Skagit Bay
Fecal Coliform Bacteria

Loading Assessment

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Cover photo: Eastern Skagit Bay including the tide flats near the mouth of the South Fork Skagit River, with Mount Baker and the Cascade Mountains in the background.

Photo provided by the Department of Ecology's Coastal Atlas shoreline photos (2000), number 000924_113400 https://fortress.wa.gov/ecy/coastalatlas/UICoastalAtlas/Tools/ShorePhotos.aspx.

Skagit Bay Fecal Coliform Bacteria

Loading Assessment

by

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Waterbody Numbers: See Table 1.

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Abstract

Skagit Bay and some tributaries are on the Washington State 2008 Section 303(d) list of impaired waterbodies for fecal coliform (FC) bacteria. Skagit Bay is in the northern part of the Puget Sound surrounded by the Skagit River delta, Camano Island, and Whidbey Island.

Study results showed that the majority of FC loading to Skagit Bay comes from the Skagit River. Even though the Skagit River had the lowest FC concentrations compared to all other waterbodies, it contributed the largest freshwater input and therefore the largest FC loading. The Skagit River itself, however, did not exceed Washington State water quality criteria for FC. West Pass contributed the second most FC loading to the bay and did exceed water quality criteria. All other surface water discharges combined contributed approximately 5% of the annual average loading to the bay.

Freshwater FC loads showed a direct relationship with marine FC concentrations. Increased precipitation showed increased FC concentrations and loading at all but one sampling location.

The highest FC concentrations were found in a small unnamed slough; however, this slough contributed relatively little loading to Skagit Bay. Irvine Slough and Williams Gate had the next highest FC concentrations. Sixteen out of 22 sample locations (73%) exceeded FC water quality criteria. FC percent reductions are recommended in order to comply with water quality criteria and protect beneficial uses. The sources of FC pollution were not positively identified.

The goal of this study is to provide an assessment of FC characteristics that will assist prioritization efforts of the water quality improvement process. The objective of this study is to evaluate FC concentrations and loads during the 2010 - 2011 sampling period and compare concentrations to water quality criteria. Targeted waterbodies include the majority of surface water sources to Skagit Bay.

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Introduction

Areas of Skagit Bay, including freshwater tributaries, exceed Washington State's surface water quality criteria for fecal coliform (FC) bacteria. Table 1 provides the waterbody names and identifications on Washington State's Section 303(d) list Category 5 for FC bacteria addressed in this report. The 303(d) list comprises those waters that are in the polluted water category, for which beneficial uses – such as drinking, recreation, aquatic habitat, and industrial use – are impaired by pollution. Category 5 waters in particular should be assessed for pollution and should have a restoration plan in order to improve water quality. Details about Category 5 waters are included in the *Federal Clean Water Act Requirements* section of this report. Figure 1 is a map of the study area showing 303(d) listed category 5 waterbodies.

Table 1. Skagit Bay Section 303(d) listed Category 5 waterbodies for FC in the Skagit Bay study area.

Waterbody Name	Listing ID	Waterbody ID	Grid Cell or LLID	Historical Waterbody ID	Waterbody Type	Latitude and Longitude or Township Range Sec		Listing History
Skagit Bay and Similk Bay	53200	390KRD	48122C4I2	WA-03-0010	Marine	48.285	-122.425	2008
	7170		48122D4D4			48.335	-122.445	1996 - 2008
	7171		48122D4D1			48.335	-122.415	1996 - 2008
	7172		48122D3C9			48.325	-122.395	1996 - 2008
	7173		48122D3B8			48.315	-122.385	1996 - 2008
	53165		48122C4G0			48.265	-122.405	2008
	53166		48122C4G1			48.265	-122.415	2008
	53197		48122C4H0			48.275	-122.405	2008
Big Ditch / Maddox Slough	45650	JK73SN	1223445483120	WA-03-2010	River/Stream	33N - 4E - 31		2008
Browns Slough	7133	VN02NL	48122D4D1	WA-03-4000	Marine	48.335	-122.415	1996 - 2008
Irvine Slough	43042	HS19KT	1223683482401	WA-05-1010	River/Stream	32N - 3E - 24		2004, 2008
Wiley Slough	7177	EE73RP	1223875483184	WA-03-4100	River/Stream	33N - 3E - 26		1996 - 2008
	45687		1223875483184			33N - 3E - 25		2008

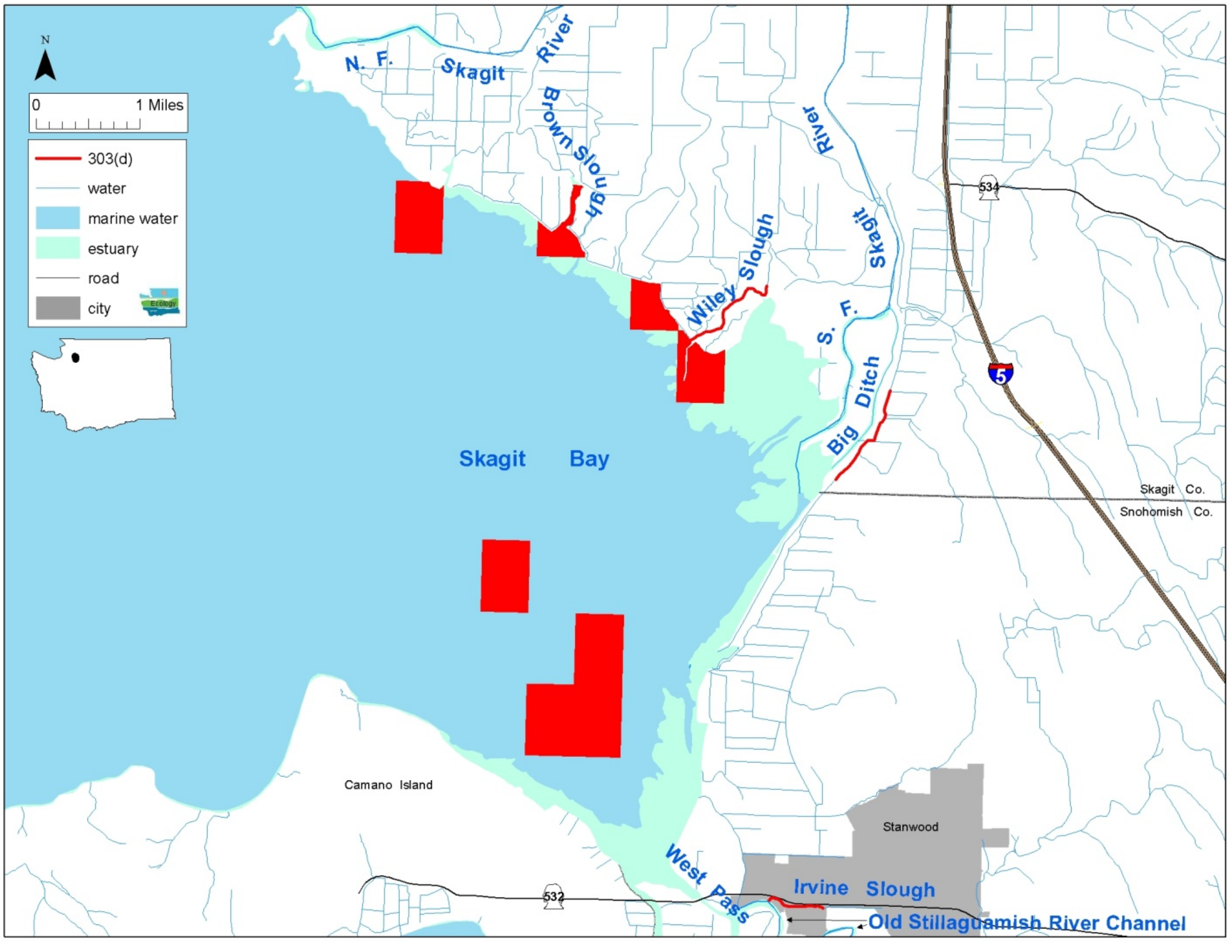

Figure 1. Section 303(d) listed category 5 waterbodies for FC bacteria in the southeast Skagit Bay area.

The Washington State Department of Ecology is required, under Section 303(d) of the federal Clean Water Act and U.S. Environmental Protection Agency regulations, to (1) provide a list of impaired waterbodies, (2) develop and implement water cleanup plans to achieve Total Maximum Daily Loads (TMDLs) for impaired waters, and (3) evaluate the effectiveness of the water cleanup plan to achieve the needed improvements in water quality.

Project Goal and Objectives

The goal of this study is to provide an assessment of FC characteristics that will assist prioritization efforts of the water quality improvement process. The study area includes the majority of surface water sources to Skagit Bay along its southern and eastern land borders. Additional samples were also taken at a few investigatory sites in agricultural waterways. Study results will be used to guide water quality improvement projects.

To meet this goal, the study objective is to evaluate FC concentrations, surface water discharge, and general water quality parameters within the watershed during the 2010-2011 sampling period. Specific tasks include the following:

- Conduct FC sampling over a 13-month period from September 2010 through September 2011.
- Compare FC concentrations to the Washington State water quality criteria.
- Evaluate the wet and dry seasonality of FC concentrations.
- Measure stream discharge at FC sampling locations where possible.
- Estimate FC contaminant loads to the bay.
- Collect nutrient and FC samples during four storm events (secondary objective).

The secondary objective of the study is to collect nutrient samples during each storm survey. Nutrient data are presented in Appendix B and may be used to further develop Puget Sound environmental monitoring efforts. Nutrient data are merely presented in this report and not included in the discussion.

Watershed Description

Skagit Bay

Skagit Bay is in the northern part of the Puget Sound surrounded by Fidalgo Island, the Skagit River delta, the Stillaguamish River delta, Camano Island, and Whidbey Island (Figure 2). The southwestern end of the bay connects with Puget Sound through Saratoga Passage. The northwestern part of the bay, known as Similk Bay, connects with the Strait of Juan de Fuca through the narrow Deception Pass. The Swinomish Channel connects Skagit Bay to Padilla Bay from the north. Three counties and Water Resource Inventory Areas (WRIAs) overlap the bay: Skagit County, Snohomish County, Island County; and WRIAs 03, 05, and 06.

Freshwater inputs to Skagit Bay include the Skagit River, the Stillaguamish River via West Pass, and agricultural waterways including Hall Slough, Browns Slough, Dry Slough, Freshwater Slough, Fisher Creek, Big Ditch, Douglas Slough, Davis Slough, and several other unnamed waterways.

Skagit Bay is a habitat for waterfowl, shorebirds, fish, bivalves, and many other aquatic species. The intertidal zone of Skagit Bay is a suitable habitat for bivalves where commercial clam harvesting and natural predation occurs. Most of the bay is less than 16 feet deep with shallower waters over the intertidal flats near the river deltas. The intertidal flats become exposed to the air during low tides. The bay is deeper near Whidbey and Fidalgo Islands, with the deepest point at 131 feet near Deception Pass (Yang and Khangaonkar, 2008).

Approximately 75% of the historic estuary habitat along the shores of Skagit Bay has been lost due to dike building, water diversion, and drainage. Dams on the Skagit River and changes in flood events on the Skagit and Stillaguamish Rivers have also contributed to loss of estuarine habitat (WDFW, 2011).

Figure 2. Surrounding area of Skagit Bay and Watershed Resource Inventory Area (WRIA) boundaries.

Skagit River Basin

The Skagit River basin has a drainage area of approximately 3,093 square miles, which includes the headwaters in British Columbia (Pickett, 1997). The Skagit River contributes 34 - 50% of the freshwater flowing into the Puget Sound, depending on the season, as well as the majority of the freshwater to Skagit Bay (Yang and Khangaonkar, 2008). River flows are mainly influenced by rainfall, glacial meltwater, snowmelt, tidal fluctuation, and reservoirs (in the upper watershed). Since 1940, the United States Geological Survey (USGS) has operated a continuous streamflow gage (Station #12200500) on the Skagit River at Mount Vernon. Peak streamflows – 24,400 cubic feet per second (cfs) – occur in June due to snowmelt; a second peak occurs during the winter months due to precipitation runoff. The lowest streamflows (baseflow), at 9,340 cfs, occur in September. The 7Q10 low flow (7-day average flow with 10 year recurrence probability) is 5,030 cfs, based on the period of 1953 - 1997 (Pater, 2000).

Streamflow in the Skagit River is tidally influenced up to Mount Vernon, at approximately river mile (RM) 19. The Skagit River splits into the North and South Forks forming Fir Island, before entering the bay. The South Fork conveys roughly 40% of the Skagit River's streamflow, while the North Fork carries the remaining 60% (Williams et al., 1975; and Yang and Khangaonkar, 2008). The Forks braid and enter the bay along 2.5 miles of marine shoreline consisting of shellfish growing areas, dikes, and Washington Department of Fish and Wildlife (WDFW) wildlife refuges.

Lower Stillaguamish River Basin

West Pass receives streamflow from the Stillaguamish River via the Old Stillaguamish River Channel. Approximately 10% of the Stillaguamish River flows through the Old Stillaguamish River Channel while the remainder flows through Hatt Slough to Port Susan. Further downstream, more branching occurs where roughly 20% of the Old Stillaguamish River Channel enters West Pass and the remaining 80% flows south into Port Susan via South Pass (Figure 2) (Pelletier and Sullivan, 2006). Church Creek, Miller Creek, Williams Gate, Borseth Gate, Grinde Gate, and other unnamed waterways, contribute small amounts of freshwater inflows to the Old Channel along with the Stillaguamish River (Joy, 2004). The Stanwood Wastewater Treatment Plant (WWTP) intermittently contributes treated effluent discharges to the Old Channel as well.

Streamflow in the Stillaguamish River is influenced by rainfall, snowmelt, and tidal fluctuation. Typically, peak streamflows occur during the winter while low flows occur during late summer. West Pass acts much like a tidal slough during the dry season when freshwater inflow becomes limited. Tidal influence from Puget Sound can extend up the Stillaguamish River to Silvana. However, a tide gate at the head of the Old Stillaguamish River Channel operates during low-flow periods from July through October. The tide gate is in place to increase freshwater flushing of the Old Stillaguamish River Channel by blocking marine water from entering the channel (Joy, 2004).

Snohomish County Public Works Surface Water Management operates a continuous streamflow gage on the Stillaguamish River at Interstate-5 (I-5) (site name: Stillaguamish R @ I-5). This site is formerly Ecology's manual stage height station 05A070 with records beginning in 1997.

Continuous streamflow monitoring was established in 2009. Construction of a temporary dam diversion in the Stillaguamish River downstream of the gage station caused artificially high water levels from late July to October 2011. Therefore, staff gage and continuous streamflow records were questionable during that time and are not used for this study.

Skagit Bay Surrounding Area Land Use

Adjacent land use around Skagit Bay is primarily agriculture, drained by waterways with tide gates and pump stations to prevent flooding from high tides and high surface water flow. Other land uses include WDFW wildlife refuges, commercial and recreational shellfish harvesting areas, and urbanization with both on-site septic systems and municipal wastewater treatment facilities.

Large watersheds, such as the Stillaguamish and Skagit watersheds, can extend for several miles upland of the bay. Land use on these seemingly far removed stream reaches has potential to influence the water quality of Skagit Bay. Land use farther upland of the bay includes agriculture, urban, residential, commercial, and forestry.

According to the United States Census Bureau (2010), over the past 10 years Skagit County's population has increased 16% (population estimate: 119,534), and Snohomish County's population has increased 15% (population estimate: 694,571).

Cities along the Skagit River include Mount Vernon (population estimate: 30,000), Burlington (8,120), and Sedro-Woolley (9,000). Urban stormwater runoff, which is known to contain FC bacteria, also flows into the Skagit River and can be carried into Skagit Bay.

Mount Vernon, Burlington, and Sedro-Woolley all have municipal WWTPs that discharge to the Skagit River. These WWTPs discharge at the following RMs of the Skagit River: Mount Vernon – RM 10.7, Burlington – RM 18, and Sedro-Woolley – RM 22.8. In 1999, a combined sewer overflow (CSO) from the Mount Vernon municipal wastewater treatment plant (WWTP) increased the FC concentrations in Skagit Bay (Lawrence, 2007). The Mount Vernon WWTP Combined Sewage System (CSS) is scheduled to be improved by 2015 allowing on average one CSO event per year. From 2005 to 2009 the Mount Vernon WWTP had an annual average of 10 CSO events. The WWTPs of Sedro-Woolley and Burlington do not have CSS and therefore no potential for CSO.

Along the Old Stillaguamish River Channel, the City of Stanwood (population estimate: 3,500) is an urban area nearest to Skagit Bay. Two point source facilities are located in Stanwood: the municipal WWTP and Twin City Foods Inc. Waterbodies pertinent to this study near Stanwood include the Old Stillaguamish River Channel, West Pass, Davis Slough, Douglas Slough, Irvine Slough, Williams Gate, Borseth Gate, and Grinde Gate.

The Stanwood WWTP discharges treated effluent directly into the Old Stillaguamish River Channel at RM 4.3. During specified upset conditions, (such as a power outage or inadequate disinfection from the ultraviolet light system), effluent is automatically diverted into a lagoon, reducing the risk of contamination of the Old Stillaguamish River Channel. The Stanwood WWTP does not have CSS or the potential for CSO. However, the treatment lagoon is prone to overtopping during flood events as evidenced by overtopping incidents in 2009 and 1990 (Snohomish County, 2011).

The City of Arlington has a WWTP that discharges effluent to the Stillaguamish River at approximate RM 18. The Arlington WWTP does not have CSS or the potential for CSO.

Twin City Foods discharges water used to process and pack vegetables. The effluent is stored in two lagoons in an agricultural area. Birds often frequent the lagoons and surrounding fields potentially contributing FC. Wildlife inputs are part of natural background levels and are not a controllable source. The lagoon water is seasonally applied to adjacent agriculture fields. Drainage ditches along these fields empty into the Old Stillaguamish River Channel and South Pass, including through the Williams, Borseth, and Grinde Gates.

Federal Clean Water Act Requirements

The federal Clean Water Act established a process to identify and clean up polluted waters. Under the Act, each state is required to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of designated uses for protection, such as cold water biota and drinking water supply, as well as criteria, usually numeric criteria, to achieve those uses.

Every two years, states are required to prepare a list of waterbodies – lakes, rivers, streams, or marine waters – that do not meet water quality standards. This list is called the 303(d) list. To develop the list, Ecology compiles its own water quality data along with data submitted by local, state, and federal governments; tribes; industries; and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before being used to develop the 303(d) list.

In Washington State, the 303(d) list is part of the larger Water Quality Assessment. The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's surface water. This list divides waterbodies into five categories:

Category 1 – Meets standards for the parameter (or parameters) for which it has been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data available.

Category 4 – Polluted waters that do not require a TMDL because they:

- 4a. – Have a TMDL approved and it is being implemented.
- 4b. – Have a pollution control plan in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, culverts.

Category 5 – Polluted waters that require a TMDL or similar study – on the 303(d) list.

Further information is available at Ecology's Water Quality Assessment website.

The Clean Water Act requires that a total maximum daily load (TMDL) or other pollution control mechanism be developed for each of the waterbodies on the 303(d) list. A TMDL is a numerical value representing the highest pollutant load a surface waterbody can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

Water Quality Criteria

In summary, the applicable FC water quality criteria for Skagit Bay and the contributing freshwater are as follows:

- Freshwater FC criteria
  - geometric mean < 100 colonies/100mL
  - not more than 10% of all samples > 200 colonies/100mL
- Marine FC criteria
  - geometric mean < 14 colonies/100mL
  - not more than 10% of all samples > 43 colonies/100mL

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state (WAC 173-201A, 2006).

The FC criteria have two statistical components: a geometric mean criterion and an upper limit criterion that 10% of the samples cannot exceed. FC samples collected randomly usually follow a log-normal distribution, which should be taken into account in the analysis.

Freshwater and marine waterbodies are required to meet water quality standards based on beneficial uses. Numeric criteria for specific water quality parameters are intended to protect designated uses. Skagit Bay and its freshwater tributaries including brackish estuaries are classified as *Primary Contact* waters. Potential sources of FC pollution in Skagit Bay include: CSOs, wastewater treatment plants, stormwater, failing onsite septic systems, agriculture, livestock, and wildlife (the latter is considered part of "natural background levels").

The application of freshwater and marine water quality criteria is based on salinity as described in the WAC 173-201A-260:

"*(e) In brackish waters of estuaries, where different criteria for the same use occurs for fresh and marine waters, the decision to use the fresh water or the marine water criteria must be selected and applied on the basis of vertically averaged daily maximum salinity, referred to below as "salinity."*

(i) The fresh water criteria must be applied at any point where ninety-five percent of the salinity values are less than or equal to one part per thousand, except that the fresh water criteria for bacteria applies when the salinity is less than ten parts per thousand; and

(ii) The marine water criteria must apply at all other locations where the salinity values are greater than one part per thousand, except that the marine criteria for bacteria applies when the salinity is ten parts per thousand or greater".

Freshwater criteria for bacteria apply when 95% of salinity values are less than ten parts per thousand (ppt). Marine criteria apply when salinity is 10 ppt or greater. Similarly, if water quality data show a 95th percentile conductivity of 17,700 micro-ohms (equivalent to salinity greater than 10 ppt), then marine criteria applies (Swanson, 2008).

Freshwater

FC criteria are set to protect people who work and play in and on the water from waterborne illnesses. FC are used as an "indicator bacteria" for the state's freshwaters by assuming that the presence of FC in water indicates the presence of waste from humans or other warm-blooded animals. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The FC criteria are set at levels that have been shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

The *Primary Contact* use is intended for waters "where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and waterskiing" (WAC 173-201A, 2006). The use is to be designated to any waters where human exposure is likely to include exposure of the eyes, ears, nose, and throat. Since children are also the most sensitive group for many of the waterborne pathogens of concern, even shallow waters may warrant primary contact protection. To protect this use category "*Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies/100 mL, with not more than 10% of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/colonies mL*" (WAC 173-201A, 2006).

If natural levels of FC (from wildlife) cause criteria to be exceeded, the standards do not allow human sources to measurably increase bacterial pollution further. Warm-blooded animals, particularly those managed by humans and thus exposed to human-derived pathogens, are a common source of serious waterborne pathogens for humans.

Marine Water

In marine (salt) waters, bacteria criteria are set to protect shellfish consumption and people who work and play in and on the water. "[Molluscan shellfish also have a long history as vectors of infectious and sometimes dangerous diseases ranging from typhoid fever and hepatitis to diarrhea and minor intestinal disorders (Rippey, 1994). These agents often originate in discharges of human sewage and indigenous marine bacterial pathogens. The unique biology of shellfish and the way we consume them contribute to our vulnerability to shellfish-borne disease. Shellfish are sedentary filter feeders, pumping large amounts of water through their bodies. This process can concentrate microbial pathogens in their tissues, causing little or no harm to the animal, but posing substantial risks for human consumers, particularly because shellfish are often eaten raw or partially cooked]" (NOAA, 1998). In waters protected for both *Primary Contact Recreation* and *Shellfish Harvesting*, FC bacteria are used as indicator bacteria to gauge the risk of exposure to waterborne pathogens.

To protect *Shellfish Harvesting* and *Primary Contact Recreation* (swimming or water play): "*Fecal coliform organism levels must not exceed a geometric mean value of 14 colonies/100 mL, with not more than 10% of all samples (or any single sample when less than ten sample points* *exist) obtained for calculating the geometric mean value exceeding 43 colonies/100mL*" (WAC 173-201A, 2006).

The *Shellfish Harvesting* and *Primary Contact Recreation* criteria are consistent with National Shellfish Sanitation Program (NSSP) rules. Marine water FC concentrations that meet shellfish protection requirements also meet the federal recommendations for protecting people who engage in primary water contact activities. Thus, the same criteria are used to protect both *Shellfish Harvesting* and *Primary Contact* uses in Washington State standards.

Previous Studies

Washington State Department of Ecology

FC bacteria TMDL studies have been conducted on the lower Skagit River (Lawrence, 2007; Pickett, 1997; and Butkus et al., 2000) and the Stillaguamish River (Lawrence and Joy, 2005). Below is a summary of relevant conclusions and recommendations from the studies, excluding redundancies between the two. Results from these studies were compared to the results of this Skagit Bay FC loading assessment.

Lower Skagit River FC Total Maximum Daily Load Water Quality Implementation Plan (1994-1995)

- Potential sources of FC pollution to Skagit Bay include: CSOs, wastewater treatment plants, stormwater, failing onsite septic systems, agriculture, and wildlife (considered part of "natural background levels").
- From 2004 through 2006 the Skagit River met freshwater FC water quality criteria. Although the South Fork met FC criteria, it did not meet the more stringent TMDL load allocation targeted to protect marine water quality criteria.
- FC data showed seasonal changes in concentration and loading. The Skagit River experienced a peak in the fall and Skagit Bay experienced seasonal FC elevations in July, November, and February-March.
- FC in the Skagit River can quickly affect Skagit Bay despite seasonal differences in loading/concentrations between the river and the bay. This was demonstrated by a CSO to the river that caused elevated FC concentrations in the bay that remained for several days.
- FC water quality has improved in the Skagit River but not in Skagit Bay except for the monitoring station near West Pass.
- Excluding the Skagit River, other freshwater sources to Skagit Bay not evaluated in the TMDL may contribute to FC pollution and should be assessed.
- FC monitoring on the Skagit River should continue with a focus on seasonal storms in order to characterize loading events to Skagit Bay. It may be important to determine how long after a storm FC concentrations remain elevated in the bay.
- WDOH should conduct a dry-season and wet-season FC shoreline survey around Skagit Bay.

Stillaguamish River Watershed FC, Dissolved Oxygen, pH, Mercury, and Arsenic (Water Cleanup Plan) Submittal Report (2000-2002)

- The mainstem Stillaguamish River, its major Forks, and a number of tributaries and smaller creeks are impaired with excess FC bacteria.
- FC water quality violations are prevalent throughout the lower Stillaguamish watershed, especially during storm events.
- Although many of the FC impairments result from non-point pollution, some stream reaches are likely affected by stormwater runoff from municipalities that have NPDES Phase I stormwater permits or that will be covered by the future NPDES Phase II permit.
- FC loads had a direct relationship with median concentrations to receiving marine waters.
- Load reductions of FC are needed in order to protect beneficial uses.
- West Pass needs 97% reduction in FC to meet water quality criterion.
- Douglas Slough needs 68% reduction in FC to meet water quality criterion.
- Irvine Slough needs 99% reduction in FC to meet water quality criterion.

Methods

Field Methods

Twenty-two locations were monitored on a monthly basis from September 2010 through September 2011. However, three of the 22 monitoring locations were sampled for a limited time during this study, due to site relocation or site addition. A total of 14 sampling events took place during the course of the study. Sampling events occurred over two-day periods except for an August storm event that occurred over the course of one day. Day one of sampling typically included most sites in WRIA 05 followed by day two where most sites in WRIA 03 were sampled. Figure 3 provides a map of sampling locations, and Table 2 provides the site identification (ID), description, and coordinates.

Parameters collected during monthly sampling included: FC bacteria, streamflow, temperature, conductivity, salinity, pH, and dissolved oxygen. FC bacteria analysis was done using the membrane filter (MF) method. However the most probable number (MPN) analytical method was also used on approximately 10% of the FC bacteria samples for comparison with the MF method.

Streamflow was measured when possible. Limiting factors not allowing streamflow measurements included: lack of access, tidal influences interfering with stream velocities, insufficient water depth, and water stagnation. Nutrient samples were also taken during storm surveys for ammonia (NH3), nitrite-nitrate (NO2/NO3), total persulfate nitrogen (TPN), orthophosphate (OP), and total phosphorus (TP). Detailed study techniques can be found in the Quality Assurance (QA) Project Plan (Kardouni, 2010) describing field methods and laboratory analysis.

The timing of sample collection typically coincided with low tides in Skagit Bay since we wanted to ensure that the sample was representative of freshwater. Washington State Department of Health (WDOH) typically sampled for FC in Skagit Bay (i.e. marine water) during high tide on the same day as Ecology sampled freshwater. WDOH's Division of Environmental Health, Office of Shellfish and Water Protection samples marine water shellfish areas around the state including Skagit Bay typically on a monthly basis. Figure 4 shows the sampling locations established by WDOH. The FC sample locations are in the southern part of Skagit Bay near Camano Island and West Pass. It is important to note that freshwater from the Skagit River mixes with Puget Sound marine water including the southern part of Skagit Bay (Yang and Khangaonkar, 2008).

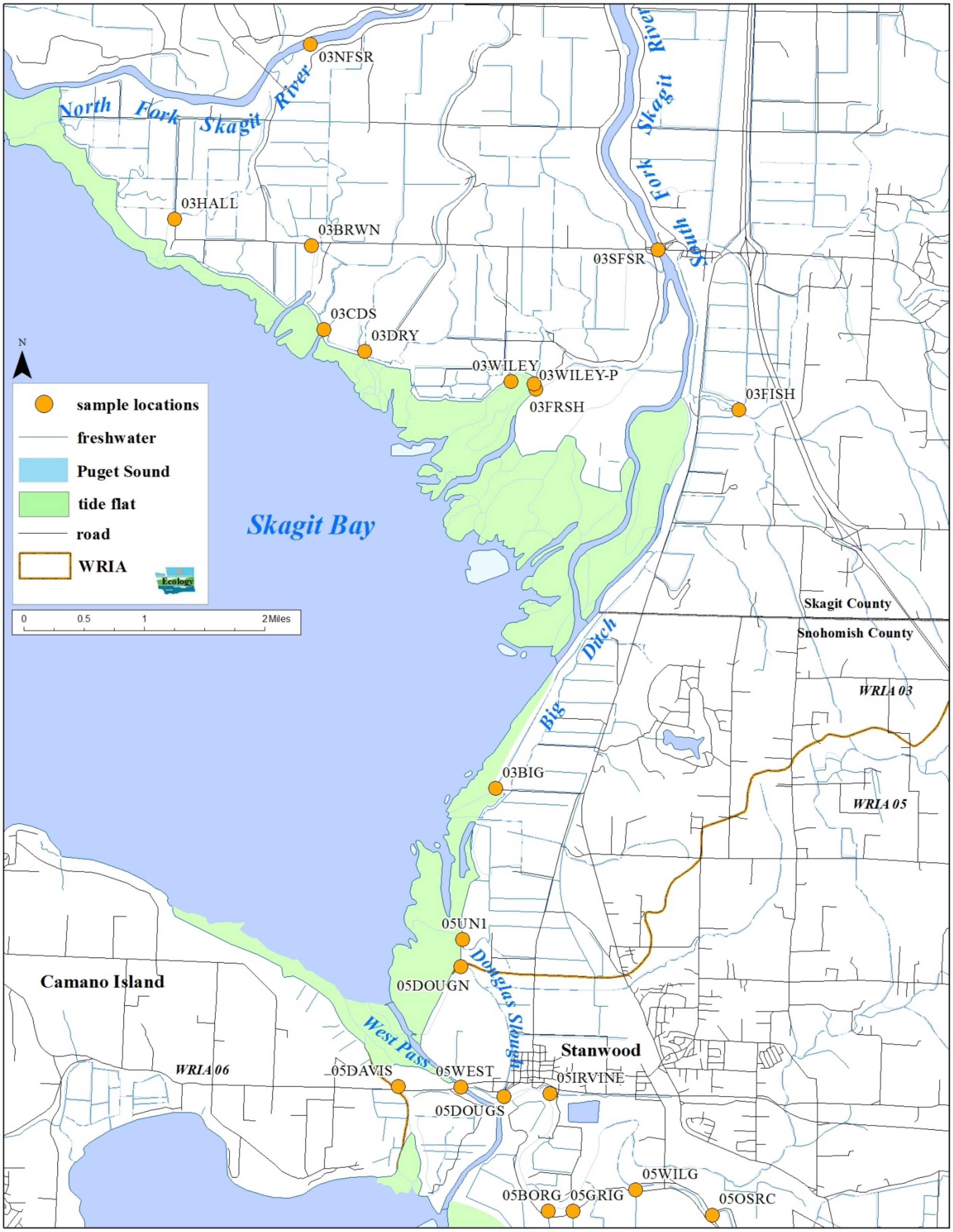

Figure 3. Water quality monitoring locations around Skagit Bay including Watershed Resource Inventory Area (WRIA).

Table 2. Monitoring locations around Skagit Bay.

Latitude and longitude datum are HARN (High Accuracy Reference Network) / NAD83 HARN.

Site ID	Site Description	Latitude	Longitude
03BIG	Big Ditch above tide gate at WDFW area	48.27619	-122.37867
05BORG	Borseth Gate at Thomle Rd.	48.22568	-122.36745
03BRWN	Browns Slough at Fir Island Rd.	48.34081	-122.41409
03CDS	Claude Davis Slough at WDFW refuge	48.33073	-122.41151
05DAVIS	Davis Slough at Hwy 532	48.24002	-122.39491
05DOUGN	Douglas Slough North at Puget Sound	48.25464	-122.38416
05DOUGS	Douglas Slough South at Hwy 532 in Stanwood	48.23914	-122.37582
03DRY	Dry Slough at WDFW refuge	48.3413	-122.39079
03FISH	Fisher Watershed upstream of Pioneer Ave.	48.32366	-122.34361
03FRSH	Freshwater Slough at Wylie Rd. WDFW boat launch	48.32495	-122.37337
05GRIG	Grinde Gate at Thomle Rd.	48.22573	-122.36291
03HALL	Hall Slough at Maupin Rd.	48.34357	-122.43887
05IRVINE	Irvine Slough upstream of pump in Stanwood	48.23968	-122.36756
03NFSR	North Fork Skagit River at Moore Rd.	48.36743	-122.40575
05OSRC	Old Stillaguamish River Channel at Marine Dr.	48.22555	-122.33787
03SFSR	South Fork Skagit River at Fir Island Rd.	48.34134	-122.35087
05UN1	Unnamed Slough 1 next to Douglas Slough North	48.25795	-122.38390
05WEST	West Pass at Hwy 532	48.24018	-122.38358
03WILEY	Wiley Slough at Wylie Rd. WDFW gate	48.32509	-122.37755
03WILEY-P	Wiley Slough pump outfall at Wylie Rd.	48.32487	-122.37339
05WILG	Williams Gate at Thomle Rd.	48.22843	-122.35173

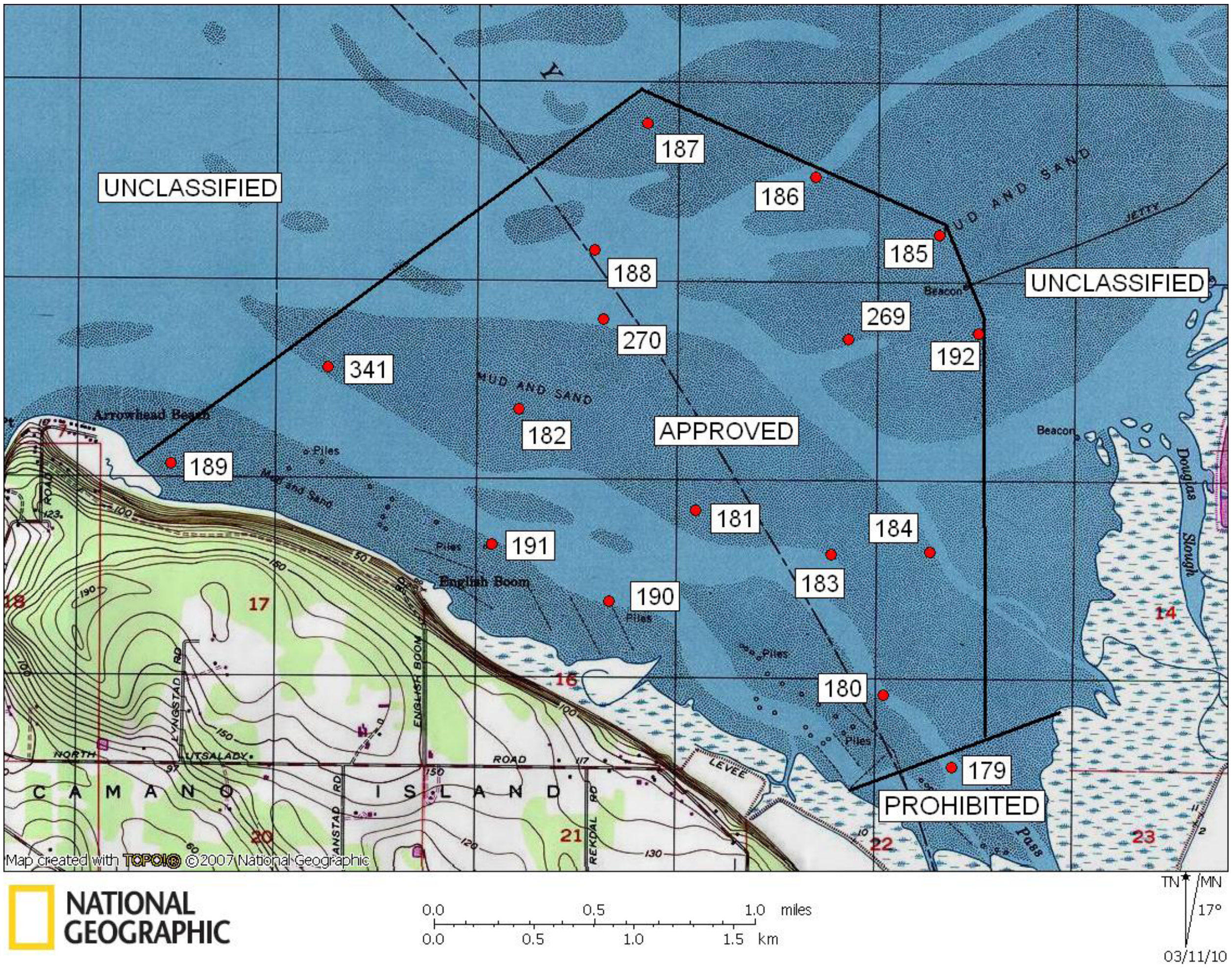

Figure 4. South Skagit Bay FC sampling locations and shellfish harvesting classifications.
Map provided by WDOH (Sullivan, 2010).

Five additional sites were sampled for FC bacteria during the course of the field study. These waterways were sampled in order to either (1) help identify FC sources by bracketing a particular reach, or (2) to collect initial data on an unknown waterway. For example, the investigatory sites on unnamed slough 1 served to bracket the waterway, while site 05UN2 (unnamed slough 2) served as initial data where no follow-up sampling occurred. Figure 5 and Table 3 show the additional sites highlighting the sampling locations. Site 05UN2 empties into the Old Stillaguamish River Channel. Site 05UN1-3 was sampled most frequently of all investigatory sites because bracketing showed reduced FC concentrations upstream (05UN1-4), and the site continued to display concentrations above water quality criteria.

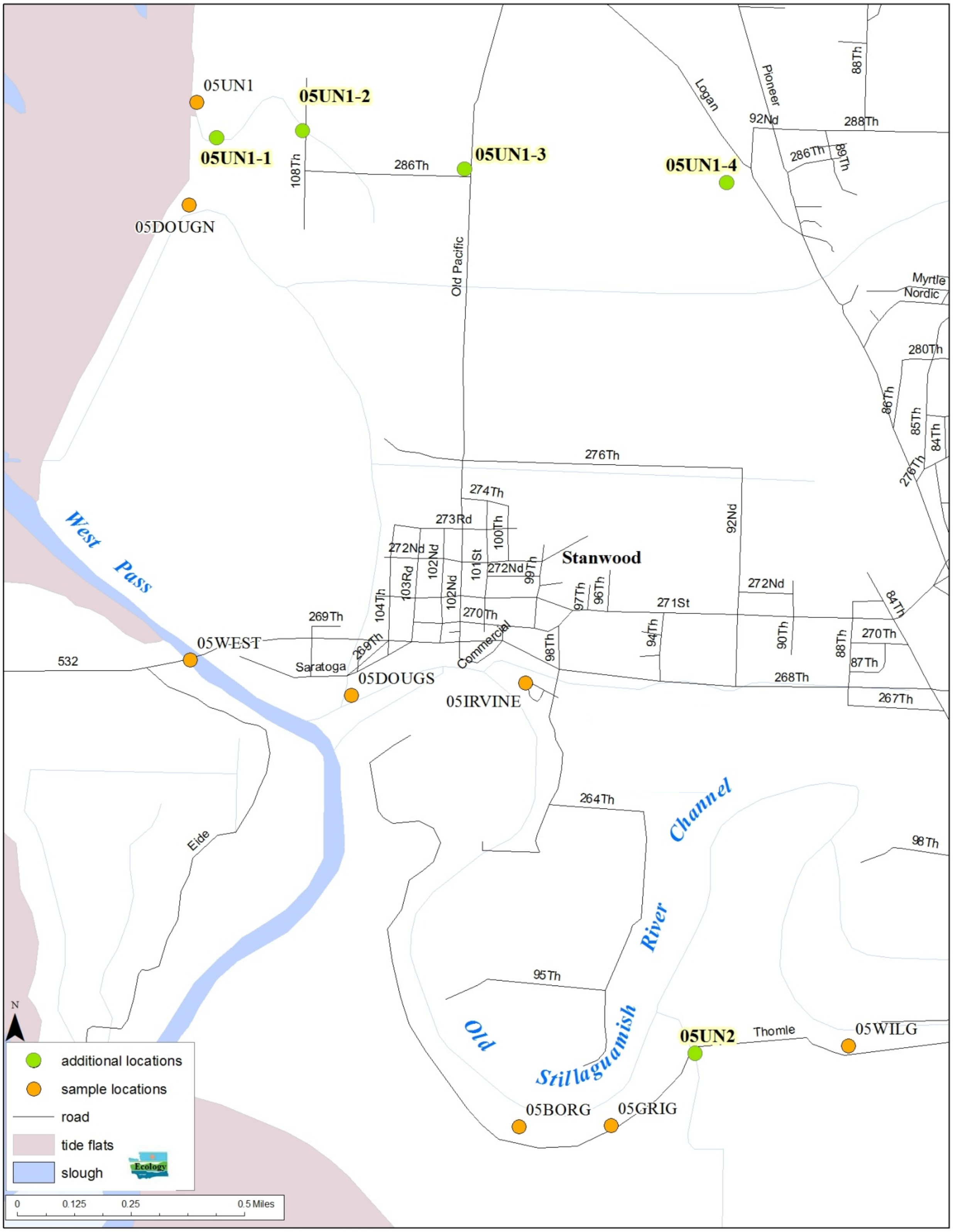

Figure 5. Additional FC sampling locations.

Table 3. Additional FC sampling locations, latitude and longitude datum are HARN.
High Accuracy Reference Network / NAD83 HARN.

Site ID	Site Description	Latitude	Longitude
05UN1-1	Unnamed Slough 1 approximately 300' upstream of UN1	48.25676	-122.38232
05UN1-2	Unnamed Slough 1 upstream of UN1 at 108th	48.25766	-122.37928
05UN1-3	Unnamed Slough 1 at 286th St. and Old Pacific Hwy.	48.25592	-122.37084
05UN1-4	Unnamed Slough 1 approximately 2,200 upstream of UN1-3	48.25586	-122.36154
05UN2	Unnamed Slough 2 at Thomle Rd.	48.22819	-122.35915

Wet and Dry Season Determination

The wet and dry seasons were determined based on average monthly precipitation and WAC recommendations. The WAC Water Quality Standards recommend that a minimum of five samples are needed in order to adequately characterize a single season (WAC 173-201A, 2006). The seasons were distributed equally throughout the year spanning 6 months each. This increases the likelihood of fulfilling WAC requirements since sampling frequency is once per month on average. Approximately 6 samples were collected at the majority of sampling sites per season. For this study, the wet season is from October through March and the dry season is from April through September.

Wet season average precipitation (3.56 inches) is greater than that of the dry season (1.83 inches). Figure 6 shows average precipitation per month. The wet season months individually have higher average precipitation than those of the dry season. These averages are based on a period of record from 1956 to 2005 at Mount Vernon.

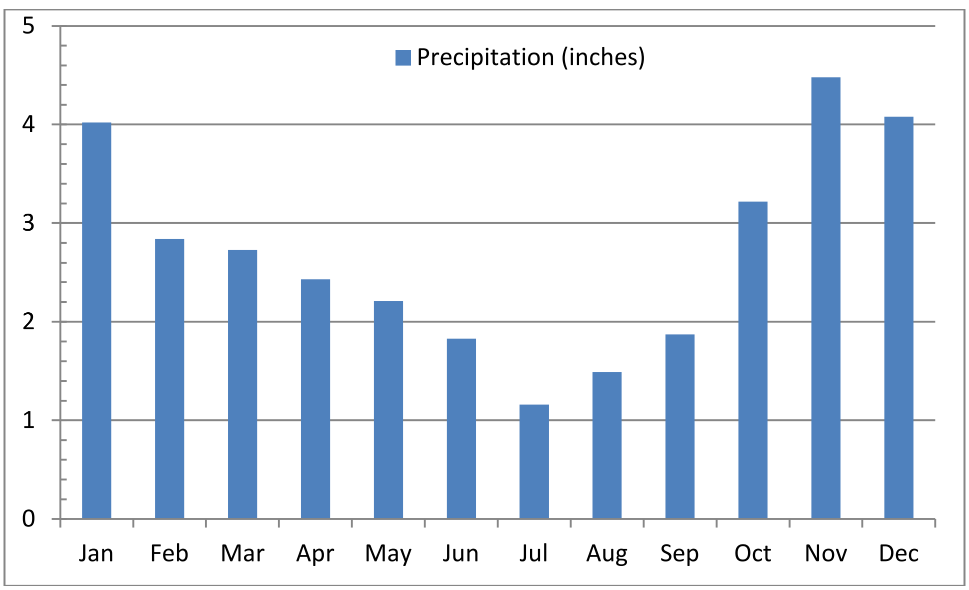

Figure 6. Monthly average precipitation (inches) based on a period of record from 1956 to 2005 at Mount Vernon.
Data provided by the Western Regional Climate Center.

Discharge Assessment

Stream discharge was assessed using a number of techniques including: direct measurements, continuous streamflow records, linear and nonlinear regression analysis, flow duration curves, or antecedent precipitation index regression. Table C-1 provides details of the methods used to assess stream discharge. Direct discharge measurement during the time of sampling was employed when possible. For larger waterbodies such as the Skagit River, the continuous flow gage at Mount Vernon (USGS 12200500) was used to estimate stream discharge during the time of sampling. Literature values were the basis for distributing the mainstem flow between the two Forks where the South Fork conveys roughly 40% of the Skagit River's streamflow, and the North Fork carries the remaining 60% (Williams et al., 1975; and Yang and Khangaonkar, 2008).

Regression analysis was used to estimate the discharge when direct measurements were not possible (Table C-1). Regression analysis involved the mathematical relationship between the observed discharges in Church Creek (independent variable) with the observed discharges in the given waterbodies (dependent variable) for this study to predict a streamflow. Church Creek is a nearby waterbody with a continuous flow gage operated by Ecology (Station ID 05L070). The nonlinear regression formula was then used to predict an estimated flow during times where there was no discharge measurements taken in the field. The continuous flow record on Church Creek was used to estimate discharge in Browns Slough and Douglas Slough North in a few instances when direct measurements were not possible. Discharges in Dry Slough and Claude-Davis Slough were estimated in some instances using a linear regression with Browns Slough.

The Old Stillaguamish River Channel and West Pass discharges were estimated using literature values (Pelletier and Sullivan, 2006) in conjunction with the continuous flow gage at I-5 (Stillaguamish R @ I-5 +SG) operated by Snohomish County. On July 27, 2011 the I-5 flow gage reported artificially high values due to a stream channel bypass and temporary dam construction. In this case a linear regression (Joy, 2004) with the USGS gage on the North Fork Stillaguamish at Arlington (12200500) (independent variable) and the I-5 gage (dependent variable) was used to estimate three stream discharges during August and September 2011 (Table C-1).

Linear regression analysis and ratio comparisons were used between Grinde Gate, Borseth Gate, and Williams Gate to estimate discharge when direct measurements were not possible (Table C-1). Discharge on Williams Gate was measured directly once, resulting in a rough estimate. The channel conditions (soft streambed and steep banks), low velocities, and difficulties obtaining a clean cross-section limited direct discharge measurements on Williams Gate. Furthermore the outfall was inaccessible for direct discharge measurement as was the case for most outfalls in the study area.

Flow duration curves were used to estimate discharge in Big Ditch and Browns Slough when direct measurements were not possible. Historical data from the ongoing United States Department of Agriculture (USDA) pesticide monitoring study were used to develop these flow duration curves. Instantaneous data span from 2006 to 2011. The Browns Slough site for the USDA pesticide monitoring study is the same sample location for this study. The Big Ditch site for the USDA pesticide monitoring study is off Old Pacific Highway in Milltown. The USDA is working with Ecology on the pesticide monitoring study. More information about the study can be found at: www.ecy.wa.gov/programs/eap/toxics/pesticides.htm

In some instances, discharge was estimated by multiple linear regressions to the antecedent precipitation index (API) similar to Pickett, 1997 (Table C-1). The API can be used to estimate rainfall retention and release in natural watersheds (Kohler and Linsley, 1951). The API is a running sum of daily rainfall, calculated by adding each day's rainfall to a fraction "K" of the previous day's API shown in the following equation.

$$I_t = I_0 K^t$$

I_0 is the initial value of the API, I_t is the reduced value after t days, and K is a constant recessive factor (K = 0.8 for this study). Average annual precipitation was used as the initial I_0 value beginning at April 4, 2008 (I_0 = 0.3 inches of precipitation for this study).

Daily rainfall records from Washington State University weather stations in Stanwood and Fir Island were used to calculate API. The runoff for each watershed in units of depth was determined by dividing the discharge by the watershed area (ft^2), and then converting discharge to inches per day.

Fisher Creek and Davis Slough had good relationships with the API (Table C-1). The regression equation between API (independent variable) and Fisher Creek (dependent variable) was applied to Hall Slough, Irvine Slough, Unnamed Slough 1, and Douglas Slough South to estimate discharge. At the time of field data collection the pumps at Irvine Slough were operating twice and the pump at Hall Slough was operating on three occasions. The API regression was used to estimate discharge of the pumps, when in operation, on Hall Slough and Irvine Slough.

Pumping rates were not directly assessed because the outfall gate at the end of the pipe interfered with measuring the necessary parameters to estimate discharge from a pipe. The pump station operation observed over the course of the study was assumed to be representative of the annual or seasonal operation. When the pumps were not in operation, no discharge was assumed and therefore no FC loading.

Discharge was estimated on Wiley Slough (03WILEY-P) at the pump station based on direct measurement downstream of the discharge point and estimated pump capacity including field observations. Wiley Slough at the pump station was operating six times over the course of field data collection. Initially Wiley Slough (03WILEY) was sampled at a location where the water remained stagnant. Another sampling location was established (03WILEY-P) in order to estimate FC loads where discharge occasionally occurred from Wiley Slough to Freshwater Slough.

Discharge was not measured or estimated on Freshwater Slough (03FRSH) or Unnamed Slough 1 (05UN1-3) at Old Pacific Highway. Samples collected near the tide gate on Unnamed Slough 1 (05UN1) were downstream of (05UN1-3) and therefore used to estimate FC loads to Skagit Bay. Freshwater Slough is a branch less than one RM downstream of the South Fork Skagit River. Discharge on Freshwater Slough may be assessed by watershed modeling or by direct measurement using a boat and velocity instruments, both of which were beyond the scope of this project. Samples collected on the South Fork Skagit River were used to estimate FC loads to the bay instead of Freshwater Slough. This was due to the Freshwater Slough sampling location being close to the South Fork Skagit River sampling location and also the lack of flow data on Freshwater Slough.

Results

Data Quality

FC bacteria data followed log normal distribution. All but five FC field replicate pairs met the measurement quality objectives (MQO) described in the Quality Assurance (QA) Project Plan (Kardouni, 2010). Lab duplicates for all parameters met the relative percent difference (RPD) criteria MQO following lab analysis protocols. All dissolved oxygen (DO) field replicates met the MQO criterion. All but two field replicates for nutrients were within the MQOs. Nutrient results are provided in Appendix B, Tables B-1 to B-3.

FC bacteria have a 24-hour holding time when using the filtration method (SM 9222D) or the most probable number method (MPN 9221 E2). In some instances the analysis of FC samples exceeded the holding time by a few minutes to a couple of hours. These samples were identified with the qualifier code 'J' assigned to them, indicating that the value is an estimate since it exceeded the holding time criteria. All estimated FC results are represented in *italics* (Table A-1). These results were used in the final data calculations since the holding time was slightly exceeded resulting as acceptable estimates (Mathieu, 2006). However, all samples collected on March 21, 2011 were omitted from data calculations because the samples were analyzed as much as 48 hours over holding time. Courier service was a day late with delivery to the lab on this particular instance.

Estimated FC results also include instances where > 150 colonies were on the incubation plate. Two or more bacteria could land in the same place during filtration; therefore the true value may be greater than or equal to the reported results. These estimated results were used for final data calculations and indicated in *italics* (Table A-1).

MQOs have been developed by Ecology for analyzing precision in field replicated FC samples (Mathieu, 2006). The MQO for FC bacteria field replicate samples recommend the following criteria: (1) 50% of the replicate pairs are below a 20% relative standard deviation (RSD), and (2) 90% of the replicate pairs are below an RSD of 50%. The RSD is defined as the percent standard deviation divided by the mean or percent coefficient of variation for the replicated QA samples. Typically, none of the samples used to assess the MQO should have a mean concentration of 20 cfu/100mL or less, potentially biasing the RSD high. However, for this study, replicates with a mean concentration < 20 cfu/100mL are included in the analysis since the results did not bias the overall RSD high.

Sample replicate analysis showed that 50% of the field replicates had an RSD of 15.7% meeting the MQO criterion, and 90% of the field replicates had an RSD of 51.4% RSD not meeting the MQO criterion. Only five out of 54 replicated pairs had a QA RSD greater than the 51.4% MQO. These five lab results were qualified as estimates and indicated in *italics* (Table A-1). These results were considered acceptable because the MQO was slightly exceeded.

Ninety percent RSD describes QA results of the higher extremes of field replicate pairs. Data analysis results were not affected by the 90% RSD MQO criterion being exceeded by 1.4%. The 90% RSD MQO estimates the upper extremes of the replicate pair comparison and covers a degree of uncertainty. Differences in replicate QA may be explained by: random errors in sampling, random error in lab analysis, inherent variability when sampling and analyzing bacteria, or increased error during laboratory analysis when bacteria counts are extremely high and difficult to decipher when crowded or stacked on the media plate as in the case where > 150 colonies on a single incubation plate.

MF and MPN FC samples were collected side by side at a limited number of sites in order for comparison. Results showed a positive correlation (r^2=0.67) between MF and MPN methods. However insufficient data were collected due to laboratory time constraints and limited sample design to develop a sufficient regression between the two methods. Instead, MF samples from freshwater sources and MPN samples from Skagit Bay were compared using freshwater loading and Skagit Bay median concentrations as shown in the *Discussion* section of this report.

Water Quality Summary Results

Water quality summary statistics were compared with Washington State criteria such as the geometric mean and the 10% of data not to exceed (Table 4). FC concentrations were reported using colony forming units (cfu)/100mL. Marine water quality criteria applied to Browns Slough, Hall Slough, Davis Slough, Douglas Slough, Unnamed Slough, and West Pass based on either observed salinity during the time of sampling or established data, as in the case of Browns Slough (Sargeant and Anderson, 2010). Freshwater water quality criteria applied to all other monitoring locations. The 90th percentile provides a margin of safety (MOS) taking in variability and uncertainty and tends to be more conservative than the geometric mean. The MOS is the means by which the analysis accounts for the uncertainty about the relationship between pollutant loads and the receiving water quality.

FC results for each day of sampling are presented in Appendix A, Table A-1. Figures 7 and 8 are box plots showing the distribution of summary statistics by sampling location with each figure grouped by WRIA.

FC data collected from September 2010 through September 2011 indicated that 16 out of the 22 sampling locations, (73%) exceeded one or more FC water quality criterion. A total of 26 locations were sampled. However, there were insufficient data to calculate water quality statistics on 4 of the 26 sampling locations. These four sites were investigatory, having one sample per site (Table A-1).

Table 4. Statistical summaries of FC samples (colonies/100mL) collected from sites around Skagit Bay from September 2010 through September 2011.

Station ID	Number of samples (n)	Geometric mean	Exceed 10% WQ criterion (%)	90th percentile	Maximum	Minimum
03BIG	12	62	**17**	284	**380**	6
03BRWN*	13	**93**	**69**	697	**1300**	6
03CDS	12	96	**17**	451	**1000**	8
03DRY	12	85	**33**	441	**1500**	13
03FISH	10	41	**10**	250	**360**	6
03FRSH	13	15	8	103	**240**	2
03HALL*	13	**24**	**46**	268	**510**	1
03NFSR	13	6	—	48	100	1
03SFSR	13	14	—	89	170	2
03WILEY	6	36	—	146	180	11
03WILEY-P	8	63	—	180	140	20
05BORG	12	44	**17**	259	**280**	3
05DAVIS*	12	**41**	**50**	458	**4200**	3
05DOUGN*	12	**142**	**75**	553	**1400**	37
05DOUGS*	10	**86**	**70**	999	**810**	4
05GRIG	11	43	**18**	532	**1500**	1
05IRVINE	12	**364**	**67**	2070	**3300**	67
05OSRC	11	54	9	188	**250**	9
05UN1*	11	**660**	**91**	8746	**14000**	40
05UN1-3	5	**7576**	**80**	73805	**130000**	200
05WEST*	12	**100**	**67**	632	**1800**	15
05WILG	12	**291**	**50**	2501	**4600**	25

Bold values exceed Washington State water quality criteria
* Marine water quality criteria apply
Marine criteria: geometric mean < 14 colonies/100mL, not more than 10% of all samples > 43 colonies/100mL

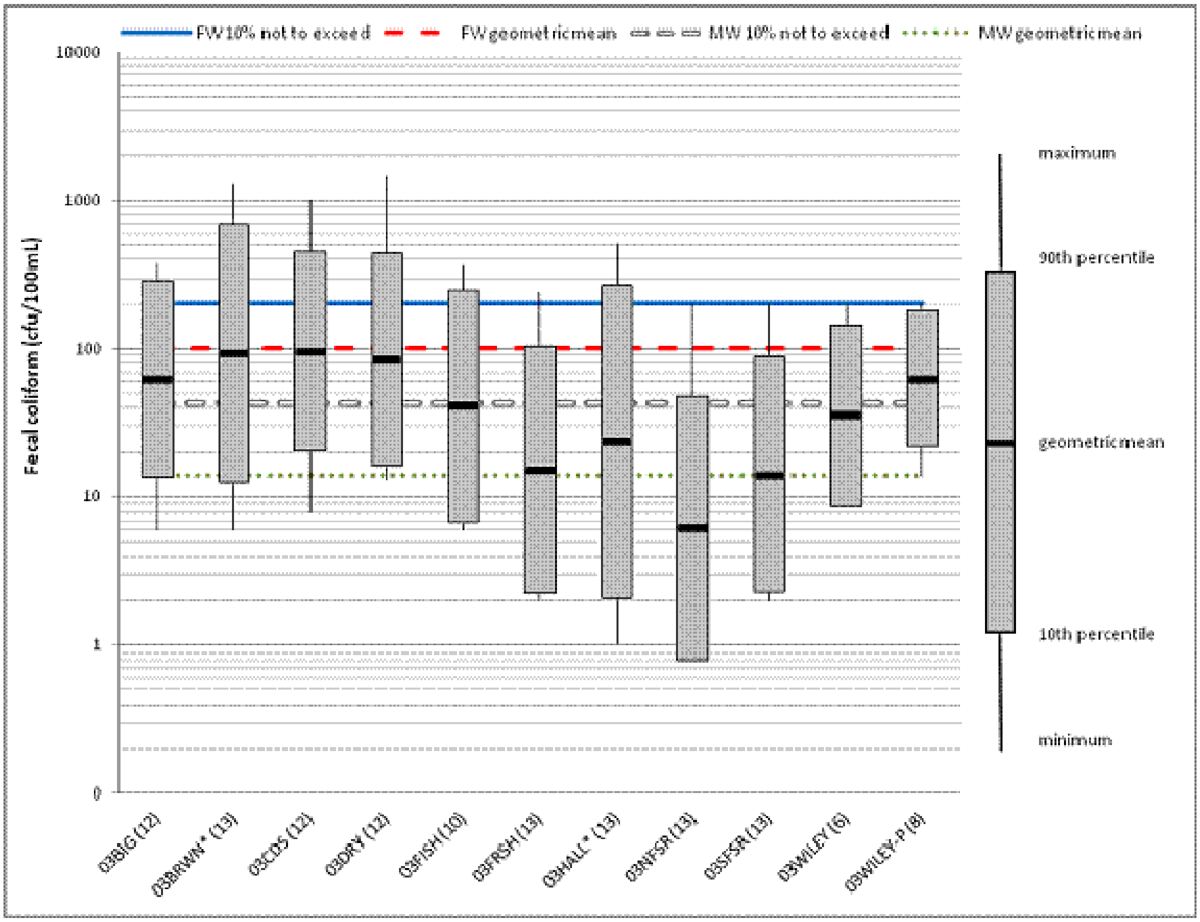

Figure 7. WRIA03 graphical summary of FC data collected from September 2010 through September 2011.

The number of samples (n) is indicated next to the site ID at the bottom of the chart.
Freshwater (FW) and Marine water (MW) water quality criteria are provided.
** indicates where marine water quality criteria apply.*

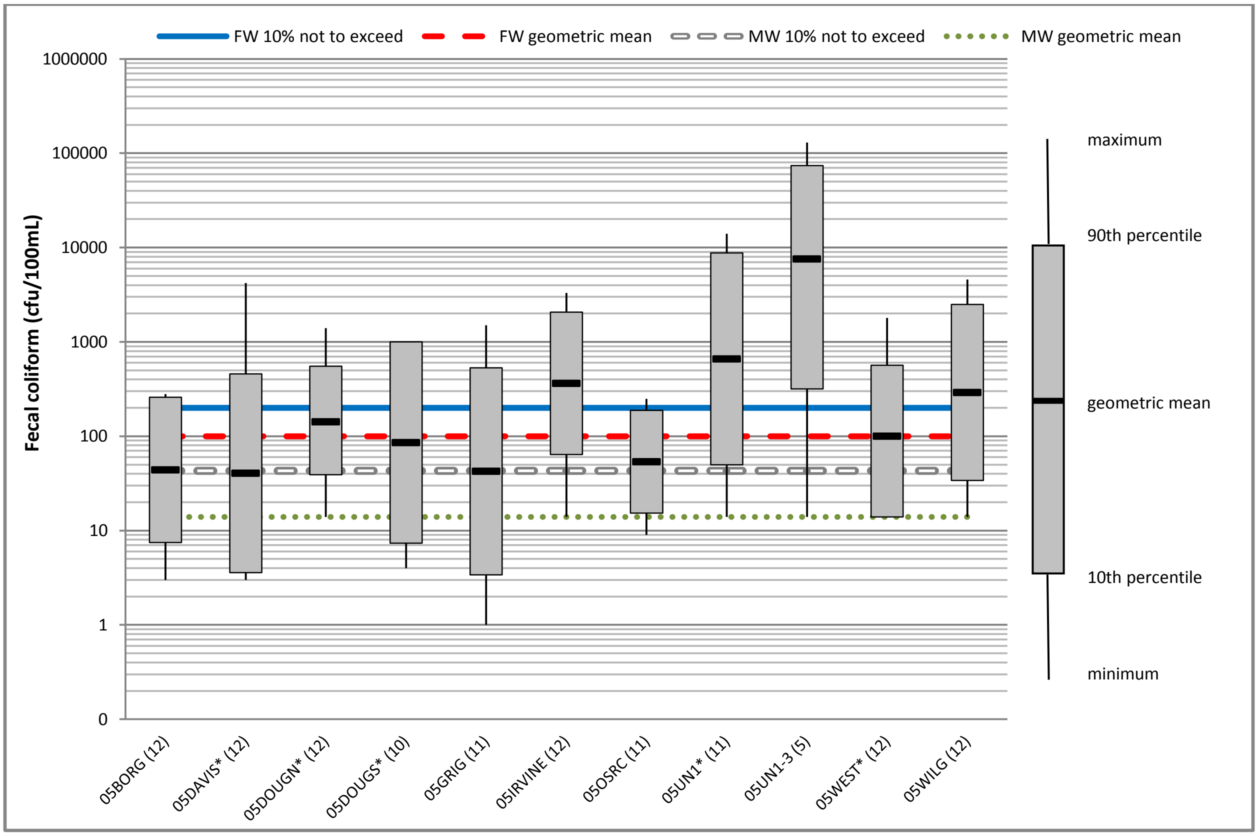

Figure 8. WRIA05 graphical summary of FC data collected from September 2010 through September 2011.

The number of samples (n) is indicated next to the site ID at the bottom of the chart.
Freshwater (FW) and Marine water (MW) water quality criteria are provided.
** indicates where marine water quality criteria apply.*

Unnamed Slough 1 (05UN1-3) had the highest FC levels for all categories including geometric mean, 10% not to exceed, maximum, and 90th percentile. The North Fork of the Skagit River (03NFSR) had the lowest FC levels including geometric mean, 10% not to exceed, maximum, and 90th percentile. Cells with no values in Table A-1 indicate one or more of the following:

1. No sample was taken due to limiting factors during sampling – such as tidal interference, insufficient water depth, or on-site construction.
2. The sampling site was yet to be established or it was relocated.
3. The time taken to process the sample in the lab far exceeded the holding time.
4. There were an insufficient number of samples taken at that location to calculate water quality criteria statistics.

For this study the wet season was from October through March and the dry season was from April through September. From 2010 - 2011 the wet season average precipitation is 4.00 inches and the dry season average precipitation is 1.74 inches. Figure 9 shows the monthly average precipitation over the course of this study (2010 - 2011) compared to the long-term average precipitation (1956 - 2005). The wet season for this study year had a greater average than the long-term record with 4.00 inches and 3.56 inches respectively. The dry season average for this study year had a lower average than the long-term record with 1.74 inches and 1.83 inches respectively.

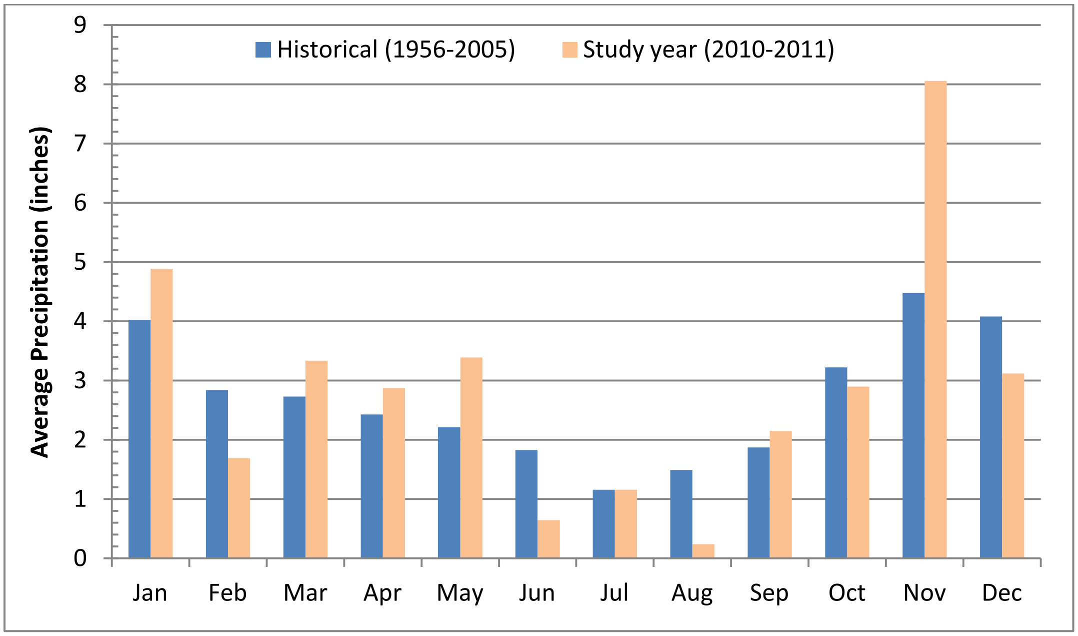

Figure 9. Monthly average precipitation at Mount Vernon for the study year (2010 - 2011) compared to the long-term (1956 - 2005).

The wet/dry season FC geometric means were compared (Figure 10). Sixteen out of 22 sites had sufficient data to characterize a single season. The WAC water quality protocols recommend that a minimum of five samples are needed in order to adequately characterize a single season (WAC 173-201A, 2006). Sites that did not have five or more samples during a single season were not included in Figure 10 such as: Wiley Slough (03WILEY and 03WILEY-P), Douglas Slough South (05DOUGS), Grinde Gate (05GRIG), and Unnamed Slough 1 (05UN1 and 05UN1-3). Thirteen out of the 16 sites with sufficient data showed dry season FC concentrations were greater than wet season concentrations.

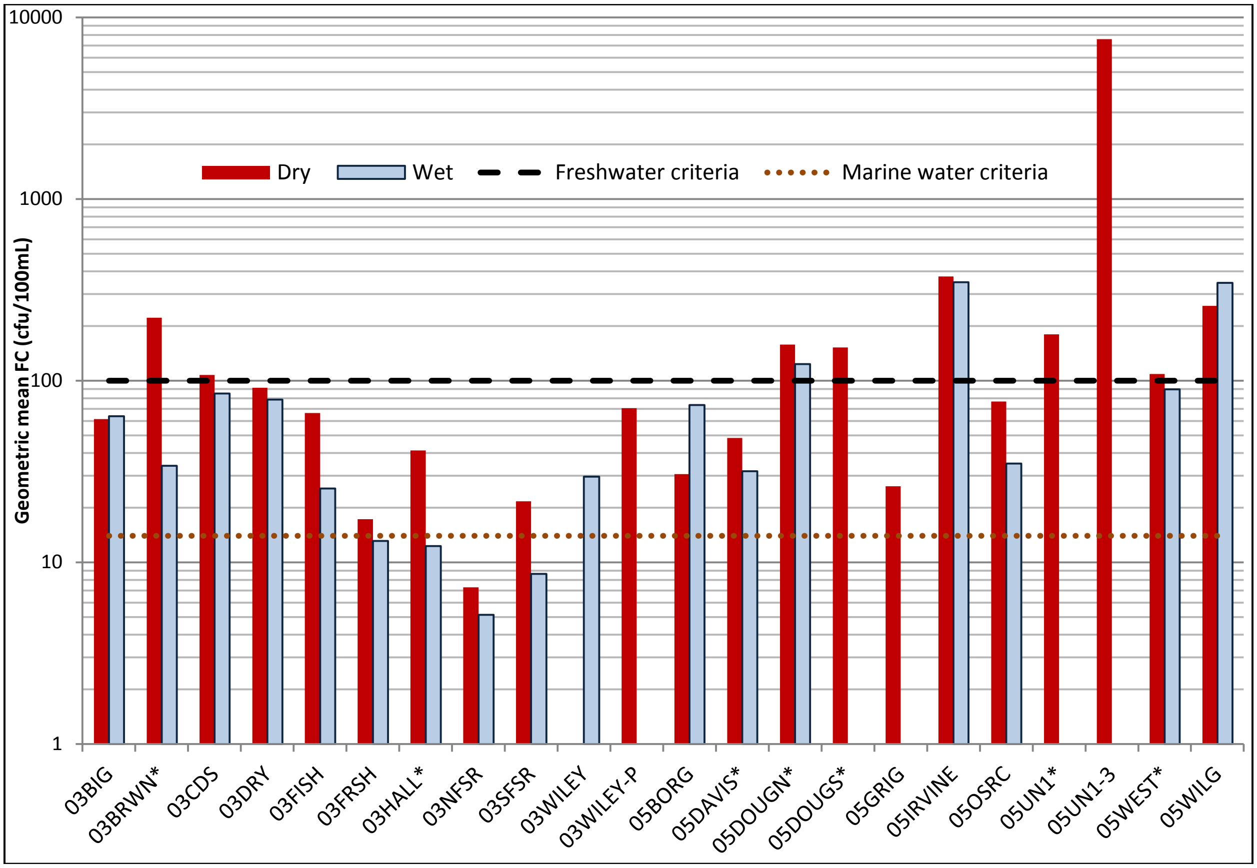

Figure 10. Seasonal comparison of the geometric means of data collected from September 2010 through September 2011 where the wet season is from October through March and the dry season is from April through September.

FC water quality criteria are provided for both freshwater and marine water.
** indicate marine water quality criteria apply.*

Loading Results

FC bacteria load estimates were calculated by multiplying FC concentration by stream discharge and then converting to daily values (billion cfu/day). The 90th percentile MOS was not used for estimating daily loading values because the observed FC concentrations at the time of sampling provide a more complete assessment of annual and seasonal variability. Loading has a direct relationship with streamflow given the same FC concentration. Streams with higher flow will carry higher loads than that of a stream with lower flow, where both streams have the same pollutant concentrations.

Table 5 and Figure 11 synonymously show FC loads averaged over the entire year (annual) and by season (wet and dry). The Skagit River (03NFSR and 03SRSR) contributes the highest FC loading to Skagit Bay followed by West Pass (05WEST). The Skagit River contributes the greatest FC loads to Skagit Bay because of its high volume of streamflow despite having the lowest FC concentrations. Freshwater Slough and Unnamed Slough at Old Pacific Highway (05UN1-3) had no streamflow results associated with the FC concentrations and therefore no loads were estimated. Appendix A, Table A-2 shows FC load estimates for each sampling day at each site.

A few sampling locations had stagnant water during some of the sampling events such as Irvine Slough, Hall Slough, Unnamed Slough 1, Douglas Slough, Wiley Slough, and Williams, Borseth, and Grinde Gates. Stagnant waterways were assumed to contribute zero loads to Skagit Bay since the water was not flowing into the bay (Table A-2). Stagnant waterways therefore decreased the overall FC loading estimates to Skagit Bay. Factors causing waterway stagnation vary, but may include: base flow, tide cycles, tide gate operations, pump station operations, and irrigation. Estimated loads reflect the actual nature of the waterbodies during the time of sampling.

Table 5. Average annual, wet season (October - March) and dry season (April - September) FC load summary for data collected from September 2010 through September 2011.

Site ID	Average FC load (billion cfu/day)		
	Annual	Wet Season	Dry Season
03BIG	238	391	124
03BRWN	38.5	27.3	47.0
03CDS	71.9	146	16.3
03DRY	145	171	125
03FISH	132	192	87.4
03FRSH	no data		
03HALL	1.23	2.87	0
03NFSR	6431	5437	7177
03SFSR	8793	7142	10031
03WILEY	no data	0	no data
03WILEY-P	11.3	13.1	10.0
05BORG	0.78	0.52	0.97
05DAVIS	101	6.78	172
05DOUGN	13.2	11.5	14.5
05DOUGS	3.69	0.91	5.78
05GRIG	0.41	0.48	0.36
05IRVINE	26.9	62.7	0
05OSRC	1620	2179	1200
05UN1	98.9	219	8.59
05UN1-3	no data		
05WEST	2666	5304	689
05WILG	20.2	3.87	32.4
Total	20406	21311	19726

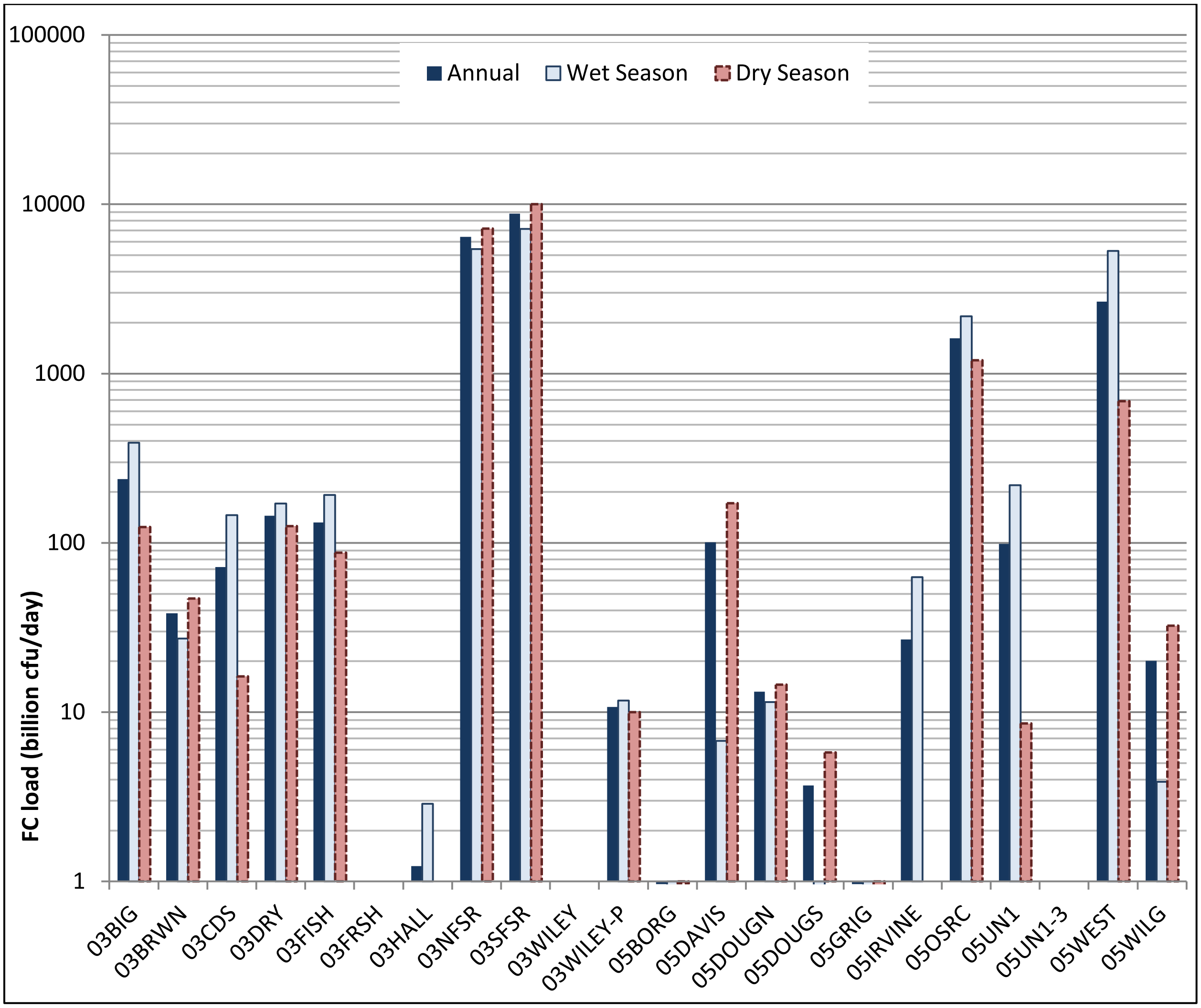

Figure 11. Average annual, wet season (October - March) and dry season (April - September) FC load comparisons for data collected from September 2010 through September 2011.

Discussion

Fecal Coliform Loading Assessment

The following assessment estimates FC loadings to Skagit Bay. Ecology evaluated loadings annually and seasonally, based upon observed FC concentrations, observed stream discharges, and estimated stream discharge at the time of sampling. Average loading was estimated by dividing the estimated total load per season or year by the total number of samples taken during the specified time. The relatively short duration of the study, the complexity of the drainage management system (pump stations, flow control structures) and the width and depth of the watercourses affected our ability to determine loading values with precision.

In addition, many sites assessed during this study were not direct contributors to Skagit Bay. For example discharge from Williams Gate must first travel in the Old Stillaguamish River Channel before reaching the bay via West Pass. With the exception of the discussion of Old Stillaguamish River Channel values, sites that did not directly discharge to Skagit Bay were omitted from the percent loading contributions and discussed separately in the section *Old Stillaguamish River Channel and West Pass Fecal Coliform Loading* section below.

FC loading was compared with meteorological precipitation data in order to assess the potential for stormwater runoff conveyance of FC. The *Precipitation and Fecal Coliform Loading* section of this report describes the relationship between FC concentrations and precipitation.

Nutrient and FC samples were also collected during storm events for three of the four calendar seasons including winter, summer, and fall. All but the spring season was captured. Nutrient data were not related to FC concentrations, but were rather collected for Puget Sound monitoring that is beyond the scope of this study. Storms results captured during regularly scheduled sampling in December (winter) and September (fall) were included in the seasonal and annual statistical calculations. However, the August 23 storm results were not included in statistical calculations. This was a targeted summer storm that did not occur on a scheduled sampling event. Sample results outside of scheduled sampling may bias statistical results.

Fecal Coliform Loading to Skagit Bay

Over the one-year study period (2010 – 2011), the North and South Forks of the Skagit River were the highest sources of bacteria loads to Skagit Bay, accounting for 81% of annual FC loadings (Figure 12). This is explained by the large volume of discharge from the Skagit River. The two Skagit River forks had the lowest geometric means and 10% not to exceed results (Table 4) of all the sites monitored during the study. West Pass (05WEST) contributes 14% of the annual FC loadings to the bay. Together, these three large sources accounted for 95% of the total FC loads over the year with all other major inputs accounting for about 5% of FC loading.

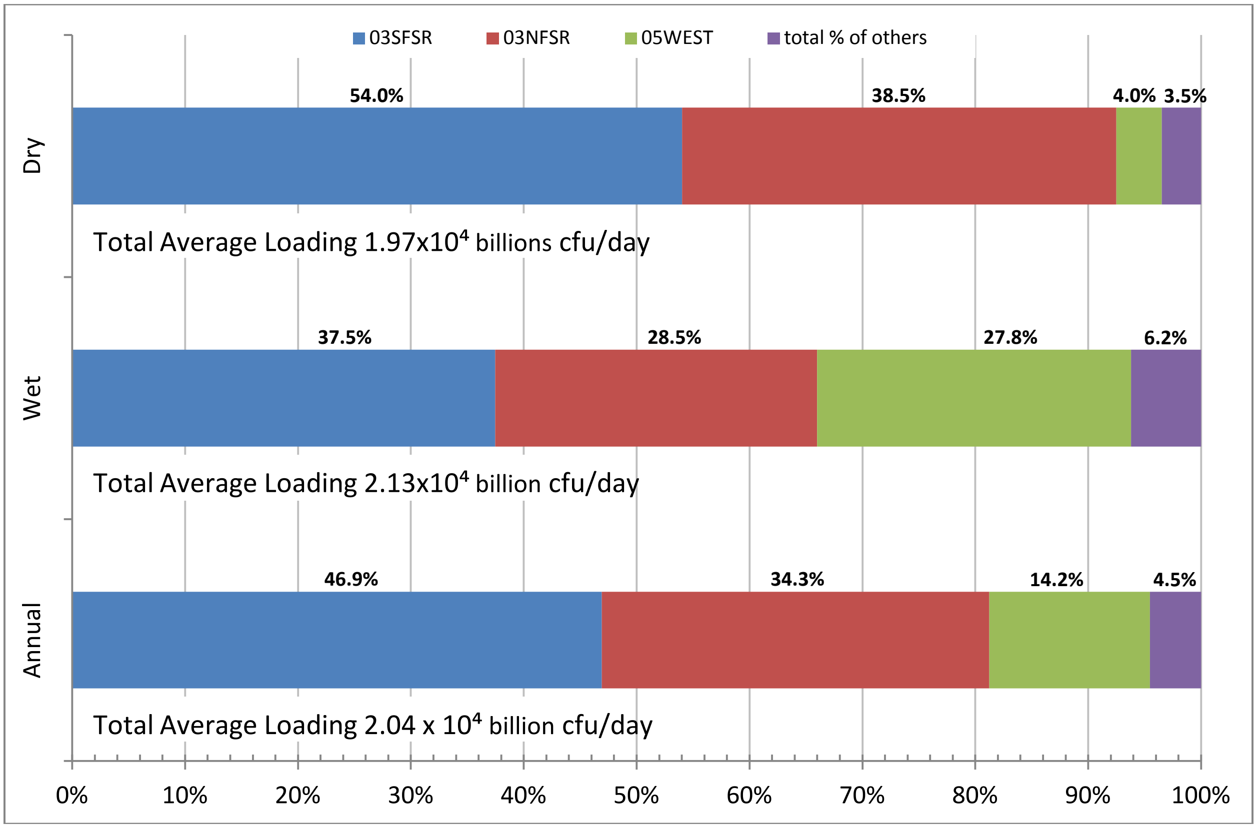

Figure 12. 2010 - 2011 FC colony forming units (cfu) and percent loading contributions to Skagit Bay segregated by annual, wet season (October - March), and dry season (April - September).

Of the remaining FC loading contributions to Skagit Bay, Big Ditch accounted for the highest followed by Dry Slough, Fisher Creek, Davis Slough, Unnamed Slough (05UN1), and Claude-Davis Slough (Figure 13). The pump at Hall Slough was discharging to Skagit Bay on three out of 14 occasions during the time of sampling. Hall Slough pump discharges were observed during the wet season only; therefore, the dry season shows no contributions. The pump at Wiley Slough was discharging to Skagit Bay via Freshwater Slough on seven out of ten occasions during the time of sampling.

Pump operations on Hall Slough, Irvine Slough, Williams Gate, and Wiley Slough influences the potential for FC loading to Skagit Bay. No loading to the bay is assumed when pumps are not running indicated in Table A-2 with a “0” value. Oppositely, when the pump is discharging, loading to the bay occurs. Pumps are designed to discharge excess freshwater to improve drainage and reduce flooding along the sloughs and adjacent land. Over the course of field sampling, the pumps were discharging more often during periods of extended rain particularly in the wet season (October - March).

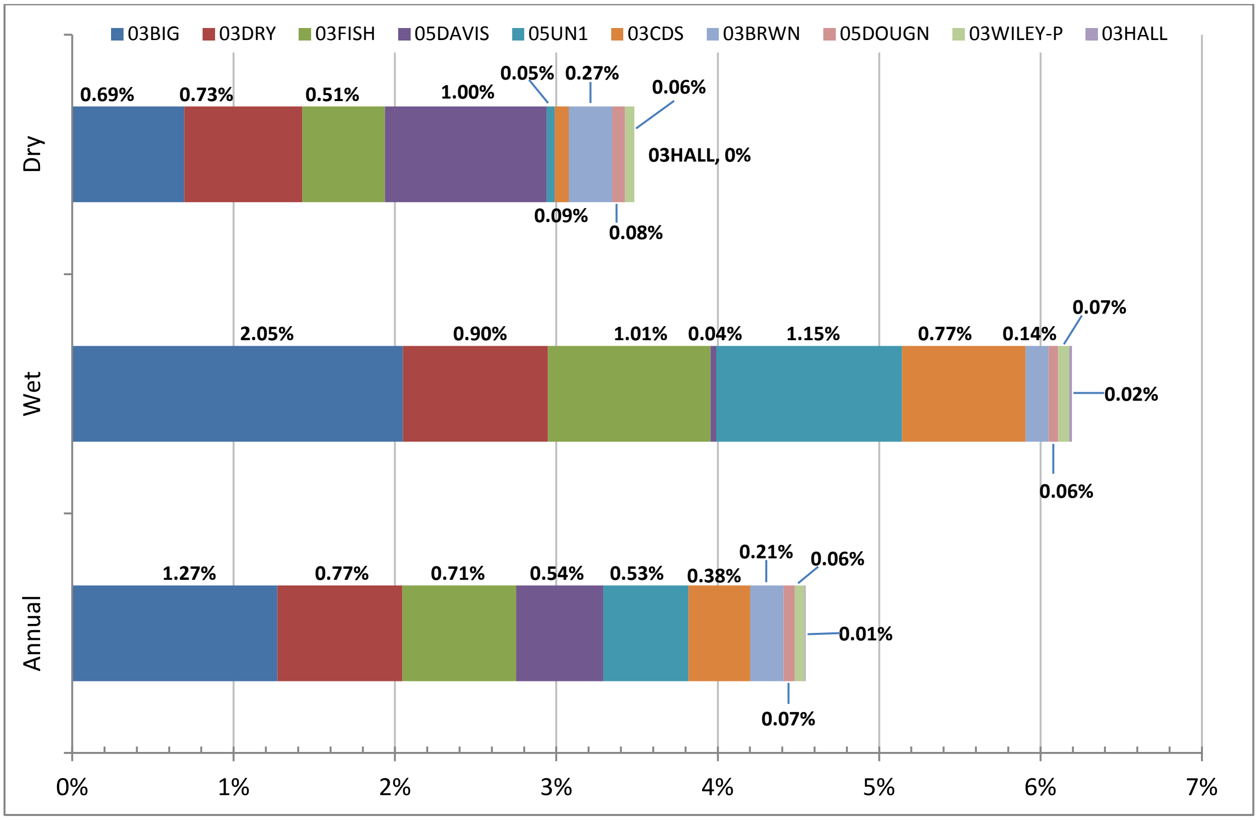

Figure 13. 2010 - 2011 FC percent loading contributions for sites with 2% or less of the overall loading to Skagit Bay segregated by annual, wet season (October - March), and dry season (April - September).

Wet and Dry Season Loading

Wet Season Base Loadings

The combined average FC loadings from all sources during wet weather (2.13×10^4 billion cfu/day) exceeded the annual loading value (2.04×10^4 billion cfu/day) (Table 5 and Figure 12). The North and South Forks of the Skagit River continued to contribute the highest overall loadings to Skagit Bay at 28.5% and 37.5% of total loadings, respectively (Figure 12). Each of these two watercourses continued to meet both of the state criteria for bacteria. West Pass was again the third largest contributor of bacteria at a much higher value of 27.8% of the total loading to the bay. The combined input of all other sources measured was higher (6.2%) during wet weather as compared to the annual loading (4.5%) value for those sources.

Dry Season Base Loadings

During the dry season, the North and South Forks of the Skagit River continued to contribute the highest overall loadings to Skagit Bay at 38.5% and 54% of total loadings, respectively (Figure 12). Each watercourse continued to meet both of the state criteria for bacteria. West Pass was again the third largest contributor of bacteria at a lower 4% value. The estimated daily load of 1.97×10^4 billion cfu/day was very close to the 2.04×10^4 billion cfu/day measured on an annual basis (Table 5 and Figure 12). The combined input of the three major FC sources during dry weather is 96.5%. Inputs from all other sources measured was slightly lower (3.5%) during dry weather as compared to the annual loading (4.5%) value for those sources.

The Old Stillaguamish River Channel exhibited loads nearly twice as high as West Pass (54% higher) (Table 5). These higher FC loadings at 05OSRC are entering the Old Stillaguamish River Channel all along the channel, both upstream and downstream of Marine Drive.

During the dry season a backflow prevention gate is activated in the Old Stillaguamish River Channel near its confluence with the mainstem Stillaguamish River upstream of the sampling location at Marine Drive. The gate reduces the back and forth movement of tidal waters in the Old Stillaguamish River Channel and promotes the forward movement of freshwaters to West Pass. Even with the gate in place, however, the Old Stillaguamish River Channel at Marine Drive will back up and flow in the opposite direction under low flow flood tide conditions. This means that loadings from Irvine Slough, the various smaller left bank discharges (Williams, Borseth, and Grinde Gates), Church Creek, and Miller Creek could be represented to some extent when backwatering conditions arise.

Old Stillaguamish River Channel and West Pass Fecal Coliform Loading

West Pass loading values were largely regulated by bacteria levels in the Old Stillaguamish River Channel. Approximately 20% of the Old Stillaguamish River Channel discharges to South Skagit Bay through West Pass (Pelletier and Sullivan, 2006). The farthest upstream contribution to West Pass is represented by the Old Stillaguamish River Channel (05OSRC) at Marine Drive. There are approximately 4.7 RMs between the sampling locations in the Old Stillaguamish River at Marine Drive and West Pass at Highway 532. West Pass had roughly 50% higher annual loading than the Old Stillaguamish River Channel, including 84% higher loading during the wet season and 54% lower loading during the dry season. The Old Stillaguamish River Channel had roughly 35% higher FC loading.

The comparison between West Pass and the Old Stillaguamish River Channel suggest that increased precipitation during the wet season increases bacteria loading from nearby adjacent land use. Extremely high loading was observed at West Pass during the December flood which may have caused the wet season loading results to collectively surpass that of the dry season (Table A-2). Furthermore Table A-2 shows that the Old Stillaguamish River Channel typically has higher daily loading estimates than West Pass. The daily load estimate was calculated by multiplying the FC concentration by the waterbody discharge at the time of sampling.

Potential discharges affecting FC bacteria loading along the 4.7 mile reach between the Old Stillaguamish River Channel and West Pass include: Williams Gate, Borseth Gate, Grinde Gate, Irvine Slough, Douglas Slough South, Unnamed Slough 2, and Stanwood WWTP.

According to Discharge Monitoring Reports over the past five years, the Stanwood WWTP met water quality permit criteria of less than 200 cfu/100mL geometric mean, and less than 400 cfu/100mL weekly geometric mean. Although this facility meets its permit requirements (Permit Number WA0020290), loading from the Stanwood WWTP is unknown and until such time, loadings may not be considered negligible. The permit states that the outfall discharges into marine waters at RM 4.1 of the Old Stillaguamish River. The discharge outfall is approximately 30 feet offshore when the tide is at mean sea level, and approximately 10 feet below mean lower low water level.

Effects of Precipitation

We further analyzed these data to characterize storm/precipitation and its effects on the water quality with respect to FC. Ecology considered the watershed to be experiencing a storm event using three criteria: (1) local meteorological precipitation data (2) antecedent precipitation levels, and (3) antecedent/ongoing rises in flow.

Table 6 shows the effects of precipitation on FC concentrations and loading categorized by the three-day cumulative precipitation totaling the day before sampling and the two days of sampling. FC concentrations geometric means were calculated for each precipitation category for each sampling location. The discharge multiplied by the FC concentration at the time of sampling was used to estimate loading for each precipitation category. The results suggest that precipitation increased FC concentrations and loading by conveying bacteria to receiving waterways. The precipitation values in Table 6 are daily totals averaged from two weather stations. One station is located in Stanwood and the other is on Fir Island. Both stations are operated by Washington State University.

05UN1-3 is the only site that experienced higher FC geometric mean concentrations during times when <0.2 inches of precipitation fell during the time of sampling (Table 6). This may be explained by high concentrations of 130,000 and 60,000 FC cfu/100mL collected during time of little to no precipitation. Unnamed Slough at Old Pacific Highway may have FC pollution sources that contribute significantly during times of little to no precipitation. In other words Unnamed Slough may have a steady pollution source where stormwater runoff is not the primary mechanism for increased FC concentrations. More information is necessary to target the cause and nature of the FC concentration characteristics of Unnamed Slough particularly at Old Pacific Highway.

Figure 14 shows daily average precipitation plotted with the Skagit River daily average discharge from September 2010 through September 2011. Sampling dates are included to illustrate the nature of precipitation and streamflow over the course of sampling.

Table 6. The effects of three-day cumulative precipitation on FC concentrations and loading during the time of sampling, from September 2010 - September 2011.

Station ID	Precipitation <0.2 inches (n=6)		Precipitation >0.2 inches (n=7)		Does precipitation cause higher FC loading or geometric means?
	Geometric means*	Average loading**	Geometric means*	Average loading**	
03BIG	27	30	135	449	yes
03BRWN	63	16	150	62	yes
03CDS	60	13	206	153	yes
03DRY	40	14	189	325	yes
03FISH	25	21	86	349	yes
03FRSH	5	no data	48	no data	yes
03HALL	15	0.08	48	2.4	yes
03NFSR	2	1058	21	11282	yes
03SFSR	6	1506	36	15397	yes
03WILEY	15	no data	87	no data	yes
03WILEY-P	49	10	90	27	yes
05BORG	26	0.41	53	1.3	yes
05DAVIS	13	2.9	77	200	yes
05DOUGN	82	3.8	246	23	yes
05DOUGS	40	0.59	198	6.5	yes
05GRIG	17	0.01	69	0.82	yes
05IRVINE	164	0	949	54	yes
05OSRC	41	484	75	3356	yes
05UN1	329	32	694	175	yes
05UN1-3	11598	no data	1474	no data	no
05WEST	59	289	123	5125	yes
05WILG	133	3	453	38	yes

* geometric mean of FC (colony forming units (cfu)/100mL)
** FC loading (billion of cfu/day)
n = number of sampling events

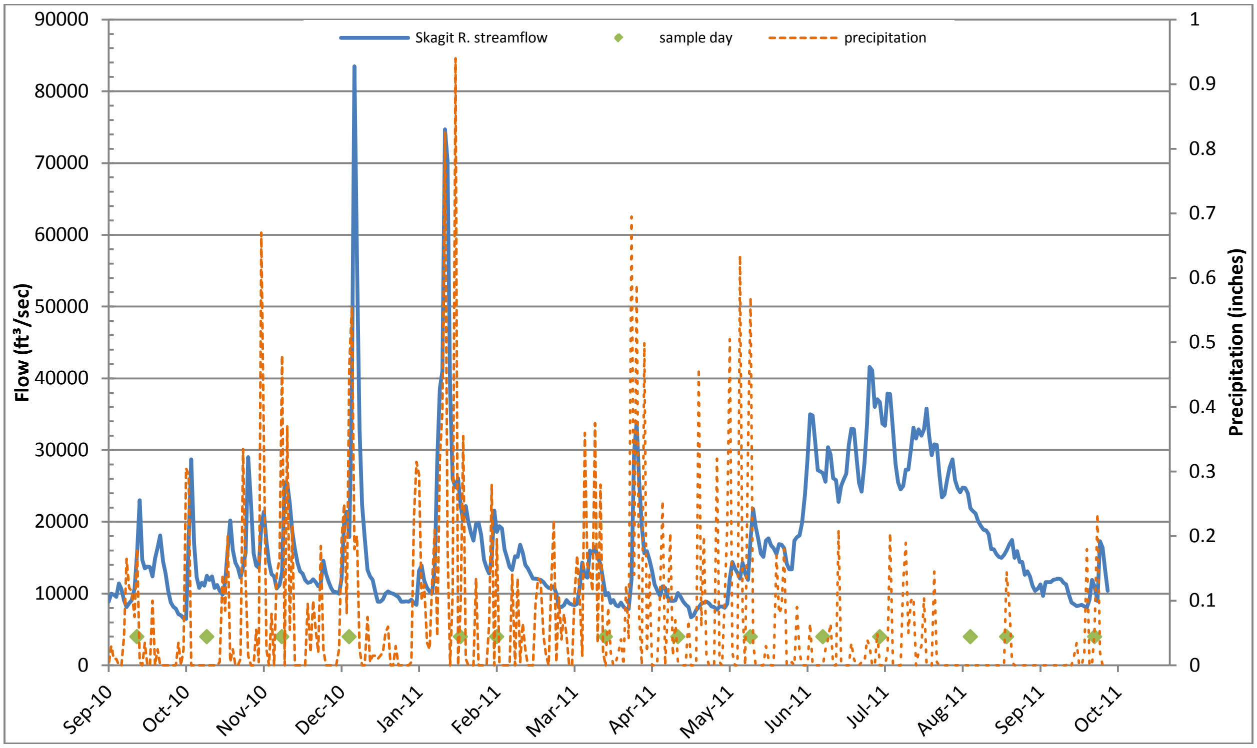

Figure 14. Daily average precipitation, Skagit River discharge, and sampling dates from 2010 to 2011.

One objective of this study was to capture data from one storm event per calendar season such as fall, winter, spring, and summer for nutrients. We were able to capture three storm events (we did not capture a spring storm event), and sampled both nutrients and FC were sampled during these events. Storms were captured during regularly scheduled sampling in December and September (Tables 6 and A-1). These results were included in the statistical calculations. However, the August 23 storm results were not included in the FC water quality statistical calculations and loading estimations. The August storm was a targeted summer storm that did not occur on a scheduled sampling event. Sample results outside of scheduled sampling may bias statistical results. Table B-1 of Appendix B shows the nutrient and FC results for storm sampling.

Figures 15 - 17 show precipitations plotted over hydrographs in order to check the timing and magnitude of runoff relative to the targeted seasonal storm sampling. The figures show sampling occurred on the rising limb of the hydrograph when precipitation caused a rise in local rivers and streams. The December storm sampling occurred over a two-day period. Samples were collected in WRIA05 (Stillaguamish watershed) on day one of sampling just before the valley flooded. Samples were collected primarily in WRIA03 (Lower Skagit) on day two when both the Skagit River and Stillaguamish River topped flood stage. The August and September storm events were not during flood or near flood conditions of the Skagit or Stillaguamish Rivers.

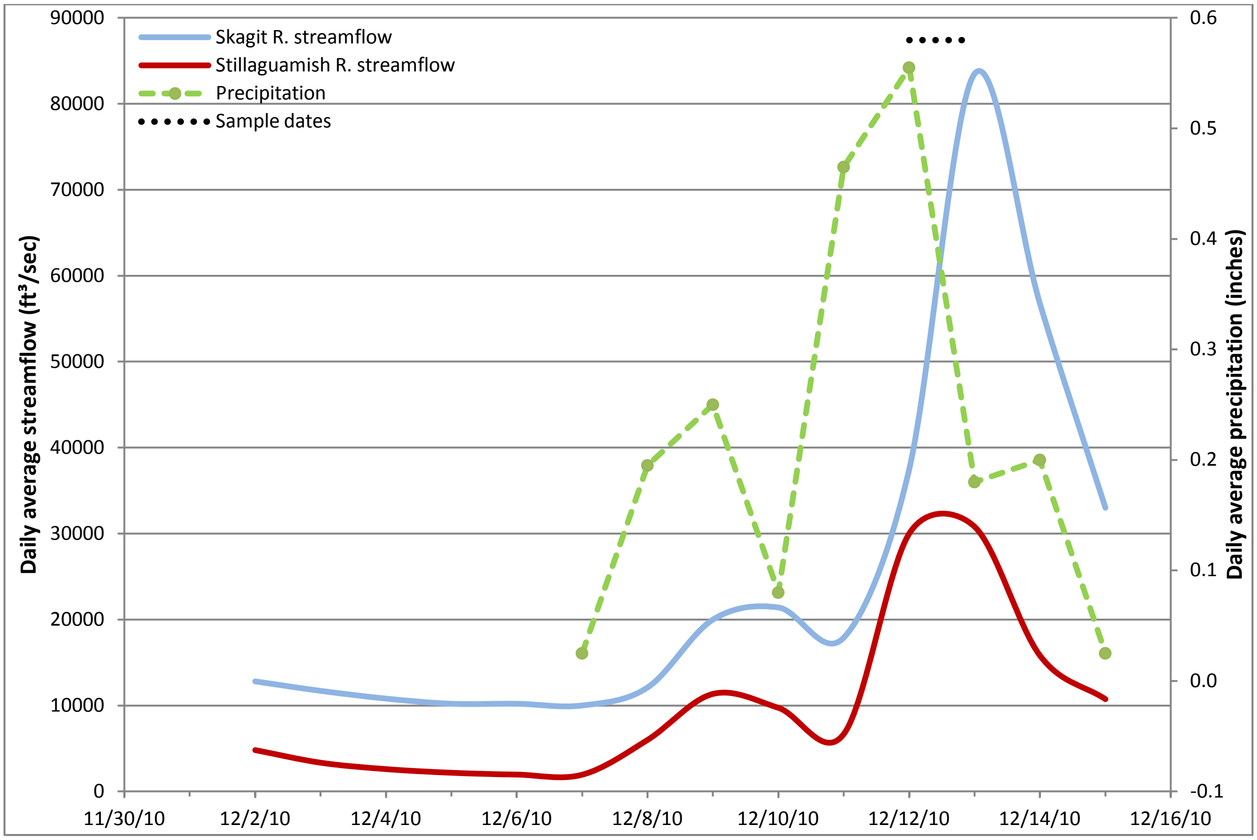

Figure 15. December 12 and 13, 2010 storm event including daily precipitation, streamflow, and time of sampling.

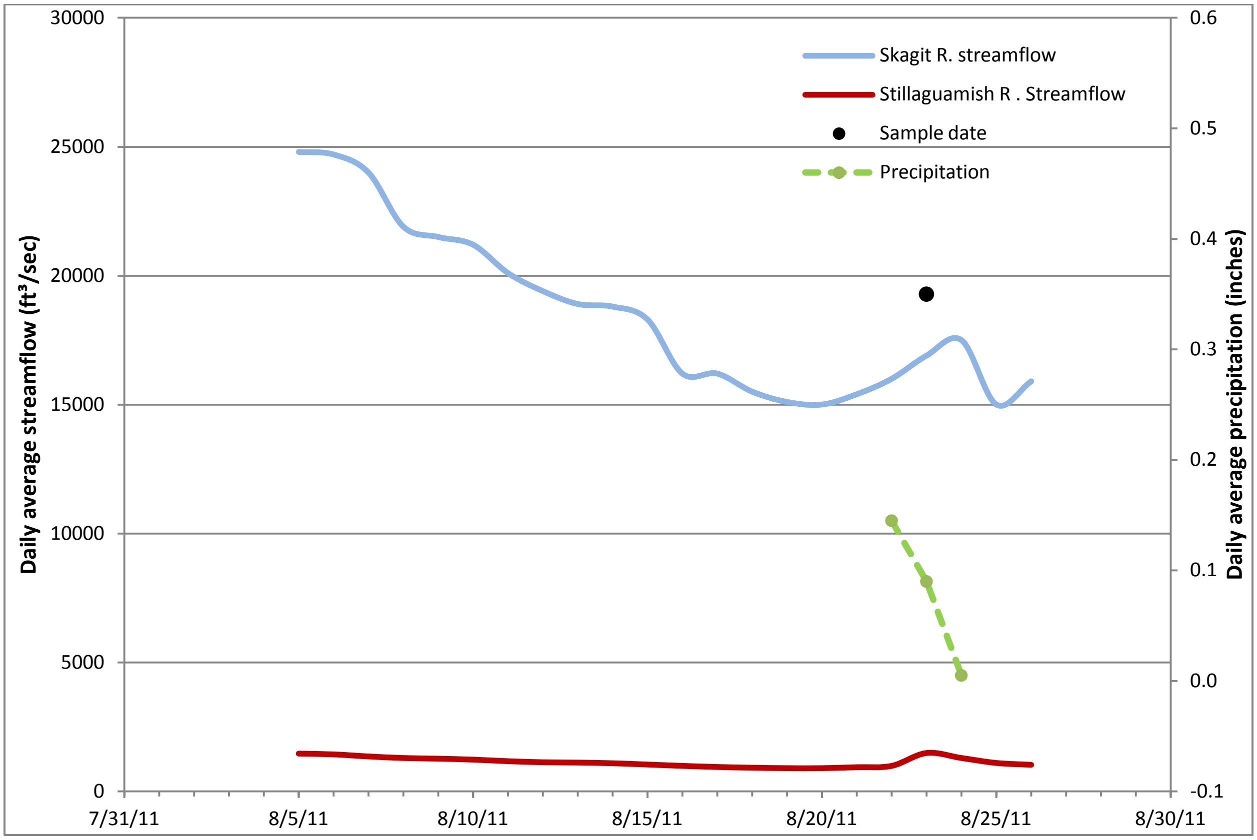

Figure 16. August 23, 2011 storm event including daily precipitation, streamflow, and time of sampling.

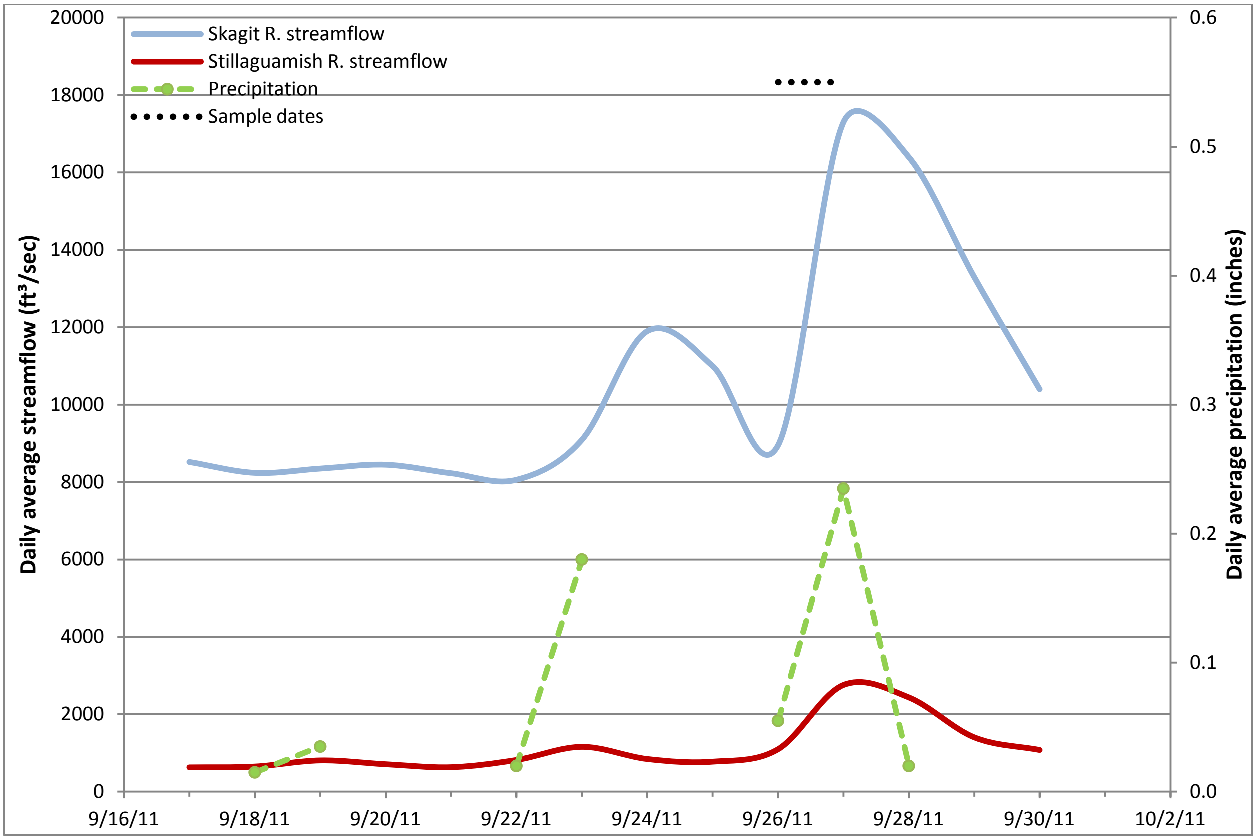

Figure 17. September 26 and 27, 2011 storm event including daily precipitation, streamflow, and time of sampling.

When possible, WDOH sampled FC in Skagit Bay using MPN analysis on the same day as Ecology sampled the nearby contributing waterbodies using FC MF analysis. Although MF and MPN methods are not directly compared in this report a positive relationship does exist between the two when the MF results are used to estimate loading. Figure 18 shows estimated total FC loading from direct sources to Skagit Bay compared to the median FC MPN of all sampling locations in the bay. Based on this study, FC loading seems to have a direct relationship with MF MPN concentrations in Skagit Bay. This same relationship was found in the Stillaguamish River study (Joy, 2004). There is a gap in FC MPN concentration data in Skagit Bay during January when the Skagit River topped flood stage on the 17th and 18th, since WDOH was unable to collect samples in the bay for that month.

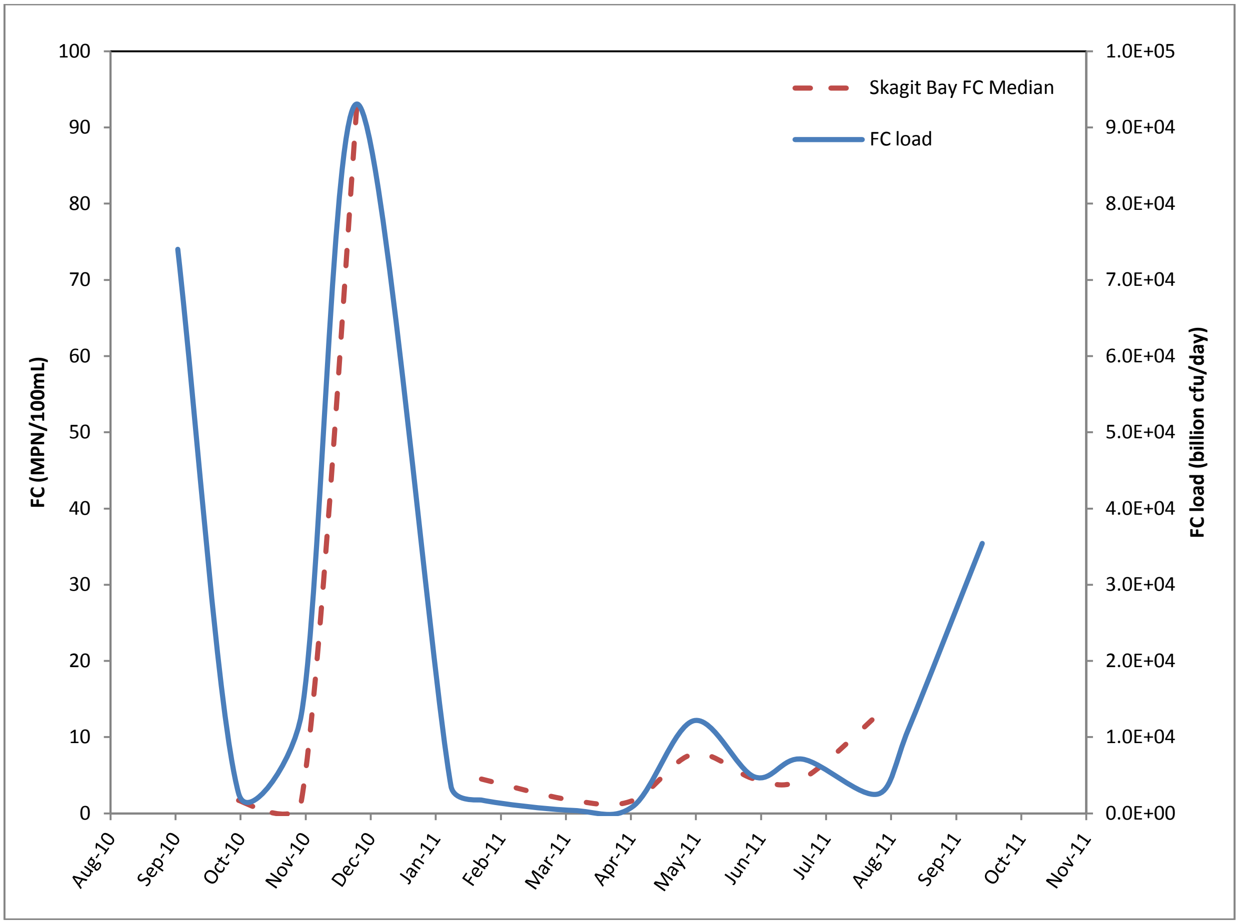

Figure 18. Estimated FC loading plotted over median FC concentration in Skagit Bay.

The Skagit and Stillaguamish River topped flood stage during the December 2010 sampling event. WDOH sampled Skagit Bay on day two of sampling (12/13/10) where salinities were low and FC MPN counts were high (Table 7). WDOH did not sample Skagit Bay in January 2011 when freshwater inputs were high (Figure 14); however, the February sampling event showed low salinities in Skagit Bay that may be explained by significant amounts of freshwater inputs. The low salinities of Skagit Bay suggest a sufficient amount of freshwater was perched on the marine water forming a halocline where freshwater and marine water do not mix very readily. Tidal cycles and wind/wave action increase freshwater and marine water mixing rates of Skagit Bay (Yang and Khangaonkar, 2008). However the magnitude of these mixing mechanisms is often reduced by abundant freshwater inputs to the bay.

Table 7. Skagit Bay FC summary of Skagit Bay during the time of the loading assessment.

Date	Geometric mean (MPN/100mL)	Average salinity (ppt)
10/19/10	2	19
11/17/10	3	19
12/13/10	97	3
2/8/11	5	2
3/22/11	2	21
4/18/11	2	10
5/16/11	8	15
6/14/11	4	13
7/6/11	6	7
8/23/11	15	12

Figure 19 presents monthly averages of FC geometric mean concentrations for the entire Skagit Bay for the last 10 years. These data were collected by WDOH for shellfish sanitation and public health monitoring purposes. All sampling locations in Skagit Bay were pooled together in order to assess the FC water quality of the bay as a whole showing monthly trends over time. Pooling and averaging data of all sites sampled will reduce the weight of extreme values and characteristics of individual sites. Characterizing individual WDOH sampling locations in the Skagit Bay is useful for assessing in detail its specific areas but was, however, beyond the scope of this project. The WAC does not recommend applying FC water quality criteria to data averaged beyond a 12-month period. However the entire data set is the best way to characterize monthly trends over the course of a year. One would expect to see increased FC concentrations in the bay during high runoff and stream discharge that typically occur during the wet season, since (as indicated by Figure 18), high discharge typically increases the potential of FC loading. However, even though the Skagit River experiences peak flows in the early summer and early winter, the highest geometric mean FC concentrations in Skagit Bay occur in August when Skagit River flows are reduced and runoff is low due to reduced precipitation.

High FC concentrations in late summer have been observed in marine bays around western Washington (Mathieu, 2011). The re-suspension of sediment containing FC bacteria during late summer may be a cause of relatively high FC concentrations. Wind and wave action will cause sediment re-suspension along with FC bacteria. However, wind and wave action occurs year-round and possibly reduces in magnitude during the summer months when compared to other months of the year that have more active weather patterns. Another possible explanation is that summer baseflow conditions do not transport FC from land-based sources very far into marine waters, and FC settles along the nearby shoreline where most samples are collected and where shellfish harvesting occurs.

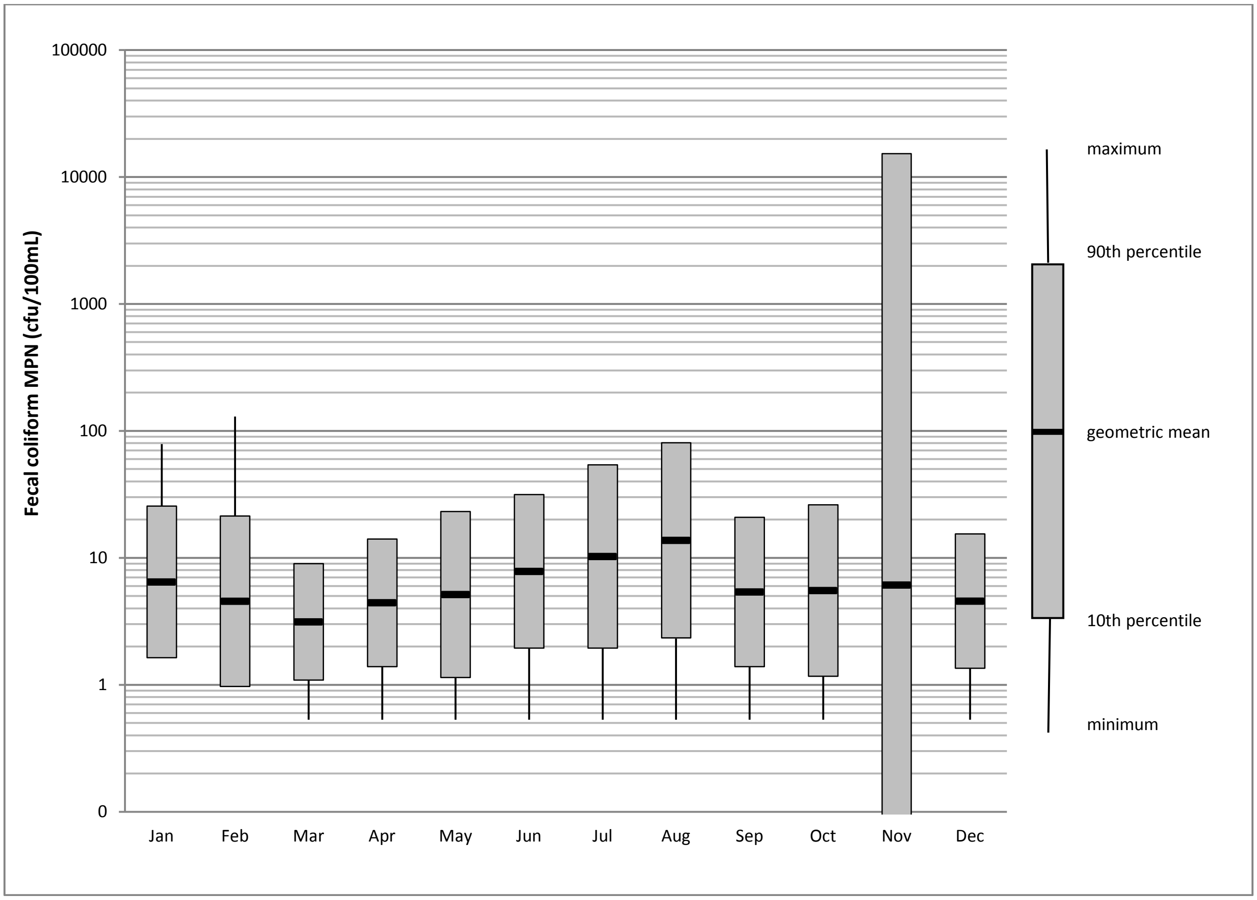

Figure 19. The past 10 years (2001 - 2011) of FC geometric concentrations for the entire Skagit Bay averaged by month.

The high variability in November (Figure 19) may be explained by land-use practices combined with increased precipitation runoff/runoff intensity, and also by increased stream discharge after the preceding dry months giving a ‘first flush’ effect. A similar pattern was observed in the Stillaguamish River Total Maximum Daily Load (TMDL) (Joy, 2004)

Fecal Coliform Recommended Percent Reductions

The geometric mean and 10% percent of data not to exceed water quality criteria have been applied to this Skagit Bay FC loading assessment. Both criterions should be applied when considering water quality compliance in freshwaters or marine waters. The freshwater FC criteria are: (1) geometric mean < 100 colonies/100mL, (2) not more than 10% of all samples > 200 colonies/100mL. The marine FC criteria are: (1) geometric mean < 14 colonies/100mL, (2) not more than 10% of all samples > 43 colonies/100mL. Forty-five percent of the sampling locations exceeded the geometric mean water quality criterion and 73% exceed the 10% not-to-exceed criterion (Table 4).

Waterbodies are subject to marine water quality standards at the point where the salinity reaches 10 ppt or greater at the 95th percentile of salinity measurements (see Water Quality Criteria section). Skagit Bay FC marine water quality criteria are the same as mentioned above where, the geometric mean < 14 colonies/100mL, or 10% of data > 43 colonies/100mL. The 10 ppt salinity line is dynamic, changing constantly as a function of tidal movement and river flow near the freshwater/marine water interface. Salinity was measured at the time of sampling in order to determine whether the freshwater or marine water criteria apply. Therefore marine water quality applies to the follow sites in this study: Hall Slough, Unnamed Slough, Douglas Slough, Davis Slough, and West Pass.

Sampling occurred during low tide over the course of this study to increase the chances of collecting a sample from upland sources of freshwater. Salinities were measured to determine the nature of the sample, whether it is freshwater or brackish/marine. Marine water quality criteria apply when daily maximum salinities are 10 ppt or greater. This means that flood tides are targeted when determining where marine water quality criteria apply. Since this study did not target flood tides, maximum salinity potentials of the sampled waterbodies were not determined. This study instead determined minimum potential salinities, underestimating maximum salinities, and therefore underestimating the boundary where marine water quality applies. To define the marine water boundary, a salinity study would be necessary during flood tide conditions.

The recommended targets and percent reductions for FC presented in this report are based on the geometric mean and the 90th percentile (Table 8). Geometric mean and 90th percentile targets, and percent reductions were recommended in order to bring the waterbody into compliance with water quality criteria and protect beneficial uses. The 90th percentile and 10 ppt salinity mixing includes an estimated MOS. FC target values and recommended percent reductions for this study were determined based on:

1. Washington State Water Quality Criteria geometric mean
2. The 90th percentile MOS
3. The data results of this study
4. Measured salinity
5. Mixing of freshwater with marine water to 10 ppt salinity as an added MOS
6. Skagit Bay background FC concentrations from WDOH data

Using measured salinity levels in Skagit Bay and the contributing freshwater sources, the percent of freshwater that would result in 10 ppt salinity was calculated (Pickett, 1997). Background FC levels of Skagit Bay and the percentage of freshwater at 10 ppt salinity, target levels for bacteria were derived from the marine water quality criteria. As a result, Table 8 shows the marine water quality target values and recommended percent reductions.

Previous FC studies have been conducted in the lower Skagit River (Pickett, 1997) and the Stillaguamish River (Joy, 2004). Table 9 compares the recommended percent reductions and geometric mean targets estimated for FC from these previous studies to this study. Only sampling locations consistent between this study and the previous studies were included.

Table 8. Recommended FC target geometric means and percent reductions for the Skagit Bay loading assessment, 2010 - 2011.

Station ID	Sample size	Based on 10 ppt salinity mix of fresh and marine waters						Target capacity including margin of safety (cfu/100mL)		
		Geometric mean (cfu/100 mL)			90th percentile (cfu/100 mL)					
		Geometric mean	Target geometric mean	% Reduction	90th percentile (cfu/100 mL)	Target of 10% of data	% Reduction	Geometric mean	90th percentile (cfu/100 mL)	% Reduction
03BIG	12	62	21	66%	284	66	77%	15	66	77%
03BRWN*	13	93	14	85%	697	43	94%	6	43	94%
03CDS	12	96	19	80%	451	60	87%	13	60	87%
03DRY	12	85	21	75%	441	65	85%	13	65	85%
03FISH	10	41	21	49%	250	67	73%	11	67	73%
03FRSH	13	15	22	—	103	70	33%	15	70	33%
03HALL*	13	24	14	41%	268	43	84%	4	43	84%
03NFSR	13	6	22	—	48	70	—	22	48	—
03SFSR	13	14	22	—	89	70	21%	14	70	21%
03WILEY	6	36	21	41%	146	68	53%	17	68	53%
03WILEY-P	8	63	21	67%	180	68	62%	24	68	67%
05BORG	12	44	18	59%	259	58	78%	10	58	78%
05DAVIS*	12	41	14	65%	458	43	91%	4	43	91%
05DOUGN*	12	142	14	90%	553	43	92%	11	43	92%
05DOUGS*	10	86	14	84%	999	43	96%	4	43	96%
05GRIG	11	43	19	55%	532	59	89%	5	59	89%
05IRVINE	12	364	21	94%	2070	67	97%	12	67	97%
05OSRC	11	54	22	59%	188	69	63%	20	69	63%
05UN1*	11	660	14	98%	8746	43	100%	3	43	100%
05UN1-3	5	7576	100	99%	351198	200	100%	4	200	100%
05WEST*	12	100	14	86%	566	43	92%	8	43	92%
05WILG	12	291	19	93%	2501	59	98%	7	59	98%

* marine water quality criteria apply based on observed salinities > 10 parts per thousand (ppt) at the 95th percentile

Table 9. Recommended FC percent reductions and target capacities comparison between currently and previously conducted studies in the Skagit Bay study area.

Site ID	From previous studies of the Skagit and Stillaguamish Rivers		From current Skagit Bay loading study	
	Percent reduction	Target geometric mean (cfu/100mL)	Percent reduction	Target geometric mean (cfu/100mL)
West Pass	97 %	3	92 %	8
Irvine Slough	99 %	7	97 %	12
Borseth Gate	99 %	3	78 %	10
Grinde Gate	98 %	24	89 %	5
Williams Gate	96 %	22	98 %	7
NF Skagit River	—	24	—	22
SF Skagit River	—	24	—	14

Based on the difference of percent reductions and target geometric means estimated, water quality has improved at West Pass, Irvine Slough, and Borseth Gate (Table 9) when comparing Joy (2004) results to the results of this study. This may be attributed to applied best management practices (BMPs) and the upgrade of the Stanwood wastewater treatment facility. However, long-term monitoring at key sites such as West Pass will be necessary in order to sufficiently assess water quality trends over time.

The Skagit River has experienced no significant change in FC concentrations over the years (Skagit County Public Works, 2011). However, target values for the Skagit River have been reduced when comparing percent reductions from Pickett (1997) with this current study (Table 9). This may be explained by the background FC concentrations used to calculate the estimated capacity. The FC background levels in Skagit Bay were 0.5 colonies/100mL for the 1997 study. For this current study the background levels were 3 colonies/100mL based on the geometric mean of 10 years of data collected by WDOH from Skagit Bay.

Land Use and Field Observations

During the course of the study, Ecology staff gained a better understanding of the land-use characteristics that play a part in local water quality. The following discussion has been included in this report to provide support for early-action activities to improve water quality where needed. Smaller watersheds have more local sources of FC pollution than larger ones. The *Watershed Description* section of this report provides information on land use of the study area.

Land-use practices surrounding Skagit Bay primarily include agriculture with low density residential housing. Stanwood is the largest city closest to Skagit Bay and may influence the water quality of nearby waterways such as Irvine Slough, Douglas Slough, and West Pass. However, upstream land use along the Skagit River and Stillaguamish River has the potential to influence water quality to the bay.

Upland cities along the Skagit River include Mount Vernon, Burlington, and Sedro-Woolley. The largest upland city along the Stillaguamish is Arlington. Agriculture is common in both the Skagit and Stillaguamish watersheds.

Skagit River

Water quality in the North and South Forks of the Skagit River, as well as in the Wiley Slough and Freshwater Slough was good throughout the study period. All freshwater criteria were met at these sites and no target capacities were needed. The North Fork Skagit River (03NFSR) had slightly lower FC concentrations and contributes less FC loading to Skagit Bay than the South Fork Skagit River (03SFSR). Relatively less loading from the North Fork Skagit River occurred even though the North Fork has a higher discharge than the South Fork (Table 5, Figure 12).

The South Fork Skagit River splits into two main channels, Freshwater Slough and Steamboat Slough, and then braids before entering the bay. The sampling location on the South Fork Skagit River at Fir Island Road (03SFSR) was approximately 2 RM upstream of the sampling location on Freshwater Slough (03FRSH). The geometric means and 90^{th} percentiles were very similar between the two sites (Table 4) with a fairly strong relationship. FC concentrations observed in the South Fork Skagit River at Fir Island Road served as a fairly good predictor of what was to be expected at Freshwater Slough based on the log of the geometric means (R^2=0.73). Variability between sampling each location may be explained by the travel time between the two sites, lag time, or potential unknown FC inputs from wildlife or land-use practices.

The pump station at Wiley Slough (03WILEY-P) discharged approximately 100 feet upstream of the site at Freshwater Slough. The sample site on Freshwater Slough is on the right bank downstream of the boat launch. Further upstream was a small group of houses along the right bank of Freshwater Slough (03FRSH). The houses have onsite sewage systems (OSS). Data presented in this report suggest little potential influence of OSS from these houses.

The Mount Vernon WWTP is the only nearby facility that has combined sewage system (CSS) with the potential for combined sewage overflow (CSO). CSSs are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. Most of the time, CSSs transport all of their wastewater to a sewage treatment plant, where it is treated and then discharged to a water body. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a CSS can exceed the capacity of the sewer system or treatment plant. For this reason, CSSs are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other waterbodies resulting in a CSO. These CSOs contain not only stormwater but also untreated human and industrial waste.

CSOs to the Skagit River in Mount Vernon were known to affect the water quality of Skagit Bay (Lawrence, 2007). On December 13, 2010 the Mount Vernon WWTP CSO discharged a total of 832,000 gallons of untreated sewage and stormwater into the Skagit River. During this time, Skagit Bay experienced high FC concentrations (Figure 18) confirming previous observations. The Mount Vernon facility is scheduled for upgrade by 2015 to reduce the frequency of CSO to one per year on average.

Because of the significant volumes of water discharged through the North and South Forks of the Skagit River, these waterbodies were the driving influence on water quality in much of Skagit Bay. Although water quality criteria for bacteria were met when calculated on an annual basis, FC levels increase in association with rain events. Existing best management practices (BMPs) for livestock production and OSS need to be maintained, and any existing deficiencies need to be corrected in these potential source categories in the North and South Fork Skagit River watersheds.

Big Ditch

Big Ditch receives water from the South Fork Skagit River near the sample location in Conway through a screw gate. The screw gate is currently operated by the Washington Department of Fish and Wildlife. The gate is manually opened from spring through summer. High tides raise the level of the Skagit River allowing more water to flow into Big Ditch through this gate. During this time, the Skagit River influences the water quality of Big Ditch, evident by a decrease in temperature and conductivity observed in Big Ditch based on field data of this study and others (Sargeant and Anderson, 2010). Flows from the South Fork Skagit River are likely to improve the water quality of Big Ditch.

Samples were collected and stream discharge was measured a few feet upstream of the Big Ditch tide gates. FC levels in Big Ditch met the geometric mean criterion. However the not-to-exceed 10% criterion was not met (Table 4). Elevated bacteria counts occurred twice, both times in association with precipitation events. Based on this study, the effects of additional flows received from the South Fork Skagit River through the Conway diversion gate are not known to increase FC loading in Big Ditch. In general, water received from the South Fork Skagit River had lower bacteria concentrations than Big Ditch waters with the exception of two September sampling events where precipitation may have been an influence. Big Ditch contributes about 1.3 % of the total estimated annual loadings to Skagit Bay with some storm events contributing 10 or more times the loadings seen during baseflow conditions (Figure 13).

The water from Big Ditch is used for irrigation and receives runoff from adjacent agricultural fields. Manure application was observed in an adjacent field during one time of sampling. However the data from that sampling event did not show an increase in FC concentration relative to the FC data of Big Ditch. Maintenance of existing best management practices (BMPs) for livestock production and onsite septic systems and correction of any existing deficiencies from these potential sources are needed in the Big Ditch watershed.

Fir Island Waterways: Hall Slough, Browns Slough, Claude-Davis Slough, Dry Slough, and Wiley Slough

Waterways on Fir Island discussed here include Hall Slough, Browns Slough, Claude-Davis Slough, Dry Slough, and Wiley Slough. The surrounding land use is primarily agriculture, and these sloughs therefore receive water drained from adjacent fields. Hall Slough (03HALL) and Wiley Slough (03WILEY-P) have pump stations that operate intermittently, discharging water into Skagit Bay and Freshwater Slough respectively. The pump station on Hall Slough was in operation three times during field data collection. When the pump was not in operation, stagnant waters occur resulting in no FC loading at that particular time. Browns (03BRWN), Claude-Davis (03CDS), and Dry (03DRY) Slough have tide gates that discharge to the bay during ebb tide.

Sampling occurred downstream of the tide gates on Browns Slough, Claude-Davis Slough, Dry Slough, and the pump station on Wiley Slough. Hall Slough was the only exception where sampling took place upstream of the pump station. Hall Slough should have marine water quality criteria applied based on salinity data collected during the time of sampling. Browns Slough is considered marine/brackish waters at the sampling location (Sargeant and Anderson, 2010). Sampling occurred during low tide and therefore is an underestimate of salinity. High tide salinity values will more than likely confirm Claude-Davis Slough and Dry Slough are in fact marine/brackish waters where marine water quality criteria should apply.

Browns Slough had the highest geometric mean at 93 cfu/100mL and Hall Slough had the lowest geometric mean at 24 cfu/100mL of the small sloughs on Fir Island (Table 4). All of these drainages were not in compliance with the not-to-exceed 10% criterion. These relatively small discharges to Skagit Bay contribute about 1.4 % of total estimated annual loadings to Skagit Bay. Although their discharge volumes were low, they pose an intermittent threat to any shellfish resources in the vicinity of their outfalls on a sporadic basis, typically during rain events.

Uncovered manure storage piles with no foundation were observed on Fir Island during field operations. However, most manure storage in the Skagit Bay study area is covered in proper housing. Maintenance of existing best management practices (BMPs) for manure storage and onsite septic systems and correction of any existing deficiencies from these potential sources are needed in the Fir Island watershed.

Fisher Creek

Fisher Creek (03FISH) is a tributary to Steam Boat Slough. Steam Boat Slough is a branch of the South Fork Skagit River. Ongoing habitat restoration work was happening on Fisher Creek during the course of this study. The objectives of restoration are to improve and develop natural wildlife habitat and to re-introduce natural flow regime that is influenced by upland flow and natural tide cycles. The predominant land uses in the Fisher Creek watershed are agriculture and low density housing. Due to construction activities at the sampling location, four samples were unobtainable.

Fisher Creek met both of the criteria for bacteria levels during the study period and generally had very low bacteria levels except during the December flood event. Fisher Creek contributed about 0.6 % of the total estimated bacteria loading to Skagit Bay. Maintenance of existing best management practices (BMPs) for livestock production, manure storage, and onsite septic systems and correction of any existing deficiencies from these potential sources should continue in the Fisher Creek watershed.

Douglas Slough North and Unnamed Slough 1

Douglas Slough and Unnamed Slough 1 receive water from upland sources and flow through agricultural fields near their outlets. Both sloughs receive water drained from adjacent fields and have tide gates designed to reduce marine water inundation. Both sloughs flow very slowly, though Unnamed Slough 1 was generally slower than Douglas Slough, and was stagnant at times during sampling. Stagnant waters resulted in no estimated FC loading at that particular time. Based on this study, at 2.84 cfs and 0.62 cfs respectively, Douglas Slough North had approximately 4.5 times the amount of average discharge than Douglas Slough South.

Extensive discussion and field investigations are already underway in order to address existing water quality issues of these two sloughs. Ecology observed high bacteria counts and BMP deficiencies in Unnamed Slough 1. A report of livestock trampling the lower right bank of Unnamed Slough 1 resulted in prompt investigation by Snohomish County Surface Water Management (SWM) and the Snohomish Conservation District (SCD), which led to the landowner voluntarily moving the livestock fence back 35 feet, creating a grass filter strip.

The high bacteria levels (geometric mean of 660 cfu/100 mL and 90th percentile value of 8,746 cfu/100 mL) at the mouth of Unnamed Slough 1 prompted additional source identification sampling by Ecology in upstream areas (Table 4). Ecology staff, the Snohomish Health District, Snohomish County Surface Water Management, and Washington Department of Fish and Wildlife (WDFW) made subsequent site visits. WDFW determined there did not appear to be excessive numbers of muskrats or nutria. Health District staff visited one residence but did not detect any obvious problems with the onsite septic system there. Snohomish County SWM is developing a source identification project for Unnamed Slough 1 and possibly a second project for Douglas Slough.

Table 10 shows all FC data collected by Ecology at Unnamed Slough 1 (05UN1-3) at Old Pacific Highway and 286th Street including samples collected after the close of scheduled field work. All data presented here were compared to the water quality criteria. Only the first five data results were used in the final statistical summaries of this report to compare with the results of other sites in this study. All follow-up data were not compared with the results of other sampling locations in this study.

Table 10. FC data collected at Unnamed Slough 1-3 (05UN1-3) including follow-up data.

Sample collection date	FC (cfu/100mL)	Geometric mean (cfu/100mL)	Percent of samples exceeding criteria (> 200 cfu/100mL)	90th percentile
5/16/2011	**800**	**3492**	**82%**	63538
6/13/2011	**130000**			
7/5/2011	**60000**			
8/9/2011	200			
9/26/2011	**20000**			
10/19/2011*	**17000**			
11/30/2011*	**8550**			
12/14/2011*	**655**			
1/25/2012*	**2200**			
2/15/2012*	**1000**			
3/7/2012*	180			

Bold values exceed water quality criteria
* Follow-up sampling results

Figure 5 shows additional investigatory site locations and Table A-1 shows FC concentration results. All investigatory sites on Unnamed Slough 1 were upstream of 05UN1. The results show upstream FC concentrations were higher than those of the downstream sampling site with only one exception in May. The cause for this relationship is unknown. Salinity levels at the sampling location of 05UN1 may cause increased bacteria die-off from upstream to downstream as the salinity increases closer to the bay. Three out of eight investigatory sampling events were considered rain events (precipitation > 0.2 inches) where the one exception of this relationship occurred.

Snohomish County's bacteria source identification includes assessing nearby land use and investigating those uses that may contribute to FC pollution such as failing onsite septic systems, manure application, cattle access, or wildlife access. Persistence and survival of bacteria outside of the host should also be considered where stagnant or slow-moving waterways exist. Bacteria may form aggregate communities within a bio-film allowing them to persist and re-grow in various environmental habitats. Sites with high nutrients, reduced flow rates, and estuaries may be environmental niches for bio-film formation and bacterial persistence (Ferguson and Signoretto, 2011). Unnamed Slough 1 and Douglas Slough provide suitable habitats that may lead to bacterial persistence and re-growth.

Other waterways with potential for bacteria persistence in the study area include, Irvine Slough, Williams Gate, Borseth Gate, Grinde Gate, Davis Slough, West Pass, the Old Stillaguamish River Channel, Big Ditch, Wiley Slough, Browns Slough, Claude-Davis Slough, Dry Slough, and Hall Slough.

Although the overall estimated loading to Skagit Bay from Unnamed Slough 1 and Douglas Slough was low (0.6 %), efforts to find and correct the high bacteria counts in these two drainage areas should be continued. Bacteria levels at site 3 on Unnamed Slough 1 were extremely high and may pose a health risk to local residents. In addition to the bacteria pollution problem, many of the agricultural fields in this area had either insufficient or nonexistent grass filter strips adjacent to watercourses.

The Stillaguamish River Valley

West Pass was the final sampling point for FC loadings from the Stillaguamish watershed. Approximately 20% of Old Stillaguamish River Channel (OSRC) water flows into West Pass on an outgoing tide with 80% travelling to Port Susan to the south. Water sampled at the West Pass site reflect flows from the OSRC sampling site, several left bank discharges (Williams Gate, Grinde Gate, and Borseth Gate), and right bank discharges of Irvine Slough, and Douglas Slough South. This study did not include sampling in Church Creek or Miller Creek, which also discharge into the OSRC. Many of these contributing waterways flow intermittently into West Pass due to low flow conditions, tide gate operation, pump station operation, or the tidal cycle. Urban land use may influence the water quality of Irvine Slough and Douglas Slough. Agriculture land practice is common around all waterways.

The Stanwood WWTP (permit number WA0020290) discharges to the Old Stillaguamish River Channel at RM 4.1, which is considered marine waters based on observed salinity values (WA0020290, FACT sheet). Therefore all tributaries downstream of the WWTP, including Grinde Gate, Borseth Gate, and Irvine Slough, also discharge to marine waters.

With a geometric mean of 100 FC cfu/100 mL, West Pass bacteria levels exceeded the marine water quality geometric mean criterion of 14 cfu/100 mL and exceeded the not-to-exceed 10% of data criterion 67% of the time (Table 4). As with all other tributaries to the OSRC, the highest bacteria concentrations and loadings were observed in association with rain events. The OSRC loadings, which should closely relate to West Pass loadings, were higher than West Pass, as expected. This may be because there was greater discharge at the OSRC than West Pass and loading was calculated by multiplying discharge volume by sample concentration. However, water quality at the Old Stillaguamish River Channel monitoring site at Marine Drive met both state bacteria criteria calculated on an annual basis. This means there may be significant bacterial pollution sources from the site on the OSRC at Marine Drive to West Pass at Highway 532.

Overall loadings from Irvine Slough, Douglas Slough South, and the left bank discharges (Williams Gate, Borseth Gate, and Grinde Gate) were among the smallest of all sites sampled on an annual basis. Irvine Slough discharges through a pump station and no information was available on pumping rates or times, so loading was roughly estimated for the two instances where it was observed in operation. Irvine Slough waters were generally stagnant through much of the study and flows from this source are likely to be underestimated in this study. Bacteria concentrations in Irvine Slough were consistently high with those waters far from meeting state standards calculated on an annual basis at 364 cfu/100 mL geometric mean and 67% exceedance of the 10% criterion value (Table 4).

One obvious source of bacterial pollution was the large number of seagulls feeding on clam harvesting wastes just adjacent to the Irvine Slough pump station along West Pass. Irvine Slough needs additional study to understand the cause of the high bacteria values. Of the three left bank discharges, Williams Gate has the highest concentrations and loadings of bacteria and would be the best of these sites for targeted source identification work in that area. Also, Unnamed Slough 2 had a high concentration of 2,700 cfu/100mL during the only investigatory sample and should be assessed in the future.

Wildlife

A rough estimate of bird count was noted during sampling. Anecdotal notes were insufficient to relate to sample data. The Stillaguamish River study (Joy, 2004) estimated between 5.6×10^4 and 1.27×10^5 billion of cfu/day are produced by birds, depending on the season of migratory patterns. FC loading from birds can vary between different species of birds, and it is affected by the type of behavior. For example, ducks primarily reside on the water, while many geese spend most of their time on fields and near shore wetlands. Joy (2004) also mentions that 300 seals have the potential of contributing FC loading of approximately 8.5×10^3 billion cfu/day, which is probably much higher than the population of seals in Skagit Bay.

Conclusions

Results of this 2010 - 2011 fecal coliform (FC) loading assessment to Skagit Bay support the following conclusions.

- FC concentrations above water quality criteria were found in the majority of sampling locations.
- High FC concentrations that exceed water quality criteria were found in Unnamed Slough 1, Irvine Slough, Williams Gate, and Douglas Slough.
- The lowest FC concentrations were found in the North and South Forks of the Skagit River, but these freshwater inflows also contributed the largest loads because of higher discharges.
- The majority of FC loading to Skagit Bay came from the Skagit River followed by West Pass, since these contribute a large portion of freshwater discharging into the Bay.
- Precipitation events likely increased FC loading to Skagit Bay.
- High flow events can significantly increase FC loading in Skagit Bay, as observed during the December 2010 flood event.
- High FC concentrations were observed in Skagit Bay during the December 2010 Combined Sewage Overflow (CSO) in Mount Vernon.
- Improving the water quality of freshwater sources to Skagit Bay can potentially improve water quality in the receiving marine waters, since freshwater FC loading was observed to be positively related with FC concentrations in the marine waters of the bay.
- Pump operation on Hall Slough, Irvine Slough, Williams Gate, and Wiley Slough influenced the potential for FC loading to Skagit Bay. No loading to the bay was assumed when pumps were not running. When pumps were discharging, loading to the bay occurred.
- Tide gate operation may influence the potential for FC loading to Skagit Bay; however, the nature of influence was not understood.
- Marine water quality criteria apply to the sites sampled on Browns Slough, Hall Slough, Davis Slough, Douglas Slough, Unnamed Slough 1, and West Pass. Marine water quality criteria will more than likely apply to the sampling locations on the Old Stillaguamish River Channel, Claude-Davis Slough, Dry Slough, and Big Ditch. However, additional salinity data collection at these sites during high tide is needed for confirmation to apply marine water quality criteria.

Recommendations

Results of this 2010 - 2011 fecal coliform (FC) loading assessment to Skagit Bay support the following recommendations.

- Take actions to reduce FC concentrations of nearby surface water (Table 8) in order to protect water quality and beneficial uses of Skagit Bay.
- Prioritize water quality restoration efforts starting with waterbodies with the highest FC geometric means and 90^{th} percentiles.
- Continue FC monitoring in order to better understand the nature of contributing sources and take action to improve water quality, such as targeted source identification, reduction, and elimination.
- Continue monitoring in key locations including the forks of the Skagit River, Big Ditch, West Pass, and the Old Stillaguamish River Channel. These recommended monitoring sites may be useful in determining long-term water quality trends in the Skagit and Stillaguamish watersheds that may potentially affect the water quality of Skagit Bay. Skagit County is currently monitoring FC in the Skagit River and Big Ditch as part of their long-term water quality monitoring program.
- Investigate sites with relatively small watersheds that have high FC geometric mean concentrations (Table 4, and Table A-1). These sites may include Irvine Slough, Douglas Slough, Unnamed Slough 1, and Williams Gate. These watersheds drain smaller areas than the Skagit and Stillaguamish watersheds. Nearby land use in smaller watersheds present local influences on water quality, whereas larger watersheds may present additional influences from upland sources farther away from Skagit Bay.
- Conduct follow-up monitoring on Unnamed Slough 2 off of Thomle Road. Unnamed Slough 2 was an investigatory site with one sample resulting in 2700 FC cfu/100mL. Unnamed Slough 2 discharges into the Old Stillaguamish River Channel along the left bank between Williams Gate and Grinde Gate (Figure 5).
- Consider the similarities and differences in land-use practices between Williams Gate, Unnamed Slough 2, Borseth Gate, and Grinde Gate. These sites are in near proximity to each other where exact land-use practices are not known based on this report (Figure 5). Williams Gate showed higher FC concentrations than Borseth Gate and Grinde Gate (Table 4 and Table A-1). Borseth Gate and Grinde Gate showed similar FC levels.
- Follow best management practices (BMPs) throughout watersheds to reduce FC contributions to Skagit Bay. Reducing FC loads from upland areas might improve downstream marine water quality.

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Appendices

Appendix A. Fecal Coliform Results

Table A-1. Statistical summaries and daily results of FC samples (cfu/100mL) collected from sites around Skagit Bay from September 2010 through September 2011.

Station ID	Sept 20 and 21, 2010	Oct 18 and 19, 2010	Nov 16 and 17, 2010	Dec 12 and 13, 2010	Jan 24 and 25, 2011	Feb 7 and 8, 2011	Mar 21 and 22, 2011	Apr 18 and 19, 2011	May 16 and 17, 2011	Jun 13 and 14, 2011	Jul 5 and 6, 2011	Aug 9 and 10, 2011	Sep 26 and 27, 2011	number of samples (n)	Geometric mean	Exceed 10% WQ criterion (%)	90th percentile	Aug 23, 2011 storm	Max
03BIG	100	*24*	*130*	**310**	77	14		6	**380**	62	49	60	80	12	62	**17**	284	*88*	**380**
03BRWN*	***240***	**80**	***80***	***110***	23	16	6	24	***160***	***480***	**66**	***700***	**1300**	13	93	**69**	697	***170***	**1300**
03CDS		57	*88*	130	**1000**	8	73	24	150	***300***	180	66	120	12	96	**17**	451	***370***	**1000**
03DRY		69	***260***	**220**	49	31	40	40	***1500***	*100*	34	13	***220[S]***	12	85	**33**	441	*49[S]*	**1500**
03FISH	160	17		**360**	*8*	37	6	*11*	120	120		51		10	41	**10**	250		**360**
03FRSH	120	9	*15*	**240**	26	2	3	8	27	*4*	9	5	100	13	15	8	103	20	**240**
03HALL*	**46[S]**	14[S]	*2[S]*	**120**	**51**	10	*2[S]*	*1[S]*	18[S]	***270[S]***	*34[S]*	***53[S]***	**510[S]**	13	**24**	**46**	268	**120[S]**	**510**
03NFSR	100	9	*16*	43	*3*	1	1	1	10	*6*	*4*	*1*	45	13	6	0	48	19	100
03SFSR	170	*9*	*20*	96	3	4	2	7	15	6	*15*	10	140	13	14	0	89	38	170
03WILEY	89[S]	20[S]	*41[S]*		180[S]	11[S]	14[S]							6	36	0	146		180
03WILEY-P				*130*		20	53	31	140	*140[S]*	110	26		8	63	0	180	40	140
05BORG	*49*	110	*140[S]*	**280[S]**	17	29[S]		***220***	*96*	*3*	8[S]	*17*	*59*	12	44	**17**	259	6	**280**
05DAVIS*	23	*6*	***110[S]***	**71**	**63**	11		3	***4200***	**100**	27	*9*	**87**	12	**41**	**50**	458	*4*	**4200**
05DOUGN*	***100***	**190**	**100**	**170**	***220***	40		37	**430**	**130**	**84[S]**	***100***	***1400***	12	**142**	**75**	553	***240***	1400
05DOUGS*	**810**			**170**	6	11		4	***370***	**150**	**150**	***110***	***640***	10	**86**	**70**	999	***310***	810
05GRIG	*54*		*96[S]*	**1500[S]**	25	27		*1*	*52*	*55*	**280**	*3*	*66*	11	43	**18**	532	11	1500
05IRVINE	**700[S]**	85[S]	***880[S]***	**270**	**3300**	*77[S]*		*67[S]*	***360[S]***	*96[S]*	***2000[S]***	***230[S]***	***1400[S]***	12	**364**	**67**	2070	***2500[S]***	3300
05OSRC		*23*	*100*	93	9	*27*		*22*	***250***	*96*	37	*96*	*110*	11	54	9	188		250
05UN1*	**66**		***4000***	**6000**	**14000**	***5000***		**300**	***1100***	**280**	**230[S]**	*40[S]*	***110***	11	**660**	**91**	8746	29[S]	14000
05UN1-3									**800**	***130000***	**60000[S]**	*200[S]*	**20000**	5	**7576**	**80**	73805	200[S]	130000
05WEST*	**370**	*15*	***100***	**1800**	*25*	**85**		**48**	***490***	**300**	**69**	*33*	30	12	**100**	**67**	632	*17*	1800
05WILG	***3900***	***250***	***4600[S]***	**2100[S]**	*25*	81[S]		***280***	***580***	160	74[S]	*84*	*120*	12	**291**	**50**	2501	60	4600
Additional investigation sites																			
05UN1-1						**8000**								1					
05UN1-2								**360**						1					
05UN1-4												75[S]		1					
05UN2										**2700**				1					

Bold values exceed water quality criteria and *italic* values are qualified as estimates

* Marine water quality criteria apply

[S] Stagnant waterway while sampling

Freshwater criteria: geometric mean < 100 colonies/100mL, not more than 10% of all samples > 200 colonies/100mL

Marine criteria: geometric mean < 14 colonies/100mL, not more than 10% of all samples > 43 colonies/100mL

Table A-2. Estimated daily FC loads (billions cfu/day) around Skagit Bay from September 2010 through September 2011. *Zero values indicate stagnant flow conditions, blank cells indicate no data, and n=count.*

Site ID	9/20 & 21/10	10/18 & 19/10	11/16 & 17/10	12/12 & 13/10	1/24 & 25/11	2/7 & 8/11	3/21 & 22/11	4/18 & 19/11	5/16 & 17/11	6/13 & 14/11	7/5 & 6/11	8/9 & 10/11	9/26 & 27/11	Annual	Wet season	Dry season	Wet (n)	Dry (n)
03BIG	39	13	572	1441	263	56		6	754	27	48	44	31	238	391	124	5	7
03BRWN	18	5	33	104	16	4	2	5	39	75	7	39	184	39	27	47	6	7
03CDS		2	35	121	700	2	16	2	47	36	20	4	12	72	146	16	6	6
03DRY		0.17	278	602	99	18	29	13	969	20	3	0.02	0	145	171	125	6	6
03FISH	296	2		1062	24	53	13	15	361	24		3		132	192	87	5	5
03HALL	0	0	0	12	5	0	0	0	0	0	0	0	0	1	3	0	6	7
03NFSR	33763	1572	5989	23671	978	285	128	131	2833	2255	1979	316	11428	6431	5437	7177	6	7
03SFSR	38264	1048	4991	35231	652	759	170	610	2833	1503	4947	2104	23702	8793	7142	10031	6	7
03WILEY-P				48		8	22	13	59	0	6	1.4	0	11	13	10	3	6
05BORG	0.21	0.44	0	0	3	0		2	6	0.004	0	0.02	0.087	1	1	1	5	7
05DAVIS	4	0.11	0	22	17	2		0.5	1354	12	0.5	0.08	0.9	101	7	172	5	7
05DOUGN	4	5	12	25	24	4		4	53	7	0	3	38	13	11	15	5	7
05DOUGS	19	0	0	5	0	0		0	9	1	2	0	12	4	1	6	5	7
05GRIG	0.08		0	0	3	0		0	3	0	0	0	0	0	0	0	4	7
05IRVINE	0	0	0	28	348	0		0	0	0	0	0	0	27	63	0	5	7
05OSRC		55	4348	7863	168	641		272	7132	1184	268	310	315	1620	2179	1185	5	6
05UN1	2	0	201	294	669	152		7	55	1	0	0	3	99	219	9	5	7
05WEST	1629	6	869	30431	114	403		119	2793	815	101	21	17	2666	5304	689	5	7
05WILG	79	5	0	0	19	0		10	167	1.1	0	0.6	0.8	20	4	32	5	7

Appendix B. Nutrient Results

Four storm events were targeted to include nutrient sampling such as: ammonia (NH_3), nitrate/nitrite (NO_2/NO_3), total persulfate nitrogen (TPN), orthophosphate (OP), and total phosphorous (TP). Nutrient results are not compared or analyzed with FC results. Three of the four targeted storm events were sampled including winter, summer, and fall. The spring season was missed and not sampled for nutrients. The seasons are based on those of the calendar year.

Table B-1. Nutrient sample data from December 2010 winter storm event around Skagit Bay.

Site ID	Day	Parameter (mg/L)					FC (#/100mL)
		NH_3	NO_2/ NO_3	TPN	OP	TP	
03BIG	13	0.08	0.01	3.07	0.040	0.27	310
03BRWN	13	0.70	**0.016 e**	5.57	0.015	0.39	110
03CDS	13	0.52	3.78	5.23	0.077	0.56	130
03DRY	13	0.78	2.49	3.66	0.077	0.64	220
03FISH	13	0.01	0.01	1.65	0.033	0.10	360
03FRSH	12	0.08	0.56	0.73	0.008	0.08	240
03HALL	12	1.15	4.31	5.97	0.031	0.47	120
03NFSR	12	0.03	0.16	0.23	0.004	0.12	43
03SFSR	12	0.03	0.17	0.26	0.004	0.13	96
03WILEY-P	12	**1.01 e**	4.09	5.38	0.011	0.16	130
05BORG	12	0.04	0.20	1.03	0.042	0.16	280
05DAVIS	12	0.20	0.27	0.74	0.057	0.40	71
05DOUGN	13	0.06	0.01	2.75	0.078	0.21	170
05DOUGS	12	1.13	1.70	2.69	0.111	0.32	170
05GRIG	12	0.07	0.64	0.95	0.026	0.36	1500
05IRVINE	12	0.16	2.53	3.91	0.018	0.19	270
05OSRC	12	0.10	0.11	0.33	0.017	2.02	93
05UN1	13	0.62	0.01	5.18	0.091	0.47	6000
05WEST	12	0.10	0.18	0.40	0.012	1.38	1800
05WILG	12	0.56	8.36	11.40	0.230	0.63	2100

Bold values indicate where field replicates did not meet MQO QA and qualified as estimates (e).

Table B-2. Nutrient sample data from August 2011 summer storm event around Skagit Bay.

Site ID	Day	Parameter (mg/L)					FC (#/100mL)
		NH_3	NO_2/ NO_3	TPN	OP	TP	
03BIG	23	0.018	0.01	0.166	0.0235	0.0797	88
03BRWN	23	0.212	0.035	0.365	0.0518	0.155	170
03CDS	23	0.05	0.01	0.308	0.493	0.67	370
03DRY	23	0.05	0.019	0.149	0.0279	0.0791	49
03FISH	—	—	—	—	—	—	—
03FRSH	23	0.034	0.031	0.076	0.004	0.0123	20
03HALL	23	0.01	0.01	0.202	0.0116	0.0782	120
03NFSR	23	0.045	0.033	0.06	0.0037	0.0103	19
03SFSR	23	0.048	0.04	0.1	0.004	0.0141	38
03WILEY-P	23	0.228	0.024	0.506	0.27	0.452	40
05BORG	23	0.079	0.014	0.333	0.35	0.454	6
05DAVIS	23	0.166	0.124	0.533	0.147	0.21	4
05DOUGN	23	0.01	0.01	0.426	0.111	0.208	240
05DOUGS	23	0.257	0.067	0.423	0.0619	0.189	310
05GRIG	23	0.026	0.01	0.277	0.0339	0.0853	11
05IRVINE	23	0.222	0.336	0.841	0.0142	0.14	2500
05OSRC	—	—	—	—	—	—	—
05UN1	23	2.27	0.01	2.66	3.65	3.86	29
05WEST	23	0.021	0.05	0.195	0.066	0.105	17
05WILG	23	0.018	0.01	0.605	5.54	5.54	60

Table B-3. Nutrient sample data from September 2011 fall storm event around Skagit Bay.

Site ID	Day	Parameter (mg/L)					FC (#/100mL)
		NH_3	NO_2/ NO_3	TPN	OP	TP	
03BIG	27	0.069	0.062	0.345	0.0276	0.0919	80
03BRWN	27	0.075	0.034	0.412	0.0802	0.242	1300
03CDS	27	0.448	0.023	0.614	0.71	1.01	120
03DRY	27	0.146	0.075	0.265	0.0241	0.087	220
03FISH							
03FRSH	27	0.015	0.076	0.104	0.006	0.0299	100
03HALL	27	0.243	0.03	0.487	0.0871	0.216	510
03NFSR	27	0.01	0.065	0.078	0.0041	0.0196	45
03SFSR	27	0.022	0.077	0.114	0.0065	0.0301	140
03WILEY-P							
05BORG	26	0.159	0.068	0.389	0.216	0.315	59
05DAVIS	26	0.207	0.12	0.387	0.193	0.32	87
05DOUGN	26	0.181	2.84	4.66	0.128	0.33	1400
05DOUGS	26	0.177	0.147	0.44	0.0648	0.15	640
05GRIG	26	0.067	0.01	0.262	0.0257	0.0705	66
05IRVINE	26	0.269	0.453	0.981	0.0187	0.11	1400
05OSRC	26	0.13	0.135	0.333	0.0164	0.212	110
05UN1	26	0.146	0.01	0.654	1.76	2.2	110
05WEST	26	0.115	0.501	0.722	0.0644	0.149	30
05WILG	26	1.09	0.014	1.54	5.15	5.41	120

Appendix C. Stream Discharge Assessment

Waterbody discharge estimates/predictions were necessary when instantaneous discharge measurements were not possible. Table C-1 includes a brief description of stream discharge measurement methods and comments including regression equations.

Table C-1. Stream/waterway discharge measurement and assessment methods for the Skagit Bay FC loading study 2010-2011.

Site ID	Discharge assessment method(s)	Comments/Equations
03BIG	instantaneous, flow duration curve	Curve based on Big Ditch at Milltown data used to estimate 3 flows
03BRWN	instantaneous, flow duration curve, flow nonlinear regression	(1) Curve based on Browns Slough at Fir Island Rd. used to predict 2 flows, (2) regression developed with the continuous flow gage on Church Creek (x) used to predict 2 flows: $y = 0.2773x^{1.3385}$ ($R^2 = 0.61$)
03CDS	instantaneous, linear regression	Regression with 03BRWN (x) used to predict 4 flows: $y = 1.0136x - 0.9543$ ($R^2 = 0.94$)
03DRY	instantaneous, multiple linear regression	Regression with 03BRWN (x) used to predict 7 flows: $y = 3.1565x - 9.6015$ ($R^2 = 0.90$)
03FISH	instantaneous, multiple linear regression	Regression with API (x) used to predict 4 flows: $y = -0.1906x^2 + 0.3826x - 0.0183$ ($R^2 = 0.9967$)
03FRSH	no data	Insufficient data were available in order to estimate discharge
03HALL	multiple linear regression	Regression with API (x) used to estimate 3 flows when the pump was running: $y = -0.1906x^2 + 0.3826x - 0.0183$ ($R^2 = 0.9967$)
03NFSR	continuous streamflow gage	USGS 12200500 Skagit River near Mount Vernon, WA
03SFSR	continuous streamflow gage	USGS 12200500 Skagit River near Mount Vernon, WA
03WILEY	no data	Stagnant
03WILEY-P	instantaneous, estimate from pump capacity	(1) 4 flows were estimated based on one instantaneous measurement during full capacity pumping, (2) 1 flow was estimated based on 1/4 of the pump's capacity
05BORG	instantaneous, estimate, linear regression	(1) Estimate based on similar observed flow of Borseth Gate, (2) 4 flows were predicted using regression with Grinde Gate (x): $y = 0.738x - 0.0036$ ($R^2 = 0.95$)
05DAVIS	instantaneous, multiple linear regression	Regression with API (x) used to predict 4 flows: $y = -1.244x^2 + 3.1632x + 0.1037$ ($r^2 = 0.93$)

Site ID	Discharge assessment method(s)	Comments/Equations
05DOUGN	instantaneous, nonlinear regression	Predicted 8 flows based on regression with Church Creek (x): $y = 1.7238x^{0.3376}$ ($R^2 = 0.97$)
05DOUGS	instantaneous, multiple linear regression	Predicted 6 flows based on API (x) regression of Fisher Creek: $y = -0.1906x^2 + 0.3826x - 0.0183$ ($R^2 = 0.9967$)
05GRIG	instantaneous, linear regression	(1) 4 flow estimated based on similar observed flow conditions of Grinde Gate, (2) 4 flows predicted based on regression with Borseth Gate (x): $y = 1.2898x + 0.0975$ ($R^2 = 0.95$)
05IRVINE	multiple linear regression	Predicted 2 flows based on API (x) regression of Fisher Creek: $y = -0.1906x^2 + 0.3826x - 0.0183$ ($R^2 = 0.9967$)
05OSRC	continuous streamflow gage, linear regression	Predicted all flows using a fraction* continuous flow values at I-5 (Snohomish County) and for 3 flow regression with the NF Stillaguamish (x) (USGS 12167000) near Arlington, WA: $y = 2.134x+2.8555$ ($R^2=0.98$)
05UN1	multiple linear regression	Predicted 2 flows based on API (x) regression of Fisher Creek: $y = -0.1906x^2 + 0.3826x - 0.0183$ ($R^2 = 0.9967$)
05UN1-3	no data	Insufficient data were available in order to estimate discharge
05WEST	continuous streamflow gage, linear regression	Predicted all flows using a fraction** continuous flow values at I-5 (Snohomish County) and for 3 flow regression with the NF Stillaguamish (x) (USGS 12167000) near Arlington, WA: $y = 2.134x +2.8555$ ($R^2=0.98$)
05WILG	instantaneous, flow ratio	Flow ratio with Borseth Gate (1:5) used to estimate 13 flows

* 10% of Stillaguamish R. @ I-5 + Pilchuck Ck. + 2.5% from Church Ck. on down.
** 10% of Stilli @ I-5 + Pilchuck + 2.5% from Church Ck on down)*0.2 (where West Pass and South Pass split 80/20).

Appendix C. Glossary, Acronyms, and Abbreviations

Glossary

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Conductivity: A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

Dissolved oxygen (DO): A measure of the amount of oxygen dissolved in water.

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10 to 10,000 fold over a given period. The calculation is performed by either: (1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Nonpoint source: Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

Pollution: Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snowmelt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Surface waters of the state: Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

Total Maximum Daily Load (TMDL): Water cleanup plan. A distribution of a substance in a waterbody designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Western Regional Climate Center: The Regional Climate Centers (RCC) deliver climate services at national, regional, and state levels working with NOAA partners in the National Climatic Data Center, National Weather Service, the American Association of State Climatologists, and NOAA Research Institutes. This successful effort resulted in jointly developed products, services, and capabilities that enhance the delivery of climate information to the American public, and builds a solid foundation for a National Climate Service. As NOAA and Congress work to help society adapt to climate change, these collaborative efforts form a framework for the service, data stewardship, and applied research components of the National Climate Service.

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

API	Antecedent precipitation index
BMP	Best management practices
CSO	Combined sewage overflow
CSS	Combined sewage system
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
HARN	High Accuracy Reference Network
I-5	Interstate 5
MEL	Manchester Environmental Laboratory
MQO	Measurement Quality Objectives
NSSP	National Shellfish Sanitation Program
NPDES	(See Glossary above)
OSRC	Old Stillaguamish River Channel
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
TMDL	(See Glossary above)
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WDOH	Washington State Department of Health
WRIA	Water Resource Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cfu/mL	bacteria colony forming unit per milliliter
ft	feet
ft/s	feet per second
mg	milligram, a unit of mass
mg/L	milligrams per liter
mL	milliliter
uS/cm	microsiemens per centimeter, a unit of conductivity