plans, and implement best management practices (C. James, 2007).

Managing stormwater runoff is one of the main tasks for reducing pollution of the Nisqually river basin. Creating storwater infiltration systems and bioretention cells (rain gardens) to treat stormwater (agricultural) runoff will reduce pollution flow into the river. Infiltration systems and bio-retention cells filtrate storwater from pesticides, nutrients, nitrogen, oil and grease. Filtrated water will have less negative effect on water quality parameters and therefore on fish.

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