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Elwha-Dungeness Watershed Planning Area Assessment of Gaged Streamflows by Modeling

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Abstract

The Washington State Department of Ecology (Ecology) is proposing a study during 2011 to evaluate Ecology streamflow monitoring gages in the Elwha-Dungeness River basins in western Washington State. This area is also called the Elwha-Dungeness watershed planning area and includes Water Resource Inventory Area (WRIA) 18 and the Sequim Bay watershed in WRIA 17.

To predict flows at Ecology stations, regression-based streamflow models will be developed and applied. Existing hydrologic models will also be evaluated for possible use to predict flows at Ecology flow monitoring stations.

The quality of all computer modeling tools applied will be evaluated, and recommendations will be made for use of the models for water management by Ecology, the Dungeness River Management Team, and the Elwha-Morse River Management Team. The two River Management Teams are comprised of local citizens and local, state, Tribal, and federal government representatives, and together make up the Elwha-Dungeness Planning Unit.

Background

Overview of the Watershed

The project study area includes WRIA 18 and the Sequim Bay watershed in WRIA 17 (see Figure 1), which is also referred to as the Elwha-Dungeness watershed planning area. The descriptions of the basin in this section are summarized from the Final Elwha-Dungeness Watershed Plan (Elwha-Dungeness Planning Unit, 2005).

Watershed Planning

One of Washington's earliest watershed planning efforts began in the Dungeness basin in the early 1990s with the *Chelan Agreement*. This led to the 1994 Dungeness-Quilcene Water Resources Management Plan, which guided river management for many years. The plan included agreements and projects for the restoration of instream flows and salmon habitat.

In 1998 the Washington legislature passed RCW 90.82, which created a statewide watershed planning program. Clallam County is Lead Agency for Watershed Planning under RCW 90.82 in WRIA 18 (www.clallam.net/environment/html/watershed_planning.htm). Initiating governments for planning include: Clallam County, City of Port Angeles, Elwha Klallam Tribe, Jamestown S´Klallam Tribe, and the Agnew Irrigation District. These governments formed the Elwha-Dungeness Planning Unit, who developed the Elwha-Dungeness/WRIA 18 Watershed Plan. A final plan was adopted by the Clallam County Board of Commissioners in June 2005 (Elwha-Dungeness Planning Unit, 2005).

The plan subdivided the watershed planning area into west and east halves (Figure 1).

- The Elwha-Morse planning area (or WRIA 18W) has the Morse Creek subwatershed as its eastern boundary and extends to the Elwha River watershed on the west. The Elwha-Morse Management Team (EMMT) has taken over planning unit duties for this area.
- The Dungeness planning area (or WRIA 18E) has the Bagley Creek subwatershed as its western boundary. The Dungeness planning area extends east to include the Sequim Bay watershed in WRIA 17. The Dungeness River Management Team (DRMT) (www.olympus.net/community/dungenesswc/index.htm) is responsible for ongoing watershed planning in this area.

The EMMT and the DRMT will be the primary forums for stakeholder input into this project.

Geography

The Elwha-Dungeness watershed planning area lies on the northern Olympic Peninsula, between the Strait of Juan de Fuca and the crest of the Olympic Mountains. The Dungeness and Elwha Rivers drain the two largest river basins, but many small creeks flow directly into the Strait.

Elevations in the planning areas range from sea level to over 7,700 feet (2,350 meters) in the highest areas of the watershed. Its upper reaches are mountainous and forested, with alpine and glaciated areas at the highest elevations. Downstream low-lying areas are relatively flat with a mixture of forest, agriculture, and developed areas.

The Elwha River watershed represents 77% of the WRIA 18W basin and 44% of the study area. The Dungeness River watershed covers 71% of the WRIA 18E basin and 27% of the study area. Other major watersheds include Morse Creek, White and Ennis Creeks, McDonald Creek, Siebert Creek, and Jimmycomelately Creek. A summary of watersheds and their proportion in the study area is shown in Table 1.

Table 1. Summary of watershed areas.

Name	Watershed Area (sq mi)	Percent of Sub-WRIA	Percent of Study Area
WRIA 18W			
Elwha River	322.8	76.8%	44.2%
Morse Creek	57.3	13.6%	7.8%
White/Ennis Creeks	11.0	2.6%	1.5%
Tumwater Creek	5.9	1.4%	0.8%
Dry Creek	4.6	1.1%	0.6%
Lees Creek	4.6	1.1%	0.6%
Valley Creek	3.9	0.9%	0.5%
Peabody Creek	3.6	0.9%	0.5%
Other small coastal streams	6.6	1.6%	0.9%
Subtotal – WRIA 18W	420.3	100.0%	57.6%
WRIA 18E			
Dungeness River	198.2	70.9%	27.1%
McDonald Creek	23.9	8.5%	3.3%
Siebert Creek	19.3	6.9%	2.6%
Bagley Creek	7.7	2.7%	1.1%
Bell Creek	7.6	2.7%	1.0%
Cassalery Creek	5.9	2.1%	0.8%
Gierin Creek	4.4	1.6%	0.6%
Other small coastal streams	12.6	4.5%	1.7%
Subtotal – WRIA 18E	279.5	100%	38.3%
Sequim Bay watershed			
Jimmycomelately Creek	16.4	54.0%	2.2%
Johnson Creek	5.8	19.2%	0.8%
Dean Creek	3.4	11.2%	0.5%
Other small coastal streams	4.7	15.5%	0.6%
Subtotal – Sequim Bay watershed	30.3	100%	4.1%
Study Area Total	**730.1**		**100%**

Climate

The study area has a temperate maritime climate characterized by cool, dry summers and mild, wet winters. In the winter, average air temperatures are typically in the 40s and 50s (or 5 to 15° C) with most of the precipitation rain in the lowlands and snow in the mountains. Summer average air temperatures are 60 to 80° F (or 16 to 26° C) and the weather is relatively dry.

Rain varies widely in the study area, with relatively low precipitation in the rain shadow of the Olympics at low elevations to the east near Sequim, and generally increasing with elevation and to the west. Coastal precipitation averages 40 to 60 inches (1,000 to 1,500 millimeters) per year at the west end of WRIA 18, to 15 inches per year (380 millimeters) near Sequim. This precipitation falls mainly in winter (October through March).

At high elevations, snow depths can reach 10 to 20 feet (3 to 6 meters). At lower elevations snow is relatively rare and melts quickly. As elevation increases snow becomes more common and stays on the ground longer. Areas above the tree line can remain snow-covered from November to well past June.

Hydrology

Flows in the higher elevations of the Dungeness and Elwha Rivers and tributaries are dominated by snowmelt during the late spring and early summer. Glaciers in the highest elevations can contribute flow throughout the summer and early fall to the Elwha River. Morse Creek also shows snow-dominated flow regimes in its higher elevations. Mid-elevation creeks and river tributaries experience a mixed rain-snow regime, while the lower elevations are rain-dominated. Low flows in late summer and early fall are generally supported by groundwater inflows and irrigation return flows.

Groundwater resources are located primarily in alluvial deposits in the stream valleys and on the coastal plain. Productive aquifers can be found in alluvial and glacial outwash sediments. The geology of aquifers is varied and not continuous across the watershed.

Information on ground water-surface water interactions is limited. The largest study exploring this issue was conducted jointly by the U.S. Geological Survey (USGS) and the Washington State Department of Ecology (Ecology) along the Dungeness River (Simonds and Sinclair, 2002).
More information of flow regimes in the gaged rivers are provided below.

Land Ownership, Land Use, and Water Use

Political jurisdictions in the Dungeness-Elwha watershed planning area include Clallam County, and the Cities of Port Angeles and Sequim - the principal centers of population in West WRIA 18 and East WRIA 18, respectively. The watershed planning area includes the Reservations and Usual and Accustomed fishing areas for the Jamestown S'Klallam Tribe and the Lower Elwha Klallam Tribe. Other local jurisdictions include the Clallam Conservation District, Clallam Public Utility District, the Agnew Irrigation District, and several other irrigation districts and companies. About three-quarters of the basin is in the Olympic National Park or Olympic National Forest.

The Elwha River has two major dams which regulate flow from over 90% of the watershed. Removal of these two dams began in September 2011 (www.nps.gov/olym/naturescience/elwha-ecosystem-restoration.htm).

The primary land uses in the entire study area are forest management and production (mostly in the foothills and higher elevations); agricultural production (hay, grain, berries, orchard fruits, turf, and lavender); and residential. The population was approximately 51,235 in 2000, and is expected to increase by 25% from 2000 to 2020. Most of the growth is occurring in the lower Dungeness River valley and around Sequim Bay. A general trend of conversion of agricultural lands to residential development has been occurring in this area.

Municipal and domestic water use has been estimated at about 5,141 acre-feet of water per year in 2002 and is expected to grow to 6,330 acre-feet per year in 2020. These water uses tend to have a steady base consumption rate throughout the year, with a seasonal increase during hot weather due to irrigation of landscape, lawn, and home gardens. Residential, commercial, and industrial water use is expected to increase with population growth.

Commercial and Industrial water demand was about 12,500 acre-feet per year in 2002 and was expected to grow to 13,700 acre-feet per year in 2020. Most of this water use can be attributed to a paper mill in Port Angeles.

Agriculture water use in the Sequim-Dungeness valley is managed by members of the Sequim-Dungeness Valley Agricultural Water Users Association (WUA). The WUA estimated its use to be 13,819 acre-feet in 2001, which includes golf courses as well as crops. The diversion and distribution of water has significant impacts on the flows in the Dungeness River and other streams in the valley.

Annual average WUA surface water diversion rates have dropped by almost half since the 1990s. The balance of agricultural water use is from ground water. There has been a general trend in decreasing agricultural water use, both from conservation practices and from land use conversion.

Non-WUA agricultural water use in the study area was estimated at 1,115 acre-feet per year in 2002. This water use is also expected to decline over time, although there is strong local interest in maintaining agriculture in the Dungeness Valley.

Streamflow Gages and Models

Streamflow Measurement

Ecology has historically operated 19 flow monitoring stations in the study area (Figure 1 and www.ecy.wa.gov/programs/eap/flow/shu_main.html). These stations consist of:

- Eleven active *telemetry* gages providing real-time data.
    - Six of these gages measure streamflow and five measure flows in irrigation ditches.
- Two historical staff gages where *manual stage height* readings were collected infrequently (at least once per month) from a staff gage over several years and converted to instantaneous flow values.
- Two historic gages where both manual stage height and *continuous* data have been collected.
- Two historical gages where multiple years of *continuous* data were collected.
- Two historical gages with less than one year of *continuous* data.

At all stations direct measurements of streamflow discharge are taken on a regular basis. These measurements and direct stage height readings are used to develop rating curves for determining flow from stage height data.

The Ecology stations that will be analyzed in this study are shown in Table 2. Active and historical stream gages with sufficient data will be included. The stations with manual stage height data over multiple years will also be analyzed. The irrigation ditch stations and stations with less than one year of data will not be included in this study.

The USGS has gaged streamflow throughout the Dungeness and Elwha River basins at a variety of sites historically and currently (USGS, 2009):

- The three active USGS stations in WRIA 18 are listed in Table 3. One of the stations is partially funded by Ecology. The flow regime at the Elwha River at McDonald Bridge gage will likely change significantly after the Elwha Dam removal, and will therefore not be used in this analysis.
- Seven historical USGS stations in WRIA 18 with continuous flow have no data after 2001 and will not be used for this analysis.

Table 2. Ecology Flow monitoring stations in the Elwha-Dungeness planning area.

ID	Station Name	Code	Status	Type[1]	Start	End	No. days	Comment
18Q240	Indian Creek below Lake Sutherland	Ind-LS	Historical	M	16-Apr-03	4-Nov-08	219	
18Q200	Indian Creek near Maple Grove	Ind-MG	Historical	M	16-Apr-03	4-Nov-08	184	
18Q050	Indian Creek at mouth	Ind-Mou	Historical	C/M	16-Apr-03	28-Sep-10	1575	
18N050	Little River near mouth	Little	Active	T	30-Oct-02	present	3070	
18M060	Ennis Creek near mouth	Ennis	Active	T	4-Sep-02	present	3077	
18C150	Morse Creek below Aqueduct	Mor-Aq	Active	T	28-Feb-03	present	2924	Historic USGS 12047300
18C070	Morse Creek at Four Seasons Ranch	Mor-4S	Historical	C	8-Aug-00	30-Sep-10	3539	
18L060	Siebert Creek at Old Olympic Highway	Siebert	Historical	C	23-Aug-02	6-Dec-10	2497	Washed out, removed
18P070	McDonald Creek at Highway 101	McD-101	Active	T	28-Feb-03	present	2745	
18A050	Dungeness River near mouth	Dun-ECY	Active	T	5-Nov-99	present	4191	Schoolhouse Road bridge
17C075	Jimmycomelately Creek at Highway 101	JCL-101	Active	T	15-Jun-05	present	1041	

[1]M: Manual Stage Height; C: Continuous; T: Telemetry

Table 3. USGS flow monitoring stations in the Elwha-Dungeness planning area.

ID	Station Name	Code	Status	Type[1]	Start	End	No. days	Cooperator[2]
12044900	Elwha River above Lake Mills near Port Angeles	El-aLM	Active	RT	26-Mar-1994	present	4142	USBR
12045500	Elwha River at McDonald Bridge near Port Angeles	El-McD	Active	RT	1-Oct-1918	present	33804	USBR
12048000	Dungeness River near Sequim	Dun-GS	Active	RT	6-Jan-1923	present	29665	ECY

[1]RT : Real-time (Telemetry)
[2]USBR: U.S. Bureau of Reclamation; ECY: Ecology

The Streamkeepers of Clallam County currently collect flow data from staff gages or direct measurements at several sites in the study area:

- Johnson Creek upstream of Marina
- Bell Creak upstream of Schmuck Road
- Cassalery Creek at Jamestown Road
- Golden Sands Slough upstream of Three Crabs Road
- Meadowbrook Creek near mouth upstream of Sequim-Dungeness Way
- Matriotti Creek near mouth downstream of Olympic Game Farm
- Matriotti Creek at Macleay Road

(www.clallam.net/streamkeepers/assets/applets/Fecal_sites_2011_Aug_.pdf).

The Streamkeepers have also collected miscellaneous flow readings from several other stream sites over the last ten years:

- Dean Creek
- Owl Creek
- Lotzgesell Creek
- McDonald Creek
- Siebert Creek
- Morse Creek
- Lees Creek
- Ennis Creek
- Peabody Creek
- Valley Creek
- Dry Creek
- Indian Creek
- Little River

Hydrologic Assessments and Modeling

Numerous hydrologic and hydrogeologic assessments have been completed for the Sequim-Dungeness area. A few relevant studies will be cited in this plan.

In 1999, USGS completed a "Hydrogeologic Assessment of the Sequim-Dungeness Area" (Thomas et al., 1999). The study area was the irrigated areas in the lower valley. As part of the study they evaluated ground water gains or losses in the Dungeness River and in fifteen smaller creeks in the area. Flow data was collected in one synoptic survey in 1997.

A joint study by USGS and Ecology of surface water-ground water interactions was conducted along the lower Dungeness River from 1999-2001 (Simonds and Sinclair, 2002). Data collected included flow data for the Dungeness River and its tributaries. Additional hydrologic modeling of ground water-surface water interactions along the Dungeness River was proposed.

Ecology conducted a Total Maximum Daily Load (TMDL) study for the Dungeness River and Matriotti Creek (Sargeant, 2002). Flow was measured as part of those studies in the Dungeness River at Schoolhouse Bridge and in Matriotti Creek at the Olympic Game Farm (Shedd, 2001). An unsuccessful attempt was made to measure flow in Meadowbrook Creek. The Dungeness Bay TMDL study (Sargeant, 2004) also measured direct irrigation ditch discharge to Dungeness Bay.

The U.S. Bureau of Reclamation did a modeling study of levee setback proposals using flow data from the Dungeness River gages (Lai and Bountry, 2007).

A flow forecast model for the upper Dungeness River (above the USGS Dungeness River gage) was developed by Pacific Northwest National Laboratory in collaboration with the National Aeronautics and Space Administration (NASA) and Peninsula College (http://pcnasa.ctc.edu/index.php). The model is described by the website:

> *The Hybrid Hydrological Model presented here was developed from a NASA grant to the North Olympic Peninsula Resource Conservation & Development Council. The model estimates unregulated streamflow at the outlet of a drainage basin, utilizing inputs such as NASA MODIS data snow covered area, NRCS SNOTel stations, NOAA CO-OP meteorology stations, USGS stream gage data, and NOAA National Digital Forecast Database short-range weather forecasts.*

The University of Washington Climate Impacts group has developed hydrologic models based on the Variable Infiltration Capacity (VIC) hydrologic modeling framework that include streamflow forecasts for climate change scenarios. Its forecasts include the USGS gages on the Elwha and Dungeness Rivers. Forecast products are available (www.hydro.washington.edu/2860/), but the modeling itself is managed by University of Washington researchers.

Streamflow Patterns

To provide a comparison of flows at gages in the watershed, Figures 2 through 5 show distributions of flows at 14 Ecology and USGS continuous and manual stage height flow monitoring stations during 8 complete years – June 2003 through May 2011.

- Figure 2 shows the range of flows at the Elwha River stations. The Elwha River has the highest flows in the study area under all hydrologic regimes. Flows are higher downstream, without any apparent effect of dam operations on downstream flows.
- Figure 2 also shows the range of flows at the Dungeness River stations. The Dungeness River has the second highest flows in the study area. Flows on the Dungeness decrease in the downstream direction, especially for the low flows. Most likely this is mostly due to irrigation withdrawals between the gages.
- Figure 3 shows flows at the Little River and Indian Creek stations. Median flows at the mouths of these two Elwha River tributaries are similar. However, Little River shows a wider range of flows, with higher high flows and lower low flows. Indian Creek flows appear to decrease from the outlet of Lake Sutherland to Maple Grove and then increase to

the mouth, but comparison between gages is limited due to the small data set from the two upstream staff gage stations.

- Flows at the two Morse Creek stations (Figure 4) are similar, although the upstream station below the aqueduct has slightly lower high flows and slightly higher low flows. This again suggests an effect of low flow withdrawal between the stations.
- The four small coastal creek stations shown in Figure 5 show similar flow regimes. The range of flows is quite wide, with low flows of 2 cubic feet per second (cfs) or less and high flows over 50 cfs. The differences are more extreme in the creeks to the east than in those to the west, likely reflecting the drier climate with more summer water diversions in the east.

Figures 6 through 9 illustrate seasonal flow patterns at the gaging stations for the 8 years from June 2003 through May 2011.

- Figure 6 shows flows at the stations in the Elwha and Dungeness Rivers. Both rivers show a "bimodal" flow, with high flows associated both with fall rainfall and spring snowmelt. Low flows can be observed both in summer and winter.
- In Figure 7, Little River also shows a somewhat bimodal flow pattern, although winter low flows are less pronounced and precipitation runoff dominates over spring snowmelt runoff. Indian Creek, by contrast, is a strongly rainfall-dominated system with little winter low flow or spring runoff.
- Morse Creek seasonal flow patterns (Figure 8) are more like Little River, with fall rainfall having a stronger effect than spring snowmelt and low flows occurring mostly in the summer.
- Like Indian Creek, the small coastal creeks (Figure 9) are rainfall dominated with extreme summer low flows. A few precipitation events trigger the highest extreme flow events.
- The interannual patterns can also be observed in these figures. For example, the 2004-05 water year (a drought year) had relatively low flows, while the 2009-10 water year had relatively high flows.

Instream Flow Rule Development

The Elwha-Dungeness/WRIA 18 Watershed Plan made recommendations for the establishment of instream flows by rule for many of the rivers and streams in the planning area. In 2007, Ecology began rule development for instream flows in eastern WRIA 18, which would become Chapter 173-518 WAC of state regulations. Rule development has been delayed due to a statewide rulemaking suspension, as well as work by local leaders to find water for new uses.

These regulatory flows would be set at specific regulatory *control stations* throughout the basin with seniority set by the date of rule adoption. When water flow at a control station reaches the rule's flow levels, water users with more junior (newer) appropriations cannot diminish or negatively affect the regulated flow and can be required to cease diversion

Regulatory flow control stations proposed for WRIA 18E by the latest draft version of WAC 173-518 are shown in Table 4. Also shown in Table 4 are other potential control stations for WRIA 18W and for the Sequim watershed in WRIA 17 based on the Watershed Plan. No rule development has yet been proposed for these areas. Some control stations correspond to active or historical Ecology flow monitoring stations (Figure 1, Tables 2 and 3).

Table 4. Potential regulatory control stations in the Elwha-Dungeness planning area.

Stream Management Unit Name	Control Station Gage Number	River Mile	Latitude (North)			Longitude (West)		
			Deg	Min	Sec	Deg	Min	Sec
Proposed instream flow control stations from draft Dungeness rule (Chapter 173-518 WAC)								
Bagley Creek at Highway 101		1.4	48	5	56	123	19	47
Bell Creek at Schmuck Road		0.2	48	5	1	123	3	25
Cassalery Creek at Woodcock Road		1.8	48	6	59	123	6	31
Dungeness River at Schoolhouse Bridge	ECY 18A050	0.8	48	8	37	123	7	43
Gierin Creek at Holland Road		1.7	48	6	5	123	4	40
Matriotti Creek at Lamar Lane		1.3	48	7	54	123	9	46
McDonald Creek at Old Olympic Highway		1.6	48	6	20	123	13	17
Meadowbrook Creek at Sequim-Dungeness Way		1.2	48	8	41	123	7	27
Siebert Creek at Old Olympic Highway	ECY 18L060	1.3	48	6	24	123	16	42
Potential instream flow control stations for the Sequim Bay watershed (from Elwha-Dungeness Watershed Plan)								
Chicken Coop Creek at East Sequim Bay Road		0.1	48	1	45	122	59	41
Dean Creek at Highway 101		0.2	48	1	26	123	0	41
Jimmycomelately Creek at Old Blyn Highway	ECY 17C075	0.3	48	1	11	123	0	26
Johnson Creek at West Sequim Bay Road		0.1	48	3	45	123	2	32
Potential instream flow control stations for Elwha-Morse watershed (from Elwha-Dungeness Watershed Plan)								
Dry Creek below Lower Elwha Road		0.8	48	7	25	123	31	23
Ennis Creek below White Creek	ECY 18M060	0.3	48	6	45	123	24	23
White Creek above Ennis Creek		0.1	48	6	39	123	24	22
Indian Creek near mouth	ECY 18Q050	0.1	48	4	0	123	35	4
Lees Creek near mouth		0.8	48	6	17	123	22	59
Little River near mouth	ECY 18N050	0.2	48	3	48	123	34	21
Morse Creek at Highway 101	ECY 18C070	1.1	48	6	38	123	21	8
Peabody Creek above Peabody Street		0.2	48	7	2	123	25	55
Tumwater Creek near mouth		0.5	48	7	5	123	27	3
Valley Creek near mouth		0.6	48	6	59	123	26	39

Project Description

Goals and Objectives

The goals of this project are to:

1. Develop computer modeling tools that can estimate streamflows in the Elwha-Dungeness planning area for Ecology flow monitoring stations.
2. Assess the ability of computer modeling tools to support Ecology, the DRMT, the ERMT, and other agencies and local stakeholders in their water management activities in the basin.
3. Support Ecology in making decisions about use of its flow gaging resources statewide.

To meet these goals, this project has the following objectives:

1. Develop statistical and simple hydrologic models that can predict streamflows at Ecology flow monitoring stations in the study area based on relationships with active long-term USGS flow stations or other Ecology flow stations.
2. Assess the quality of the results of the modeling tools developed for objective 1.
3. Provide support in determining a long-term approach to flow discharge assessment that combines direct monitoring of stage height with modeling approaches, thus allowing the total number of flow monitoring stations using continuous stream gage measurements to be reduced.
4. Identify any data gaps found in the modeling analysis and, if warranted, recommend more complex modeling approaches that might reasonably improve the use of models for flow discharge assessment.
5. Provide training and technology transfer of project products to Ecology staff and local partners.

A secondary objective of the project is to assess proposed or potential regulatory control stations in the study area and provide suggestions for flow measurement sites and flow estimation methods.

Model Development

The first study objective will be met by an analysis of (1) the streamflow records for the gages in the study area and (2) other relevant information such as geographical, geological, or meteorological data. The planned approach is to select *reference stations*, such as active long-term USGS flow stations, and then predict flow data at Ecology stations (*study stations)* from one or more of the reference stations. Based on the results of the analysis, one or more Ecology flow stations may also be selected as a reference station.

Several methods will be explored for this analysis, including:

- Simple linear regression or correlation with data transformations such as log-transformation.
- Areal flows (discharge per watershed area) and drainage area ratios.
- Time-lagging of data.
- Hydrograph separation.

- Simple hydrologic routing models.
- Inclusion of meteorological, geographical, and other non-hydrologic data to adjust predictive equations.

This list is provided roughly in order from the simplest to the most complex approach. The analysis will begin with the simplest approach and will only progress to more complex approaches depending on:

- The quality of the results from the simpler approach.
- Whether the available data support a more complex approach.
- The time available in the project schedule to pursue a more complex approach.
- The potential use of the modeling tools.
- The priority of the station to local stakeholders and Ecology.

An example of the simplest kind of correlation is provided in Table 5. Correlations were developed[1] between continuous flow time series from the Ecology and USGS stations. This initial analysis shows how some gages will correlate well, while others will have much poorer relationships. These correlations will be used as the starting point to choose reference stations with the closest statistical relationship to each study station.

- One reference station will be the USGS station with the best correlation.
- A second reference station will be the station with the best correlation (other than the first choice) that is either a USGS station or an Ecology station that is also a control station.
- Two more stations will be selected for analysis from the stations with the best correlations (other than the first two choices).

Model Quality Assessment

Best practices of computer modeling should be applied to help determine when a model, despite its *uncertainty*, can be appropriately used to inform a decision (Pascual et al., 2003).

Specifically, model developers and users should:

1. Subject their model to credible, objective peer review.
2. Assess the quality of the data they use.
3. Corroborate their model by evaluating how well it corresponds to the natural system.
4. Perform sensitivity and uncertainty analyses.

The study will follow this approach to meet the fourth study objective of assessing the quality of model results.

[1] The Correlation analysis tool was used from the Excel® Analysis ToolPak.

Table 5. Correlations between flows from gages in the Elwha-Dungeness planning area.

Coefficient colors emphasize strongest correlations (blue = greater than 0.9, green = between 0.8 and 0.9, red = between 0.7 and 0.8). Station colors and footnotes explained in legend (upper right). Station ID defined in Tables 2 and 3.

	JCL-101	Dun-ECY	McD-101	Siebert**	Mor-4S*	Mor-Aq	Ennis	Little	Ind-Mou*	Ind-MG*	Ind-LS*	El-aLM	El-McD
Dun-ECY	0.62												
McD-101	**0.86**	0.50											
Siebert**	**0.87**	0.61	**0.78**										
Mor-4S*	**0.79**	**0.85**	**0.72**	**0.86**									
Mor-Aq	**0.78**	**0.84**	**0.77**	**0.77**	**0.94**								
Ennis	**0.86**	**0.70**	**0.87**	**0.86**	**0.85**	**0.84**							
Little	**0.82**	**0.76**	**0.80**	**0.84**	**0.91**	**0.89**	**0.89**						
Ind-Mou*	0.69	0.42	0.51	0.58	0.61	0.57	0.60	**0.70**					
Ind-MG*	0.67	0.30	0.64	0.52	0.46	0.49	0.59	0.63	**0.93**				
Ind-LS*	**0.73**	0.41	**0.71**	0.69	0.55	0.54	0.70	**0.71**	**0.90**	**0.92**			
El-aLM	0.57	**0.91**	0.48	0.62	**0.87**	**0.85**	**0.70**	**0.80**	0.43	0.32	0.42		
El-McD	0.58	**0.89**	0.51	0.66	**0.88**	**0.87**	**0.71**	**0.80**	0.46	0.31	0.45	**0.99**	
Dun-GS	0.57	**0.97**	0.48	0.61	**0.84**	**0.83**	0.69	**0.76**	0.35	0.24	0.35	**0.92**	**0.92**

ECY-Telemetry

ECY-Manual Stage Height

USGS

Potential Control Station

***Historical gage**

****Damaged gage**

Study results will undergo a technical peer review by a designated Ecology employee with appropriate qualifications. Review of the study by Ecology staff, local stakeholders, and the public will also ensure quality.

Practices 2 through 4 above are addressed through *Model Evaluation*. This is the process for generating information over the life cycle of the project that helps to determine whether a model and its analytical results are of a quality sufficient to serve as the basis for a decision. Model quality is an attribute that is meaningful only within the context of a specific model application. Evaluating the uncertainty of data from models is conducted by considering the models' accuracy and reliability.

Accuracy Analysis

Accuracy refers to the closeness of a measured or computed value to its *true* value, where the *true* value is obtained with perfect information. Due to the natural heterogeneity and random variability of many environmental systems, this *true* value exists as a distribution rather than a discrete value.

In this project, accuracy is determined from measures of the *bias* and *precision* of the predicted value from model results, as compared to the observed value from flow measurements on the assumption that measured flows are closer to the *true* value. The known precision and bias of flow measurement values will also be taken into account in interpreting results.

Bias describes any systematic deviation between a measured (i.e., observed) or computed value and its *true* value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration.

Bias will be inferred by the precision statistic of relative percent difference (RPD)[2]. This statistic provides a relative estimate of whether a protocol produces values consistently higher or lower than a different protocol. Bias will be evaluated using RPD values for predicted and observed pairs individually and using the median of RPD values for all pairs of results.

RPD =

where:

P_i = ith prediction
O_i = ith observation

The RPD was chosen over other measures of bias because of the wide range in flows found in hydrologic records. Using residuals or mean error would tend to underemphasize predictive error during critical low-flow periods and overemphasize error during the highest flows. On the

[2] RPD commonly uses the absolute value of the error, but a formulation without an absolute value is used in this report to retain the sign, which indicates the bias of the predicted value relative to the observed value.

other hand, percent error tends to overemphasize error for low flows. RPD provides the most balanced estimate of error over a wide range of flows.

Precision of modeled results will be expressed with percent relative standard deviation (%RSD). Precision will be evaluated using this statistic for predicted and observed pairs individually and using the mean of values for all pairs of results.

The %RSD presents variation in terms of the standard deviation divided by the mean of predicted and observed values.

$\%RSD = (SD_i * 200) / (P_i + O_i)$, where
SD_i = standard deviation of the i^{th} predicted (P_i) and observed (O_i) pair.

Percent error measures have been selected for assessment of accuracy because of the wide range of values expected in the flow record. Uncertainty in flow measurements is usually reported as a percentage; the same approach is being adopted for flow modeling.

Reliability Analysis

Reliability is the confidence that potential users have in a model and its outputs such that the users are willing to use the model and accept its results (Sargent, 2000). Specifically, reliability is a function of the performance record of a model and its conformance to best available, practicable science. Reliability can be assessed by determining the robustness and sensitivity.

Robustness is the capacity of a model to perform equally well across the full range of environmental conditions for which it was designed and which are of interest. Model calibration is achieved by adjusting model input parameters until model accuracy measures are minimized. Robustness will then be evaluated by examining the quality of calibration for different seasons and flow regimes. The variation between accuracy measures for model results from different seasons and flow regimes provides a measure of robustness of model performance.

Sensitivity analysis is the study of how the response of a model can be apportioned to changes in a model's inputs (Saltelli et al., 2000). A model's sensitivity describes the degree to which the model result is affected by changes in a selected input parameter. Sensitivity analysis is recommended as the principal evaluation tool for characterizing the most- and least-important sources of uncertainty in environmental models. Uncertainty analysis investigates the lack of knowledge about a certain population or the real value of model parameters.

Sensitivity analysis can be conducted using Morris's one-at-a-time (OAT) approach (Saltelli et al., 2000). With this approach, each input value is perturbed by a given percentage away from the base value while holding all other input variables constant. Morris's OAT sensitivity analysis methods yield local measures of sensitivity that depend on the choice of base case values. Morris's OAT approach provides a measure of the importance of an input factor in generating output variation. While this approach does not quantify interaction effects, it does provide an indication of the presence of interaction. This test will be applied if the complexity of the model, importance of model results, and the need for additional model quality information are sufficient to justify the level of effort needed.

Other approaches may also be explored to evaluate the sensitivity of regression models to changes in instream flows caused by implementing water management programs in the Elwha-Dungeness planning area.

Quality Characterization

The uncertainty and applicability of model results will be assessed by evaluating model *quality* results on an annual basis and for summer baseflow conditions. The median %RSD value will be used for comparison for each model at each station within the season or range of flow measurements being considered. Terminology similar to the following will be used to describe model results:

Median %RSD for annual streamflow and summer baseflow	Characterization
Less than 5%	Very Good
Greater than 5% and less than 15%	Good
Greater than 15% and less than 30%	Fair
Greater than 30%	Poor

Flow Gaging Assessment

Project Objectives 3 and 4 will be accomplished by evaluating the results of the model assessments described above. Each flow monitoring study station will have a preferred modeling approach identified and an evaluation of the quality of the model. That evaluation will include a recommendation for the gage at each station based on the quality of the model and redundancy of flow information with other gages.

This information will be provided to Ecology staff and local stakeholders to support decisions about allocation of resources for flow gaging. The overall process of assessing both Ecology's and local stakeholders' needs for gaging information will occur as a separate process on a parallel track.

Possible recommendations for use of the Ecology flow monitoring stations resulting from this project could include:

- Continuing operation of the gage as a telemetry gage with full Ecology support.
- Reallocating the station to a *manual-stage-height* station using modeling combined with spot-flow measurements for confirmation of modeled flows.
- Decommissioning the station and using modeling to assess flows at the site.
- Transferring the station to another party.
- Continuing operation of the gage as a telemetry gage with cooperative funding from stakeholders.

As a result of the analysis, data gaps may be identified that limit the ability to use modeling tools to estimate streamflows. Recommendations for potential changes in data acquisition to fill these gaps will be made where warranted.

In addition, if the analysis in this study points towards other, more complex, models that could improve the quality of flow estimation, recommendations will be made for using those models in possible future work.

Project Report and Public Involvement

During the course of the project, internal review, input, and guidance will be provided by the Gaging Strategy Workgroup (GSW) and other Ecology staff identified in the Organization and Schedule section below. Input from local partners and the public during the project will be through the DRMT and EMMT. The form and timing of input during the project will be determined by the project and client leads.

A project report will present the results of the study. Review of the draft report will be the primary mechanism for providing input to the final conclusions and recommendations.

Training and Technology Transfer

The final objective will be achieved by providing (1) modeling tools to interested parties through the internet or other means and (2) presentations and training to Ecology staff and local partners. The timing and content of presentations and training during this project will be determined through consultation with project clients and responsible staff and groups.

Organization and Schedule

The people listed in Table 6 are involved in this project. All are employees of the Washington State Department of Ecology.

Table 6. Organization of project staff and responsibilities.

Staff	Role	Responsibilities
Cynthia Nelson SEA Program Southwest Regional Office Phone: (360) 407-0276	Client, Regional Watershed Lead	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report. Serves as Ecology liaison between the project manager and the DRMT and EMMT.
Bill Zachmann SEA Program Phone: (360) 407-6548	Client, Statewide Watershed Coordinator	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report. Serves as liaison with Ecology WAG and SEA Program.
Brad Hopkins Freshwater Monitoring Unit Western Operations Section, EAP Phone: (360) 407-6686	Client, Manager of Ecology's Statewide Flow Monitoring Network	Clarifies scopes of the project. Provides internal review of the QAPP and approves the final QAPP. Reviews the project report.
Robert F. Cusimano Western Operations Section, EAP Phone: (360) 407-6698	Section Manager for Client and for Study Area	Reviews the project scope and budget. Reviews the draft QAPP and approves the final QAPP. Approves the project report.
Paul J. Pickett MISU, SCS, EAP Phone: (360) 407-6882	Project Manager/ Principal Investigator	Writes the QAPP. Organizes, analyzes, and interprets data. Develops model and analyzes quality of data and model. Writes the draft report and final report.
Karol Erickson MISU, SCS, EAP Phone: (360) 407-6694	Unit Supervisor for the Project Manager	Provides internal review of the QAPP. Approves the budget and approves the final QAPP. Tracks progress. Reviews and approves the project report.
Will Kendra SCS, EAP Phone: (360) 407-6698	Section Manager for the Project Manager	Reviews the project scope and budget. Reviews the draft QAPP and approves the final QAPP. Approves the project report.
William R. Kammin Phone: (360) 407-6964	Ecology Quality Assurance Officer	Reviews the draft QAPP and approves the final QAPP.

SEA: Shorelands and Environmental Assistance.
EAP: Environmental Assessment Program.
MISU: Modeling and Information Support Unit.
SCS: Statewide Coordination Section.
QAPP: Quality Assurance Project Plan.

As described above, updates to the Planning Unit and any internal decision-making will be determined on an as-needed basis by the project manager and clients. Table 7 shows the schedule proposed for completion of the reports for this study.

Table 7. Proposed schedule for completing reports.

Final report	
Author lead	Paul Pickett
Schedule	
Draft due to supervisor	October 2011
Draft due to client/peer reviewer	October 2011
Draft due to external reviewer(s)	November 2011
Final report due on web	January 2012

Training and technology transfer will begin with the review of draft reports and will continue after the publication of the Project Report on an as-needed basis.

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Figures

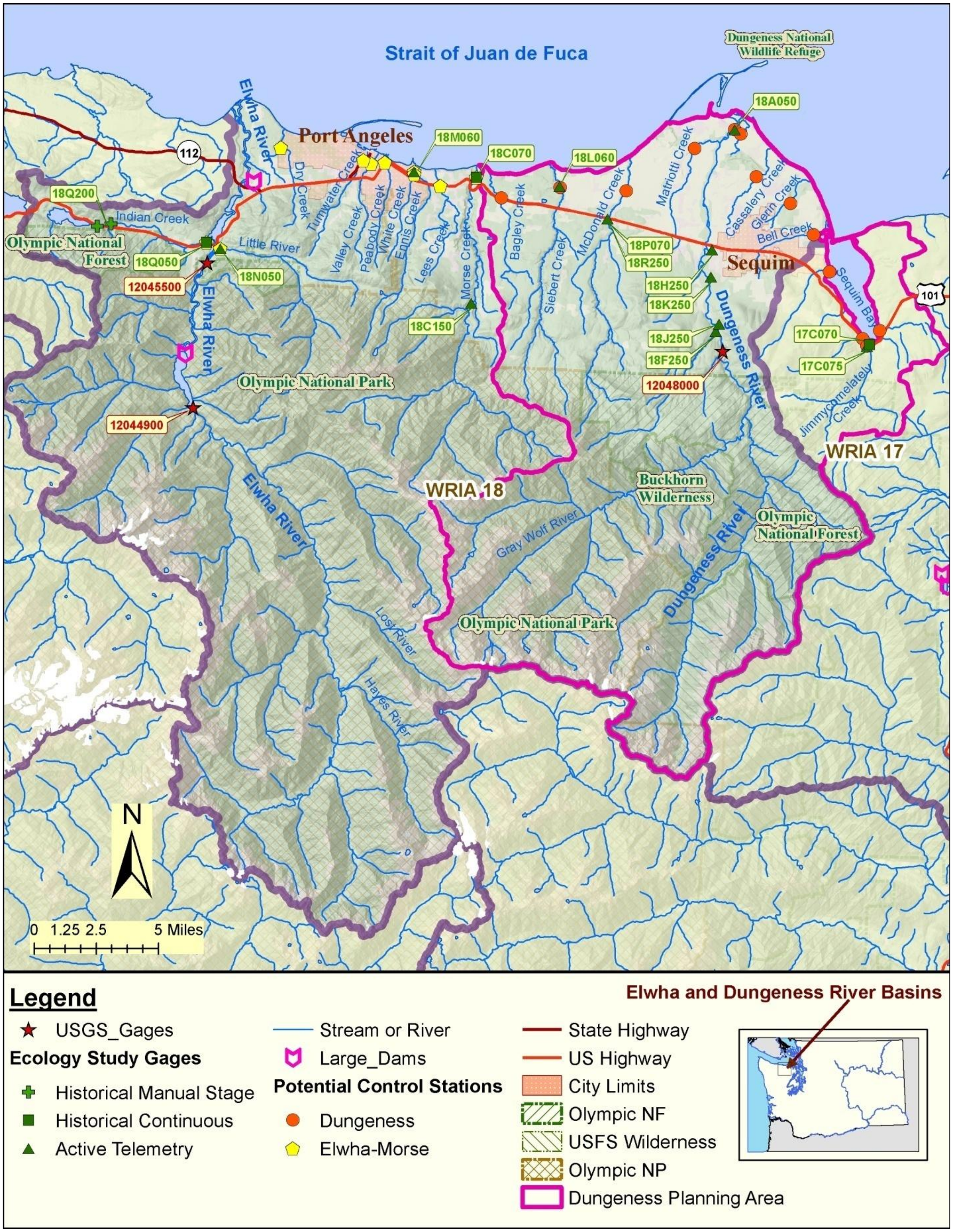

Figure 1. Elwha-Dungeness watershed study area.

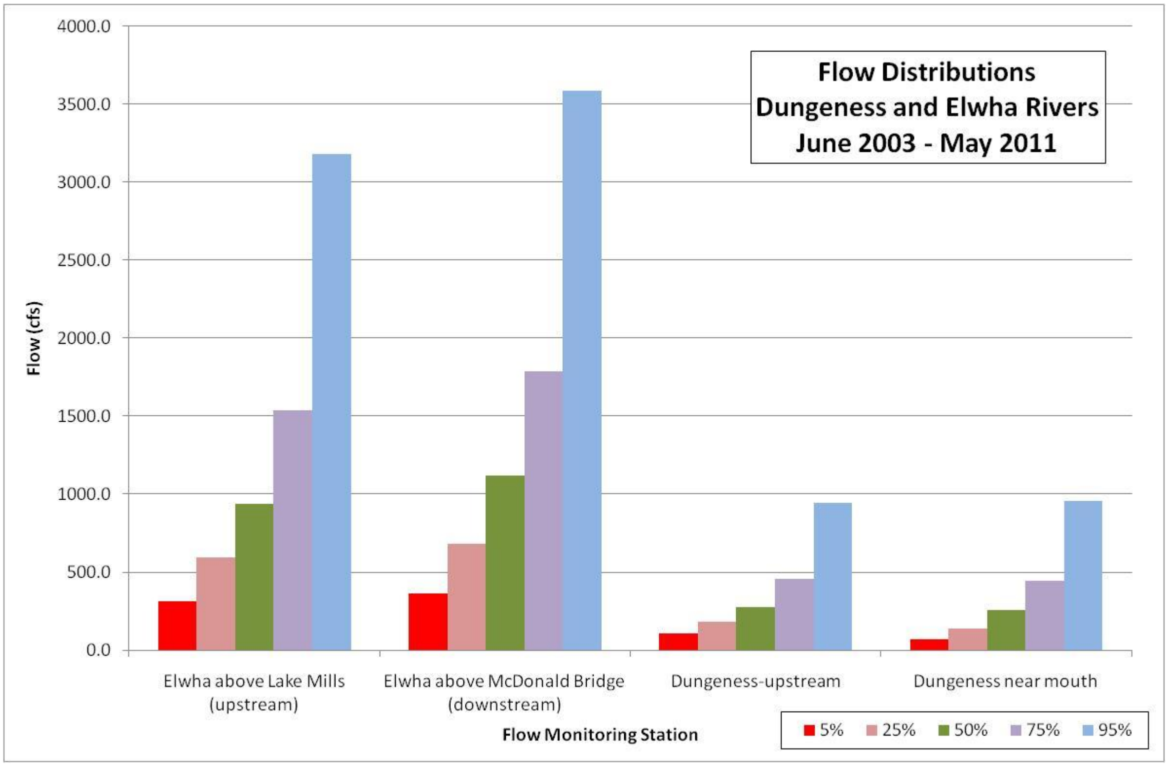

Figure 2. Flow distributions for Elwha and Dungeness River gaging stations.

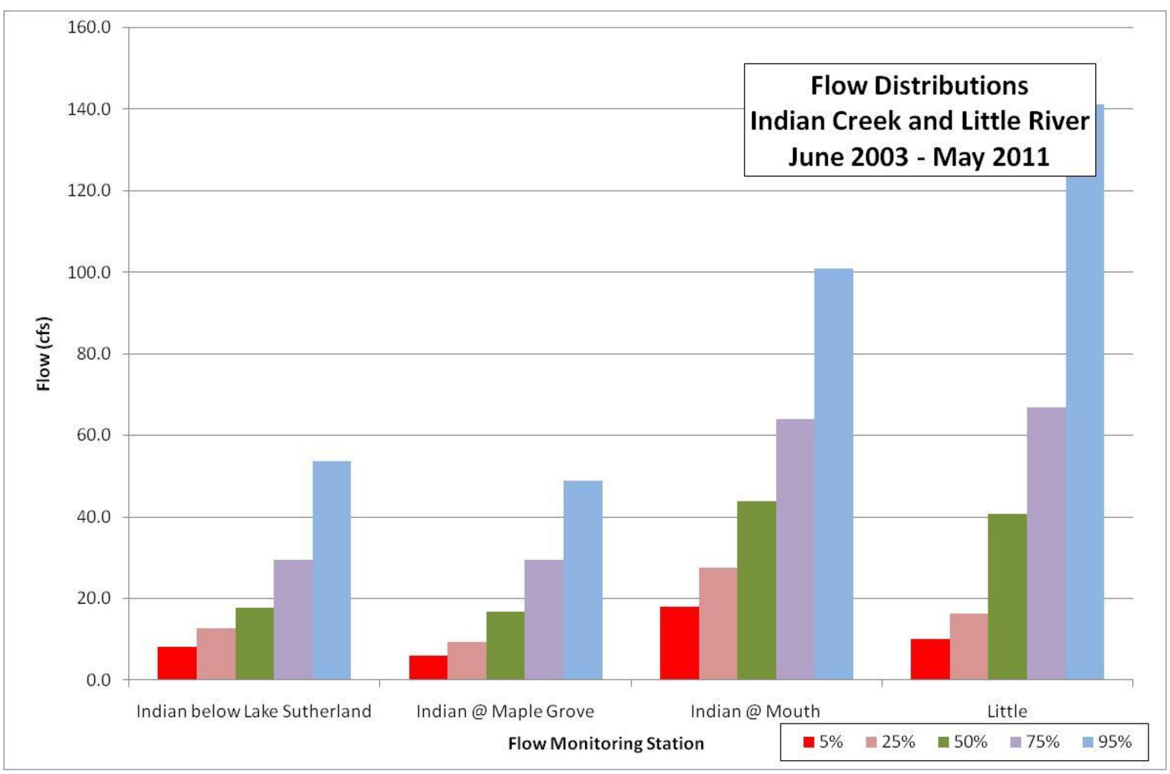

Figure 3. Flow distributions for Indian Creek and Little River gaging stations.

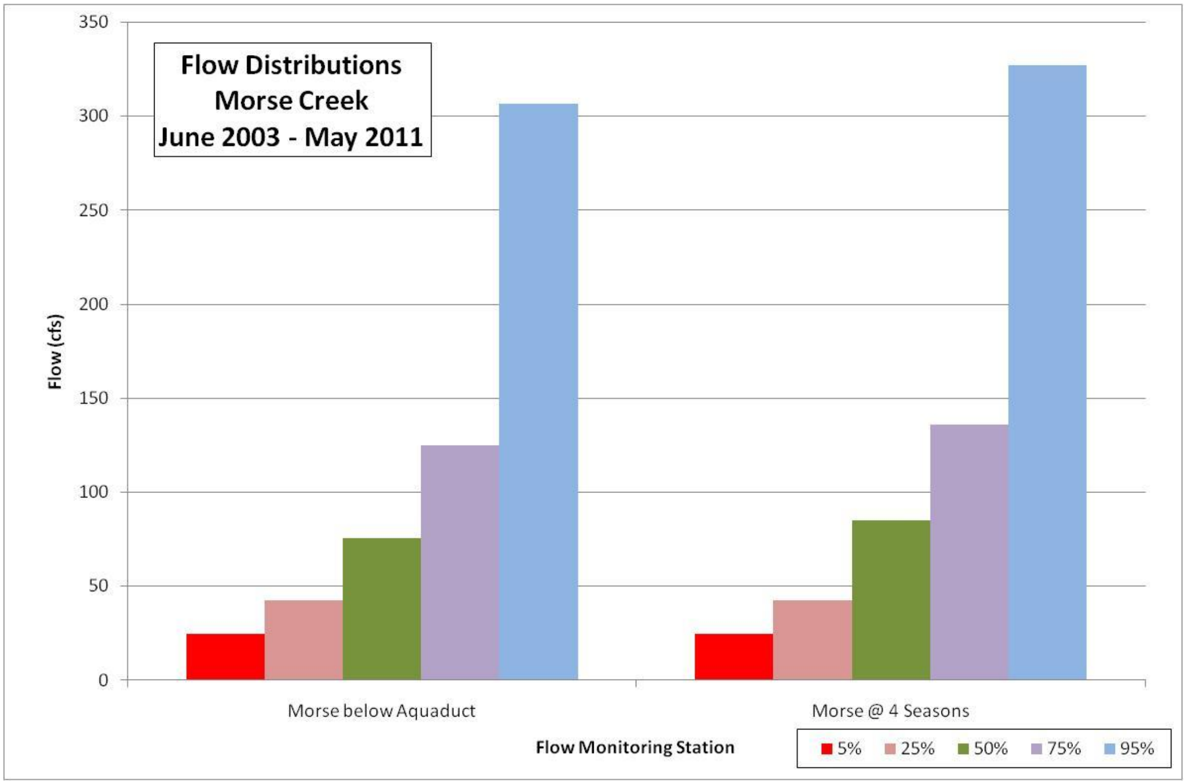

Figure 4. Flow distributions for Morse Creek gaging stations.

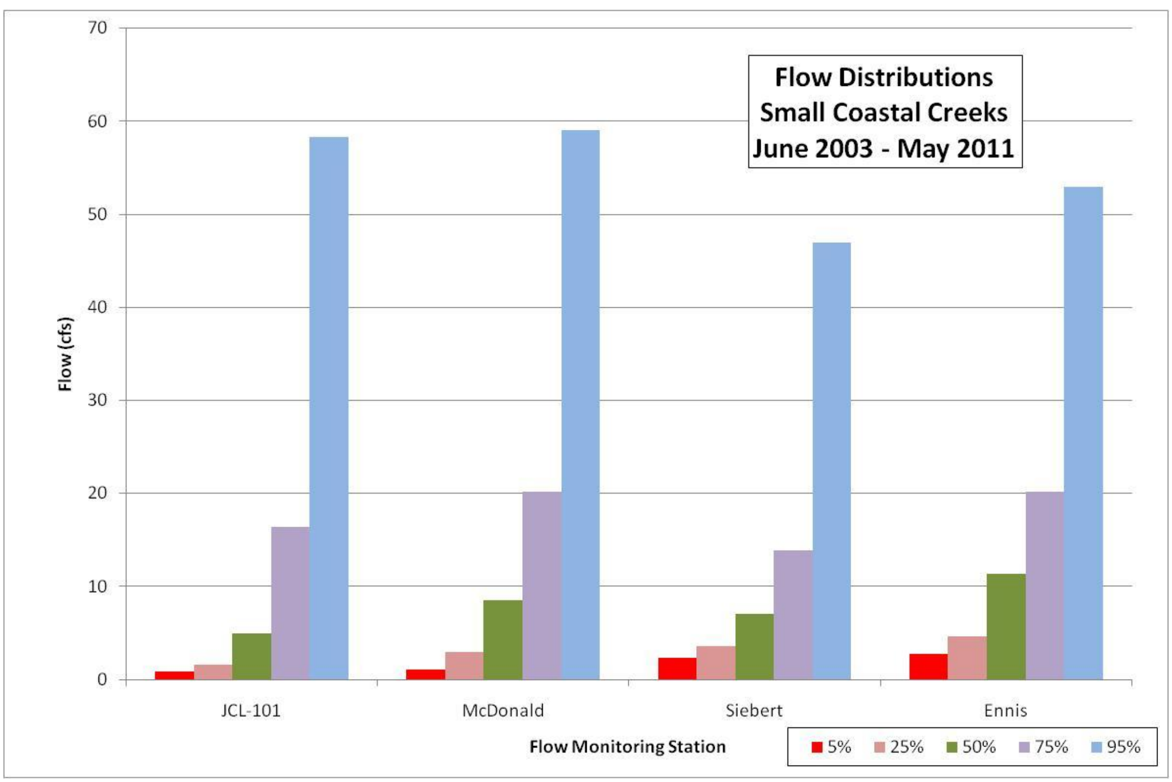

Figure 5. Flow distributions for small coastal creek gaging stations.

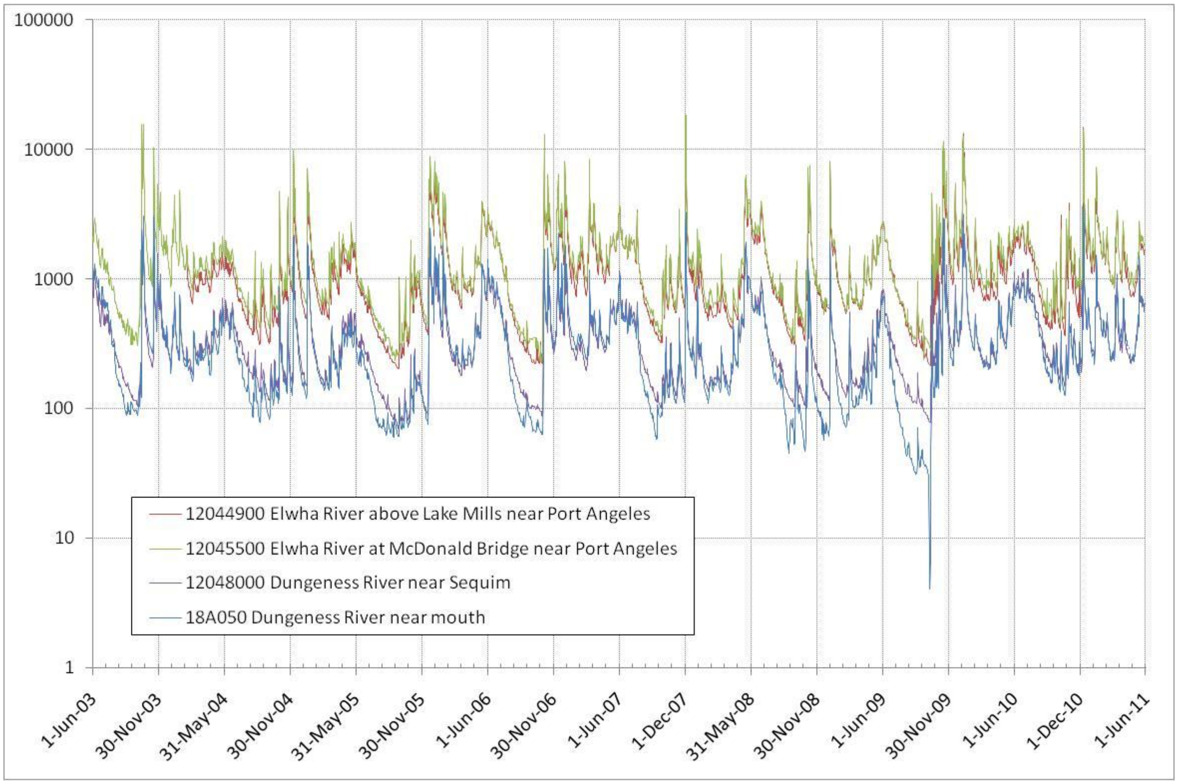

Figure 6. Flow at Dungeness and Elwha River gaging stations, June 2003-May 2011.

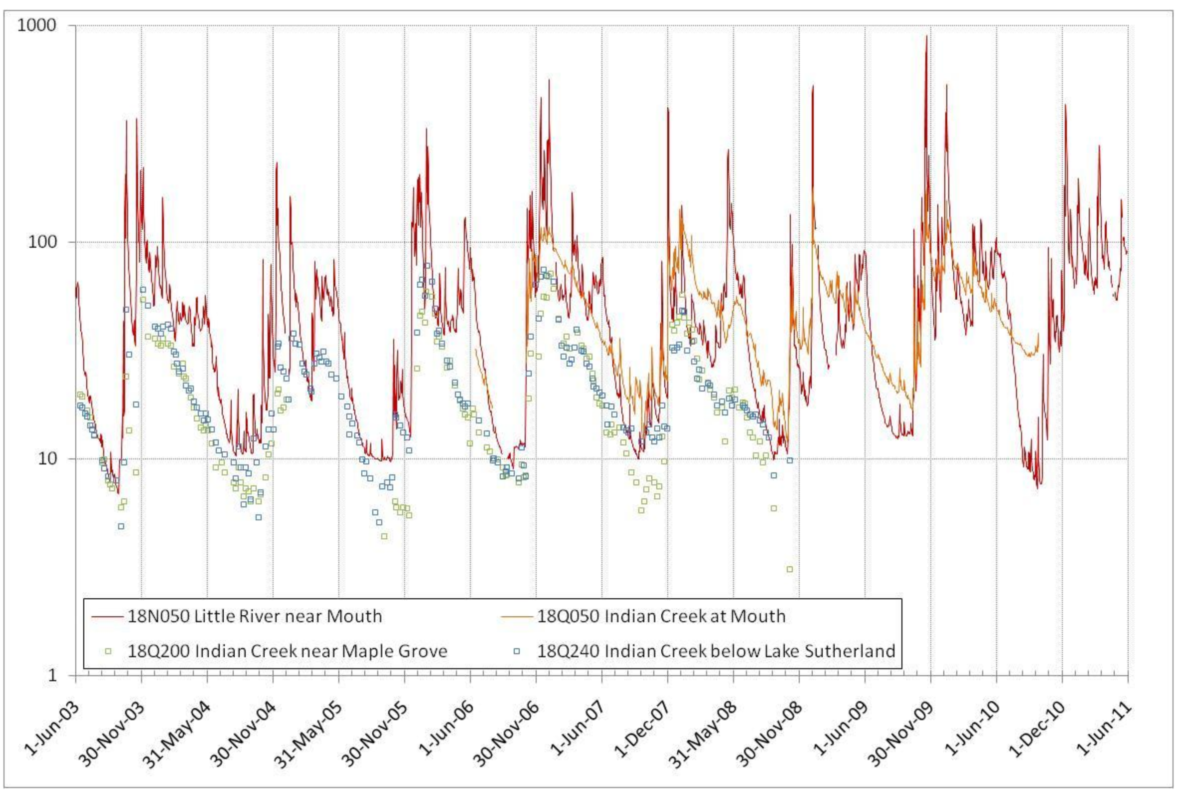

Figure 7. Flow at Indian Creek and Little River gaging stations, June 2003-May 2011.

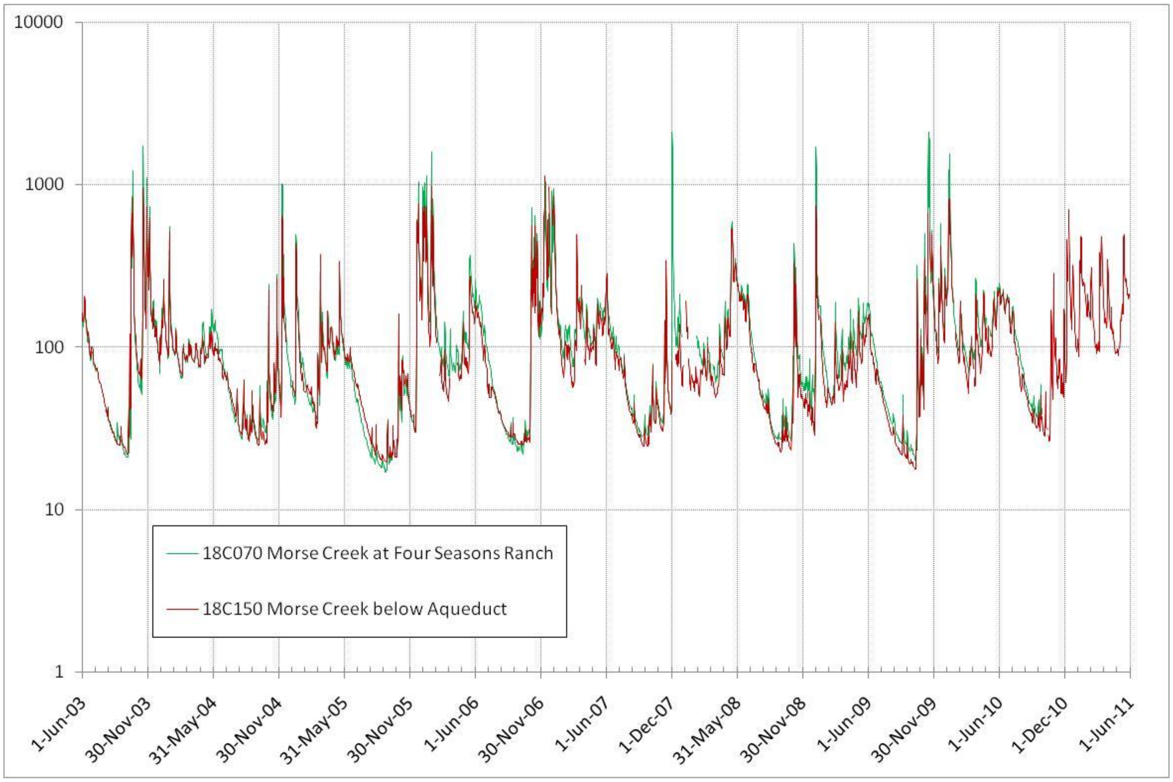

Figure 8. Flow at Morse Creek gaging stations, June 2003-May 2011.

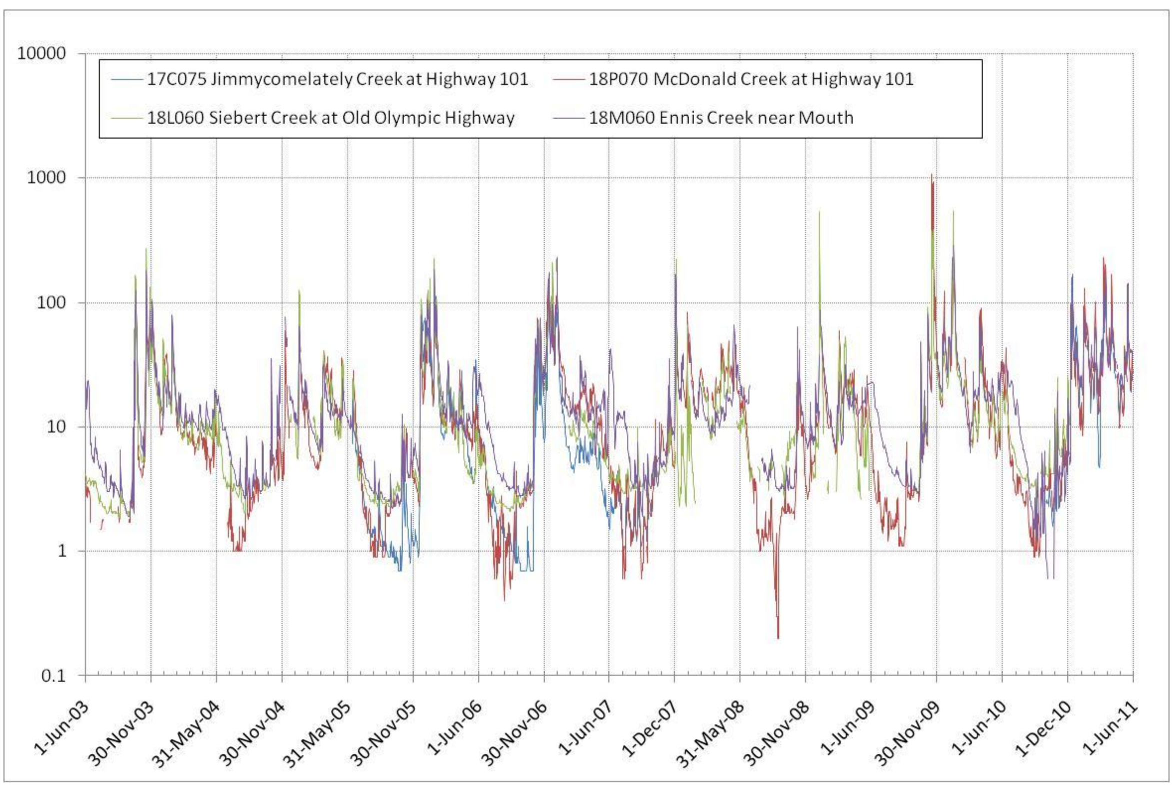

Figure 9. Flow at small coastal creek gaging stations, June 2003-May 2011.

Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Areal flow: Surface water discharge per unit of watershed area, in units of length per time (for example, inches per day).

Baseflow: The component of total streamflow that originates from direct groundwater discharges to a stream.

Hydrologic: Relating to the scientific study of the waters of the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water in streams, lakes, and on or below the land surface.

Hyporheic zone: The area beneath and adjacent to a stream where surface water and groundwater intermix.

Instream flow rule: A rule adopted by Ecology as part of the Washington Administrative Code which establishes a priority date for stream flow levels that must be taken into account when making water right decisions.

Parameter: A physical chemical or biological property whose values determine environmental characteristics or behavior.

Reach: A specific portion or segment of a stream.

Seepage run: A study of streamflow that identifies gaining and losing reaches and determines reach-specific magnitudes of groundwater/surface water exchange by calculating a detailed flow balance for the stream from a synoptic series of flow measurements.

Stage height: Water surface elevation from a local datum.

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.

Streamflow: Discharge of water in a surface stream (river or creek).

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.

Telemetry: The automatic transmission of data by wire, radio, or other means from remote sources.

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.

Water year (WY): An annual period defined by hydrologic characteristics. The water year used in this study is October 1 through September 30, and the number of the year represents the calendar year at the end of the water year. For example, WY 2010 describes the water year beginning October 1, 2009 and ending September 30, 2010.

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

%RSD	Percent relative standard deviation
DRMT	Dungeness River Management Team
Ecology	Washington State Department of Ecology
EMMT	Elwha-Morse Management Team
GIS	Geographic Information System software
NF	National Forest
No.	Number
NOAA	National Oceanic and Atmospheric Administration
RCW	Revised Code of Washington
RM	River mile
RPD	Relative percent difference
USGS	U.S. Geological Survey
USFS	U.S. Forest Service
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WY	(See Glossary above)

Units of Measurement

cfs	cubic feet per second, a unit of flow discharge
cms	cubic meters per second, a unit of flow discharge
ft	feet
g	gram, a unit of mass
in/d	inches per day
kg	kilograms, a unit of mass equal to 1,000 grams
kg/d	kilograms per day
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	million gallons
mgd	million gallons per day
mg/d	milligrams per day
mg/Kg	milligrams per kilogram (parts per million)
mL	milliliters