Elwha-Dungeness Watershed Planning Area

Prediction of Gaged Streamflows
by Modeling

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Elwha-Dungeness
Watershed Planning Area

Prediction of Gaged Streamflows
by Modeling

by

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Abstract

This study evaluates flow gaging stations in the Elwha-Dungeness watershed planning area, which includes Water Resource Inventory Area (WRIA) 18 and the Sequim Bay watershed in WRIA 17. The study addresses six telemetry flow stations that the Washington State Department of Ecology (Ecology) currently operates, as well as five Ecology continuous and manual staff gages no longer in operation.

This study developed regression-based models using data through August 2011 from Ecology study gages, based on other reference gages in the basin using power or linear relationships and a hydrograph separation method. The quality of these regressions was assessed using statistical methods.

The quality of the regression-based models was very good (median percent relative standard deviation less than 5%) for summer flows at one station, good (5-10%) to fair (10-20%) at seven stations, and poor (>20%) at three stations.

Recommendations were made for Ecology's gages based on study results:

- Ecology gages *McDonald Creek at Highway 101* and *Jimmycomelately Creek at Highway 101* should be retained.

- Ecology gages *Dungeness River near Mouth* and *Morse Creek below Aqueduct* should be retained, but alternative management approaches to reduce the need for Ecology resources should be explored.

- The models for the Ecology gages *Little River near Mouth* and *Ennis Creek near Mouth* had good to fair quality results and could be considered for decommissioning or transfer.

- Regression-based models for Ecology gages currently inactive are available for use if needed. If direct flow measurements are needed for any of these stations and resources become available, reactivation could be considered.

The needs of Washington State and of local partners for this flow information should be evaluated and be compared to the quality of the regression-based models to determine whether direct flow measurements or the models are adequate to meet those needs.

Acknowledgements

The following people contributed to this study, and their help is greatly appreciated.

Introduction

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).

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.

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 as 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.

Land Ownership, Land Use, and Water Use

Political jurisdictions in the Dungeness-Elwha watershed planning area include Clallam County as well as 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 is 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 one-half since the 1990s. The balance of agricultural water use is from groundwater. 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.

Watershed Planning Process

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 the 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 DRMT has been the primary forum for stakeholder input into this project, and EMMT members have been kept informed through DRMT.

Flow Monitoring

Department of Ecology Stations

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 historical 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 were analyzed in this study are shown in Table 1. Active and historical stream gages with sufficient data were included. The stations with manual stage height data over multiple years were also analyzed. The irrigation ditch stations and stations with less than one year of data were not included in this study.

USGS Stations

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 2. 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 was therefore not used in this analysis.
- Seven historical USGS stations in WRIA 18 with continuous flow have no data after 2001 and were not used for this analysis.

Other Flow Measurements

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).

Table 1. Ecology flow monitoring stations in the Elwha-Dungeness watershed planning area addressed by this study.

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 2. USGS active flow monitoring stations in the Elwha-Dungeness watershed planning area used in this study.

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 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

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 is currently in progress in the Dungeness after a delay due to the statewide rulemaking suspension. Local leaders have also been working 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 3. Also shown in Table 3 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 and USGS flow monitoring stations (Figure 1, Tables 1 and 2).

Table 3. 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

Study 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 EMMT, and other agencies and local stakeholders in their water management activities in the Elwha-Dungeness planning area.

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.

Methods

The methods used in this study were described in the Quality Assurance Project Plan (Pickett, 2011). The implementation of that plan is described in this section.

Data Sources and Characteristics

Flow Data

Daily average flow data were compiled for eleven Ecology stations and three USGS stations with continuous data, and instantaneous flows were compiled for the eight Ecology stations with manual staff gage readings (Tables 1 and 2). Flows at Ecology stations were analyzed from the beginning of the data sets through August 18, 2011. Flow data were withheld from the analysis when derived using interpolations or correlations.

Data sets for these stations were obtained from the Ecology River and Stream Flow Monitoring website (www.ecy.wa.gov/programs/eap/flow/shu_main.html) and from the USGS National Water Information System website (http://waterdata.usgs.gov/wa/nwis/sw).

Some of the flow data have been labeled as *provisional*, meaning that final data quality checks had not been completed. Ecology and USGS flow data are constantly under review and are updated as the review is completed. Provisional data were used for the development of the regressions with the understanding that the regressions would likely be updated in the future using the finalized flow information. This is reasonable since the provisional data are likely to be similar to the final values, and because the regressions will likely also be updated with additional data collected after August 2011.

Figures 2 through 12 show the streamflows for each of the Ecology stations as compared to flows from other selected gaging stations. Flows are presented using a logarithmic scale to more clearly illustrate patterns over time and allow comparison of flows of varying discharge amounts from different stations.

Flow patterns vary widely between stations at different locations in the basin. Notable characteristics of the flow patterns are:

- The lowest flows are found during the summer months in Ennis, Siebert, McDonald, and Jimmycomelately Creeks, with flows commonly less than 10 cfs and in some cases 1 cfs or less. These are also the "flashiest" creeks, with a very wide range between the lowest and highest flows.

- Morse Creek and Little River show intermediate flows of 10 to almost 1000 cfs.

- The Dungeness River has the highest flows, mostly between 100 and 1000 cfs, but dropping below 100 cfs in most summers and with peak flows occasionally over 1000 cfs.

- Indian Creek has the most stable flows, with a relatively narrow range from lowest to highest flows. The combination of Lake Sutherland at the headwaters and the many wetlands downstream may serve to support low flows and dampen high flows.

Areal Flows

To get a better understanding of the hydrologic response of the watershed to precipitation and snowmelt, flows were standardized to *areal flows* (sometimes called *unit flows* in hydrology literature) by dividing the streamflow by watershed area and converting the values to units of inches per day. This allows comparison to precipitation and snowmelt in the same units.

Two stations were selected to illustrate meteorological conditions in the basin for comparison to areal flows:

1. Waterhole SNOTEL station (Station Code "WHST")
   www.wcc.nrcs.usda.gov/nwcc/site?sitenum=974&state=wa

2. Dungeness SNOTEL station (Station Code "DUNST")
   www.wcc.nrcs.usda.gov/nwcc/site?sitenum=943&state=wa

3. Port Angeles Fairchild Airport National Weather Service station (Station Codes "PAAP" and "KCLM") www.wunderground.com/history/airport/KCLM/

Areal flows from the Ecology telemetry and stand-alone stations are shown in Figures 13 through 23. Also shown are (1) precipitation data from the Port Angeles Airport and (2) non-snow precipitation, snowmelt, and average daily air temperatures from the Waterhole or Dungeness SNOTEL station.

Snowmelt was calculated from the daily change in snow water equivalent (SWE), with negative changes in SWE representing snowmelt. Losses in SWE can also occur from evaporation or sublimation, but this method provides an estimate of the potential contribution of snow pack loss to river flows.

Some characteristics in the data patterns shown in Figures 13 through 23 are of interest:

- The strongest response to snowmelt can be seen in the Dungeness River and Morse Creek, which are the largest basins with the highest elevation headwaters.

- Little River and Ennis and McDonald Creeks show more of a mixed rain-snow regime, with a small response to snowmelt but a strong response to rain events.

- The most rain-dominated systems are Indian, Siebert, and Jimmycomelately Creeks, with little evidence of a snowmelt response.

Regressions and Other Analysis Methods

Flow data were first evaluated by comparing daily average flows from each study station for the entire record (November 5, 1999 through August 18, 2011) with flows from several USGS and Ecology reference stations using either linear or power regressions. A linear regression is in the form y=mx+b, while a power regression takes the form of $y=cx^d$. The regression between paired values of x and y determines either the coefficient m and the intercept b, or the coefficient c and the exponent d. A power regression is arithmetically identical to the linear regression of two log-transformed data sets.

A hydrograph separation technique was used to improve regression relationships. Hydrologic baseflow is the groundwater inflow component of a stream hydrograph. In reality, baseflow varies seasonally and from year to year. As a simplifying assumption for this analysis, baseflow was defined as all flows below a threshold level on either an annual or seasonal basis for all years considered in the analysis. The term *baseflow* will be used in this sense for the rest of this report.

Flow data were first reviewed, and values not derived from direct stage measurements (derived from interpolations or regressions from neighboring dates or stations) were removed. Data were also reviewed for periods of spurious values, and data clearly of poor quality were removed.

Reference stations were selected by evaluating correlations between the stations (Table 4). Reference stations were chosen from the best correlations in the following order:

1. At least one station with the best correlation at a stable, long-term USGS gage.

2. At least one station with the best correlation at a USGS gage or Ecology gage most likely to be retained, such as critical control stations.

3. Two more correlations at any gage with a long data record.

Regressions were then developed using the following process:

1. Simple regressions were developed between the study stations and the reference stations, and quality metrics were calculated. For these and all other regressions, linear and power regressions were evaluated, and the one that produced a better fit with data was chosen.

2. Areal flows were calculated for the study and reference stations.

3. Where the time-of-travel in the streams differ, offsetting or lagging flow information in time can sometimes improve the relationship between gages. To evaluate whether time-of-travel differences existed, flow time series were compared to determine whether transient flow peaks coincided or were offset by one or two days.

    The baseflow threshold at each study gage was determined by comparison of the flow time series to precipitation and snowmelt. The threshold was selected to capture the majority of flows unaffected by precipitation events from early summer through mid-autumn. At some stations, flows below the baseflow threshold were also observed during cold spells in the winter.

4. For each reference gage (the independent variable in the regression), a baseflow threshold was then selected that produced baseflow periods most similar to the study gage. (Specifically, this was the median of the flows from the reference gage on the dates at the beginning and ending of a baseflow period for the evaluation gage.)

5. The "summer" season was separated from the "winter" season by determining the month when spring freshet flows ended and baseflows began, and the month when baseflows ended. Different choices of beginning and ending months were evaluated to determine the split that produced the best quality regressions.

6. For each reference station, the flow records for paired study and reference station flows were split into two categories, four categories, or three categories for analysis:

   a. Two categories:
      o *Baseflows* – less than the baseflow threshold occurring all year.
      o *Non-baseflows (Freshet and storm flows)* – greater than the baseflow threshold occurring all year.

   b. Four categories:
      o *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      o *Winter baseflows* – less than the baseflow threshold occurring from late autumn through early summer.
      o *Winter non-baseflows* – greater than the baseflow threshold occurring from late autumn through early summer.
      o *Summer non-baseflows* – greater than the baseflow threshold occurring from mid-summer through early autumn.

   c. Three categories, either:
      o *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      o *Summer non-baseflows* – greater than the baseflow threshold occurring from mid-summer through early autumn.
      o *Winter flows* – flows occurring from November through June.
      or:
      o *Summer baseflows* – less than the baseflow threshold occurring from mid-summer through early autumn.
      o *Winter baseflows* – less than the baseflow threshold occurring from late autumn through early summer.
      o *Non-baseflows (Freshet and storm flows)* – greater than the baseflow threshold occurring all year.

   Quality metrics were evaluated for all combinations.

Table 4. Correlations between study area flow monitoring stations.

Coefficient colors emphasize strongest correlations: blue/bold = greater than 0.9, green/bold italic = between 0.8 and 0.9, red/italic = between 0.7 and 0.8, grey = less than 0.8. Station colors are explained in legend (upper right). Station IDs are defined in Tables 1 through 3.

Legend:
- ECY-Telemetry
- USGS
- ECY-Manual Staff
- *Potential Control Station*
- * Historical gage

	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	0.51												
McD-101	0.82	0.51											
Siebert*	0.87	0.61	0.78										
Mor-4S*	0.79	0.85	0.72	0.86									
Mor-Aq	0.65	0.84	0.75	0.77	0.94								
Ennis	0.74	0.70	0.84	0.86	0.85	0.84							
Little	0.69	0.76	0.78	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	0.45	0.90	0.50	0.62	0.87	0.84	0.70	0.80	0.43	0.32	0.42		
El-McD	0.47	0.89	0.52	0.66	0.88	0.87	0.72	0.80	0.46	0.31	0.45	0.99	
Dun-GS	0.37	0.79	0.37	0.49	0.70	0.71	0.58	0.63	0.29	0.22	0.32	0.80	0.79

Quality Analysis

As described in the project plan (Pickett, 2011), model accuracy was assessed by comparison of paired daily flow values from the measured and modeled time series. Bias was assessed by calculating the relative percent difference (RPD) for all predicted and observed pairs individually, and then evaluating the median of RPD values for all predicted and observed pairs.

$$RPD_i = [100 * (P_i - O_i)] / [(O_{i +} P_i) / 2], \text{ where}$$
$$P_i = i^{th} \text{ prediction}$$
$$O_i = i^{th} \text{ observation}$$
$$RPD_i = \text{relative percent difference of the } i^{th} \text{ predicted and observed pair}$$

Precision was assessed with the percent relative standard deviation (%RSD) for predicted and observed pairs individually and using the median 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.

$$\%RSD_i = (SD_i * 100) / [(P_i + O_i) / 2], \text{ where}$$
$$SD_i = \text{standard deviation of the } i^{th} \text{ predicted and observed pair}$$
$$\%RSD_i = \text{percent relative standard deviation of the } i^{th} \text{ predicted and observed pair}$$

The uncertainty of the flows determined by each regression equation was evaluated using the %RSD for all flow conditions and for baseflows. For evaluating the regression for baseflows, observed and modeled data from the study gage were stratified using the baseflow threshold for that station.

The following terminology will be used to describe model results:

Median %RSD for annual streamflow or summer baseflow	Characterization
Less than 5%	Very Good
Greater than 5% and less than 10%	Good
Greater than 10% and less than 20%	Fair
Greater than 20%	Poor

Results

Regression-based Model Parameters

For all pairs of stations evaluated, peak flows occurred most often on the same date, so time-lagging of data was not used in the analysis.

Table 5 presents the results of the regression modeling analysis. For each study gage, regressions from a primary and a secondary reference station are presented. Alternative regression options are presented because of the possibility that some the gages could be discontinued or data might not be available for other reasons.

For each study station, the following is shown:

- The reference flow monitoring station (see Tables 1 and 2 for station codes and full station information).

- The reference station baseflow threshold used for hydrograph separation.

- The season and flow category for separating flow for each regression.

- Whether the regression is a linear or a power regression.

- The coefficient and y-intercept of the linear regression, or the coefficient and exponent of the power regression.

- The r^2 of the regression (a measure of the goodness-of-fit for each individual regression).

- The number of values (n) that each regression is based on.

Regression-based Model Quality

Table 6 shows the quality of each regression. Goodness-of-fit is indicated by the median %RSD values for all flows and for the summer baseflows.

- Primary regression-based models had a very good fit for summer baseflow (%RSD values below 5%), and a fair fit for all flows (%RSD values between 10% and 20%), at *Morse Creek at Four Seasons Ranch.*

- Five stations had primary regression-based models with a good fit for summer baseflows and a fair fit for all flows:
  - *Indian Creek at Mouth*
  - *Little River near Mouth*
  - *Ennis Creek near Mouth*
  - *Morse Creek below Aqueduct*
  - *Siebert Creek at Old Olympic Highway*

- The primary regression-based models had a good fit for all flows and a fair fit for summer baseflows at the station *Dungeness River near Mouth*.

- The primary regression-based models had a good fit for summer baseflows and a poor fit for all flows at the *Jimmycomelately Creek at Highway 101* station.

- The primary regression-based models had a poor fit for summer baseflows and for all flows at the *McDonald Creek at Highway 101* station.

- The quality of regression-based models was fair for all flows at *Indian Creek below Lake Sutherland*, and poor for all flows at *Indian Creek near Maple Grove*. However, both of these manual staff gage stations have good quality regression-based models based on the historic gage *Indian Creek at Mouth*.

Figures 24 through 34 show the measured and modeled values for each study station based on the primary reference station, along with the goodness-of-fit as RPD shown on the right axis. A few patterns should be noted:

- Small differences in very low flows can produce RPD values of high magnitude[1]. This is not representative of the goodness-of-fit for low flows and would tend to inflate the average RPD for the model.

- For higher flows, extreme RPD values highlight the differences in the hydrograph behavior between the study and reference station.

- Over all flows, the median RPD was good, with a range of +/- 3% for all stations, except for McDonald Creek station which was over 13%. For baseflows, the RPD values were biased high, with most stations between 2% and 5%, while two stations had median values of 9.6% and 30.8%. This is consistent with the tendency of RPD at low flows to produce high values.

- The range of RPD values varied among the stations: from the narrowest range of -64% to 81% at the Indian Creek at Mouth station, to the widest range of -167% to 182% at the McDonald Creek station. Note that the right-hand scale on the graph varies between figures so that the temporal patterns can be seen clearly.

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[1] For example, flows of 24.6 and 25.1 cfs produce an RPD of 1.9%, but flows of 0.2 and 0.7 cfs produce an RPD of 113.7%, even though the difference for both is 0.5 cfs.

Table 5. Regressions for study gages using the hydrograph separation method.

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation Season	Hydrograph Separation Flow level	Linear or Power?	Coefficient	Intercept or Exponent	r²	n
18Q050	Indian Creek at Mouth	Ennis (Primary)	5.48	Jul-Nov	base	Power	23.8	-0.0912	0.013	369
				Jul-Nov	non-base	Power	11.5	0.443	0.69	236
				Dec-Jun	all flows	Linear	0.471	50.4	0.29	899
18Q050	Indian Creek at Mouth	Mor-Aq (Secondary)	42.7	Jul-Nov	base	Linear	0.351	10.4	0.25	319
				Jul-Nov	non-base	Power	3.15	0.540	0.71	326
				Dec-Jun	all flows	Linear	0.0740	51.1	0.16	888
18N050	Little River near Mouth	Ennis (Primary)	3.7	Aug-Oct	base	Power	8.01	0.300	0.21	472
				Aug-Oct	non-base	Power	3.27	1.02	0.86	246
				Nov-Jul	all flows	Power	5.92	0.787	0.80	2334
18N050	Little River near Mouth	El-aLM (Secondary)	487.8	Aug-Sep	base	Power	5.11	0.134	0.05	275
				Aug-Sep	non-base	Linear	0.0235	-2.32	0.72	156
				Oct-Jul	base	Linear	0.0270	4.20	0.20	161
				Oct-Jul	non-base	Linear	0.0370	7.89	0.58	2082
18M060	Ennis Creek near Mouth	Little (Primary)	12.4	Aug-Oct	base	Power	0.0927	1.46	0.37	402
				Aug-Oct	non-base	Linear	0.280	-0.199	0.86	316
				Nov-Jul	all flows	Power	0.281	1.02	0.80	2334
18M060	Ennis Creek near Mouth	McD-101 (Secondary)	2.2	Sep-Oct	base	Linear	0.120	2.91	0.008	138
				Sep-Oct	non-base	Linear	1.03	0.228	0.9	275
				Nov-Aug	base	Power	4.00	0.208	0.03	307
				Nov-Aug	non-base	Linear	0.692	7.696	0.68	2009
18C150	Morse Creek below Aqueduct	El-aLM (Primary)	488.9	Aug-Sep	base	Power	0.637	0.642	0.63	286
				Aug-Sep	non-base	Linear	0.0534	5.51	0.71	155
				Oct-Jul	base	Power	0.530	0.683	0.38	158
				Oct-Jul	non-base	Power	0.0710	1.02	0.74	2043
18C150	Morse Creek below Aqueduct	Dun-ECY (Secondary)	104.1	Aug-Sep	base	Power	11.0	0.202	0.21	260
				Aug-Sep	non-base	Linear	0.111	20.0	0.79	242
				Oct-Jul	base	Linear	0.285	11.1	0.23	212
				Oct-Jul	non-base	Power	0.832	0.828	0.69	2280
18C070	Morse Creek at Four Seasons Ranch	El-aLM (Primary)	500.4	Aug-Oct	base	Power	0.515	0.683	0.65	401
				Aug-Oct	non-base	Linear	0.0575	3.94	0.61	212
				Nov-Jul	all flows	Power	0.0970	0.992	0.78	1754
18C070	Morse Creek at Four Seasons Ranch	Mor-Aq (Secondary)	none	All year	All year	Power	0.993	1.02	0.96	2429

Table 5, continued. Regressions for study gages using the hydrograph separation method.

Ecology Telemetry Gages

Station ID	Station Name	Reference Station Code	Baseflow Threshold (cfs)	Hydrograph Separation		Linear or Power?	Coefficient	Intercept or Exponent	r²	N
				Season	Flow level					
18L060	Siebert Creek at Old Olympic Highway	JCL-101 (Primary)	1.78	Aug-Sep	base	Linear	0.752	1.70	0.21	154
				Oct-Jul	base	Linear	3.23	0.138	0.04	121
				All year	non-base	Power	1.75	0.864	0.82	542
18L060	Siebert Creek at Old Olympic Highway	Little (Secondary)	14.7	Aug-Sep	base	Power	1.05	0.408	0.07	301
				Oct-Jul	base	Linear	0.0415	3.22	0.002	219
				All year	non-base	Power	0.1840	1.03	0.56	1862
18P070	McDonald Creek at Highway 101	Ennis (Primary)	3.94	Aug-Sep	base	Linear	0.0634	1.50	0.002	320
				Aug-Sep	non-base	Power	1.11	0.330	0.07	109
				Oct-Jul	base	Linear	0.0944	2.49	0.005	170
				Oct-Jul	non-base	Linear	0.98	-0.551	0.68	2130
18P070	McDonald Creek at Highway 101	JCL-101 (Secondary)	1.93	Aug-Sep	base	Power	1.37	-0.150	0.006	157
				Aug-Sep	non-base	Power	1.93	0.112	0.06	31
				Oct-Jul	base	Power	2.54	-0.145	0.010	154
				Oct-Jul	non-base	Power	1.68	0.884	0.76	758
18A050	Dungeness River near Mouth	Dun-GS (Primary)	148	Aug-Oct	base	Linear	0.457	24.8	0.16	471
				Aug-Oct	non-base	Linear	0.974	-47.2	0.97	552
				Nov-Jul	all flows	Linear	1.01	-20.3	0.94	3242
18A050	Dungeness River near Mouth	Mor-Aq (Secondary)	30.1	Aug-Oct	base	Power	0.0705	2.16	0.37	392
				Aug-Oct	non-base	Linear	3.16	51.7	0.88	357
				Nov-Jul	all flows	Power	4.86	0.909	0.69	2245
17C075	Jimmycomelately Creek at Highway 101	Ennis (Primary)	3.77	Aug-Sep	base	Power	0.473	0.903	0.14	149
				Aug-Sep	non-base	Linear	0.405	0.0600	0.88	42
				Oct-Jul	all flows	Power	0.322	1.17	0.73	901
17C075	Jimmycomelately Creek at Highway 101	McD-101 (Secondary)	1.63	Aug-Sep	base	Linear	0.281	1.01	0.11	104
				Oct-Jul	base	Power	1.73	0.362	0.13	37
				All year	non-base	Power	0.664	1.02	0.81	959

Table 5, continued. Regressions for study gages using the hydrograph separation method.

Ecology Manual Staff Gages									
Station ID	Station Name	Reference Station Code	Reference Station Priority	Hydrograph Separation	Linear or Power?	Coefficient	Intercept or Exponent	r^2	n
18Q240	Indian Creek below Lake Sutherland	Little	(Primary)	All year	Power	2.16	0.616	0.72	214
		McD-101	(Secondary)	All year	Power	8.65	0.413	0.63	85
		Ind-Mou	(reference)	All year	Power	0.596	0.945	0.87	174
18Q200	Indian Creek near Maple Grove	Little	(Primary)	All year	Power	1.74	0.626	0.61	179
		McD-101	(Secondary)	All year	Power	7.05	0.435	0.53	74
		Ind-Mou	(reference)	All year	Power	0.322	1.07	0.87	142

Table 6. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Median %RSD for regression-based model					
				<5%	5-10%	10-15%	15-20%	20-25%	25-30%
				Very good	Good	Fair	Fair	Poor	Poor
Ecology Telemetry Gages									
18Q050	Indian Creek at Mouth	Ennis	Summer baseflow		X				
			All flows			X			
18Q050	Indian Creek at Mouth	Mor-Aq	Summer baseflow			X			
			All flows			X			
18N050	Little River near Mouth	Ennis	Summer baseflow		X				
			All flows			X			
18N050	Little River near Mouth	El-aLM	Summer baseflow		X				
			All flows				X		
18M060	Ennis Creek near Mouth	Little	Summer baseflow		X				
			All flows			X			
18M060	Ennis Creek near Mouth	McD-101	Summer baseflow		X				
			All flows				X		
18C150	Morse Creek below Aqueduct	El-aLM	Summer baseflow		X				
			All flows			X			
18C150	Morse Creek below Aqueduct	Dun-ECY	Summer baseflow		X				
			All flows			X			
18C070	Morse Creek at Four Seasons Ranch	El-aLM	Summer baseflow	X					
			All flows			X			
18C070	Morse Creek at Four Seasons Ranch	Mor-Aq	Summer baseflow		X				
			All flows		X				
18L060	Siebert Creek at Old Olympic Highway	JCL-101	Summer baseflow		X				
			All flows			X			
18L060	Siebert Creek at Old Olympic Highway	Little	Summer baseflow		X				
			All flows					X	
18P070	McDonald Creek at Highway 101	Ennis	Summer baseflow					X	
			All flows					X	
18P070	McDonald Creek at Highway 101	JCL-101	Summer baseflow					X	
			All flows						X
18A050	Dungeness River near Mouth	Dun-GS	Summer baseflow			X			
			All flows		X				
18A050	Dungeness River near Mouth	Mor-Aq	Summer baseflow			X			
			All flows			X			

Table 6, continued. Model quality results for regressions as median %RSD for study gaging stations.

Station ID	Station Name	Reference Station Code	Hydrograph Separation Unit	Median %RSD for regression-based model					
				<5%	5-10%	10-15%	15-20%	20-25%	25-30%
Ecology Telemetry Gages				Very good	Good	Fair	Fair	Poor	Poor
17C075	Jimmycomelately Creek at Highway 101	Ennis	Summer baseflow All flows		X			X	
17C075	Jimmycomelately Creek at Highway 101	McD-101	Summer baseflow All flows		X				X
Ecology Manual Staff or Recent Telemetry Gages				Very good	Good	Fair	Fair	Poor	Poor
18Q240	Indian Creek below Lake Sutherland	Little McD-101 Ind-Mou	All flows All flows All flows		X	X X			
18Q200	Indian Creek near Maple Grove	Little McD-101 Ind-Mou	All flows All flows All flows		X			X X	

Table 7 summarizes the reference stations analyzed for the Ecology study stations. The numbers in the grid indicate whether the active station is the primary (1°) or secondary (2°) preference. Totals for each station are shown at the bottom. Table 7 gives some sense of which gages were most useful as reference stations.

Table 7. Summary of study and reference flow monitoring stations.

Reference stations → / Study Stations ↓	Little	Ennis	Mor-Aq	McD-101	Dun-ECY	JCL-101	El-aLM	Dun-GS
Ind-Mou		1°	2°					
Little		1°					2°	
Ennis	1°			2°				
Mor-Aq					2°		1°	
Mor-4S			2°				1°	
Siebert	2°					1°		
McD-101		1°				2°		
Dun-ECY			2°					1°
JCL-101		1°		2°				
Ind-LS	1°			2°				
Ind-MG	1°			2°				
No. Primary	3	4	-	-	-	1	2	1
No. Secondary	1	-	3	4	1	1	1	-
TOTAL	4	4	3	4	1	2	3	1

Preferences: 1° = Primary; 2° = Secondary

Discussion

The gaged streams in the Elwha-Dungeness watershed planning area can vary widely in their range of flows. Runoff patterns also vary depending on the elevation and land use. Based on this analysis, some patterns emerge:

- The station at *Morse Creek at Four Seasons Ranch* has been discontinued, and the quality of the model at this site (very good in summer and fair for all flows) suggests that the model could suffice to support the current level of water management. This location has been proposed in the Elwha-Morse planning area (WRIA 18W) basin plan to serve as a regulatory control station, but there is currently no instream flow rule in place. If the need arises for direct continuous measurements at this location for future water management needs, reactivation of this station could be considered.

- Three Ecology stations have regression-based models that show a good fit for summer baseflows and a fair fit for all flows and are located in the Elwha-Morse planning area (WRIA 18W). They have been proposed in the basin plan to serve as regulatory control stations, but there is currently no instream flow rule in place or active management of water resources: *Indian Creek at Mouth, Little River near Mouth,* and *Ennis Creek near Mouth.*

  The active stations should be considered for decommissioning or transfer, with the possibility of reactivation should water management become more active and resources become available. The Indian Creek gage is already decommissioned, but could be included in that reassessment should water management needs merit direct flow gaging at that station.

- The model for Ecology *Siebert Creek at Old Olympic Highway* station shows a good fit for summer baseflows and a fair fit for all flows. This station is currently discontinued due to the instability of the former site in high flows. The draft Dungeness instream flow rule includes this site as a regulatory control station.

  Because of the lack of a dependable site on Siebert Creek, the regression-based model could be used as an interim measure until it proves inadequate for the level of management on the stream. At that time, if resources to support a new gage on this stream are available, a thorough assessment of the stream would be needed to identify a dependable location and technology for gaging.

- The model for Ecology *Morse Creek below Aqueduct* station shows a good fit for summer baseflows and a fair fit for all flows. This station is currently actively used for management of flows in Morse Creek.

  Several options could reduce the need for Ecology's support of this gage. Flows are also measured at the diversion weir by Clallam Public Utility District, and could supply accurate flows at certain times of the year. Because of the management of Morse Creek for diverse uses, local partners could be found to serve as cooperators at this station. And at some times of the year when management needs are low, the model may be adequate to assess flow needs. Ecology and stakeholders should explore whether some combination of these approaches could reduce the level of Ecology's support at this station.

- The station *Dungeness River near Mouth* is currently a core station for management of the Dungeness River. The regression-based model could not meet the needs for flow data at this station during the irrigation season. The quality of the model for winter flows is good, and the need for direct flow measurements during certain times of the year may be less. This is an important station for Ecology to support, but it may be worthwhile to work with local stakeholders to determine if the use of this gage as a seasonal gage would meet their needs.

- The quality of the model results for Ecology stations *McDonald Creek at Highway 101* and *Jimmycomelately Creek at Highway 101* are both poor. The McDonald Creek station has been proposed as a regulatory control station in the draft Dungeness rule. The Jimmycomelately Creek site has a relatively short record and is the site of a major stream channel restoration project. Continued funding and operation of these stations is recommended.

- None of the manual staff stations in the basin are in service. Models were developed for use at these stations for flow assessment, and the models are available should the need arise.

Conclusions and Recommendations

This study draws the following conclusions and recommendations:

- The hydrograph separation method can be used to develop regression-based computer models to estimate streamflow at Ecology gaging stations in the Elwha-Dungeness watershed planning area (WRIA 18 and the Sequim Bay watershed in WRIA 17).

- The quality of the streamflow estimates from these regression-based models was evaluated, and based on the results of that evaluation, recommendations are provided for Ecology's support of flow gaging stations:

  o *Little River near Mouth* and *Ennis Creek near Mouth*: Decommissioning or transfer of these stations should be considered.

  o *Indian Creek at Mouth*, *Morse Creek at Four Seasons Ranch*, and *Siebert Creek at Old Olympic Highway*: These stations should remain deactivated.

  o *Morse Creek below Aqueduct*: Continued funding and operation of this station is recommended. However alternatives should be explored, such as a combined use of the weir gage and model, or cooperative funding of the gage with local partners.

  o *Dungeness River near Mouth*: Continued funding and operation of this station is recommended. However alternatives should be explored, such as seasonal operation of the gage, or cooperative funding of the gage.

  o *McDonald Creek at Highway 101* and *Jimmycomelately Creek at Highway 101*: Continued funding of these stations is recommended.

- Regressions are available to predict flows for decommissioned staff and continuous gage stations.

- If water management efforts increase, resources become available, and the need for direct flow gaging is identified at stations that have been discontinued, those stations should be reevaluated for possible reactivation.

- The accuracy of the regression-based models should be evaluated against flow monitoring needs for Ecology and the local community to determine whether the models provide an acceptable substitute for flow gaging. All regression-based models for study flow stations should be used for specific purposes with consideration as to whether their accuracy serves that purpose. Stations may be redundant in terms of the ability of the regression to predict flows, but removal of a station may lose other information or the ability to use that flow data for other analyses. Conceptually the regressions should be used as "screening tools" to trigger a direct evaluation of flow, or used for purposes where a rough estimate is acceptable.

- Regressions from provisional data should be of sufficient quality to be applied to the regression-based models. Updating of regression models with quality-checked data could slightly improve the quality of the regressions. Regression-based models should be updated

when additional measured flow data are available and when flow data quality reviews are completed.

- Technology transfer of these regression-based models and training on the use and updating of the models should be provided as needed to staff from Ecology, local partners, or other agencies.

References

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Pickett, P., 2011. Quality Assurance Project Plan: Elwha-Dungeness Watershed Planning Area Assessment of Gaged Streamflows by Modeling. Washington State Department of Ecology, Olympia, WA. Publication No. 11-03-112. www.ecy.wa.gov/biblio/1103112.html.

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Figures

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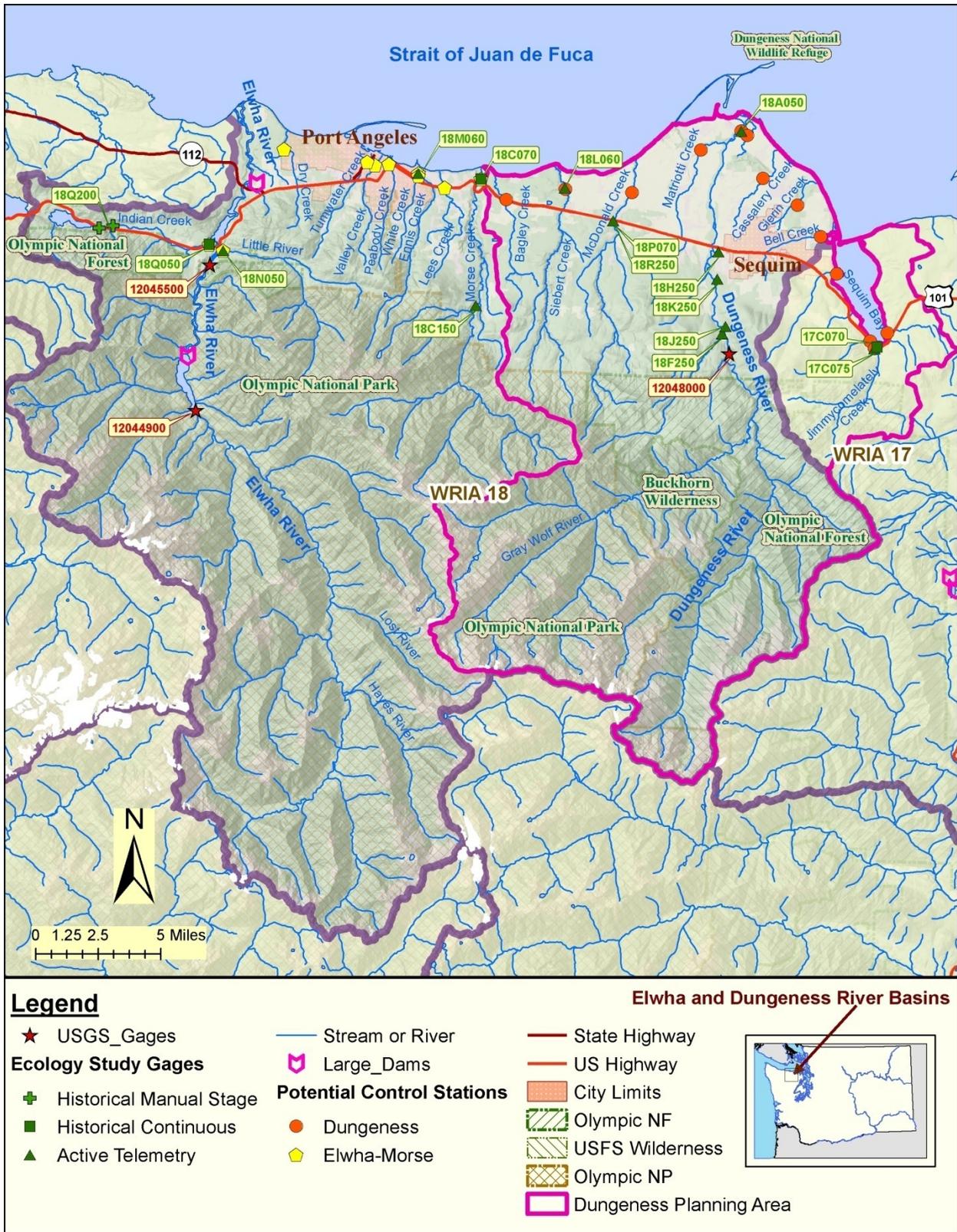
Figure 1. Elwha-Dungeness watershed planning area (study area).
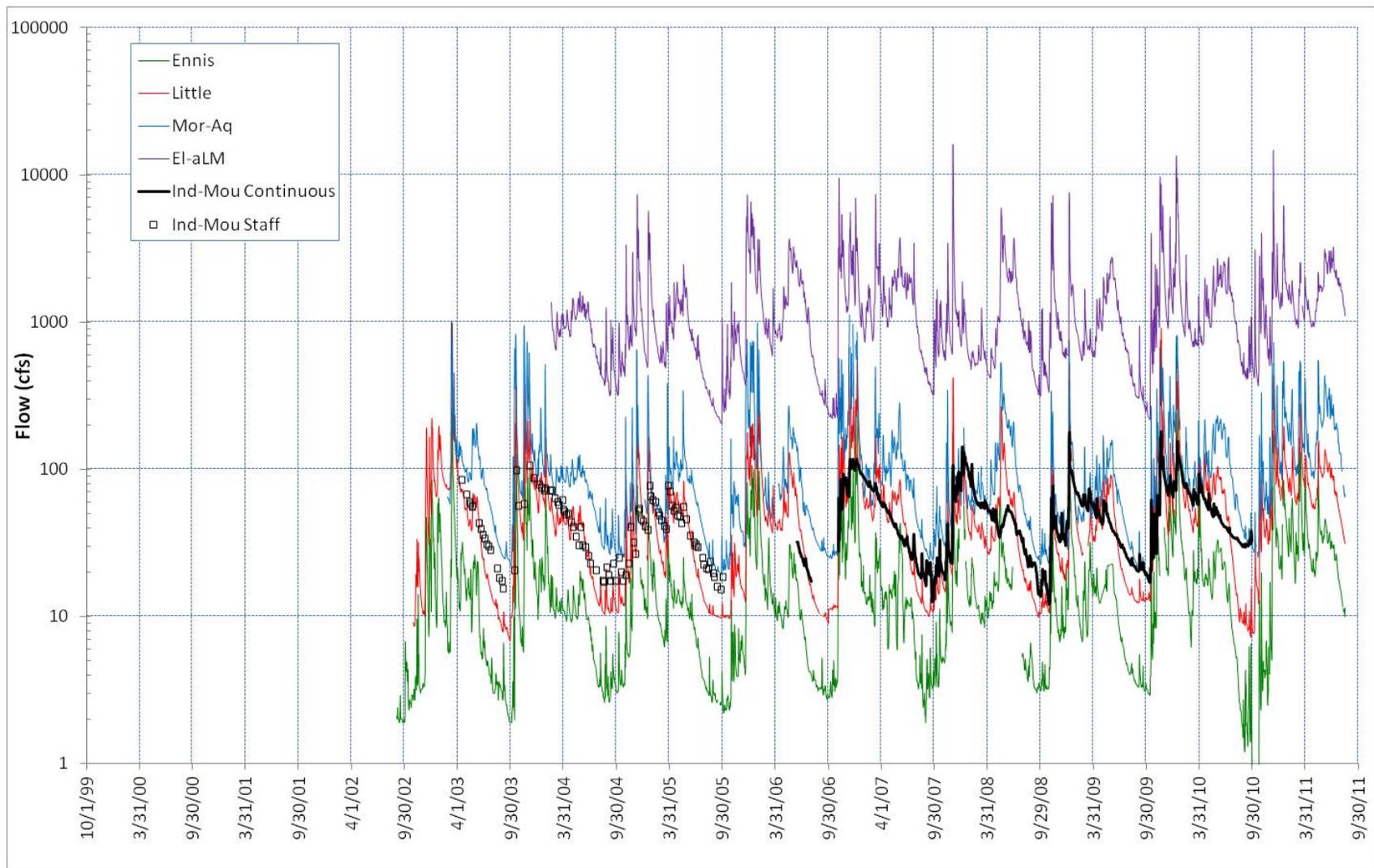
Figure 2. Measured flows at the Ecology "Indian Creek at Mouth" gaging station, with flows from other selected gages.
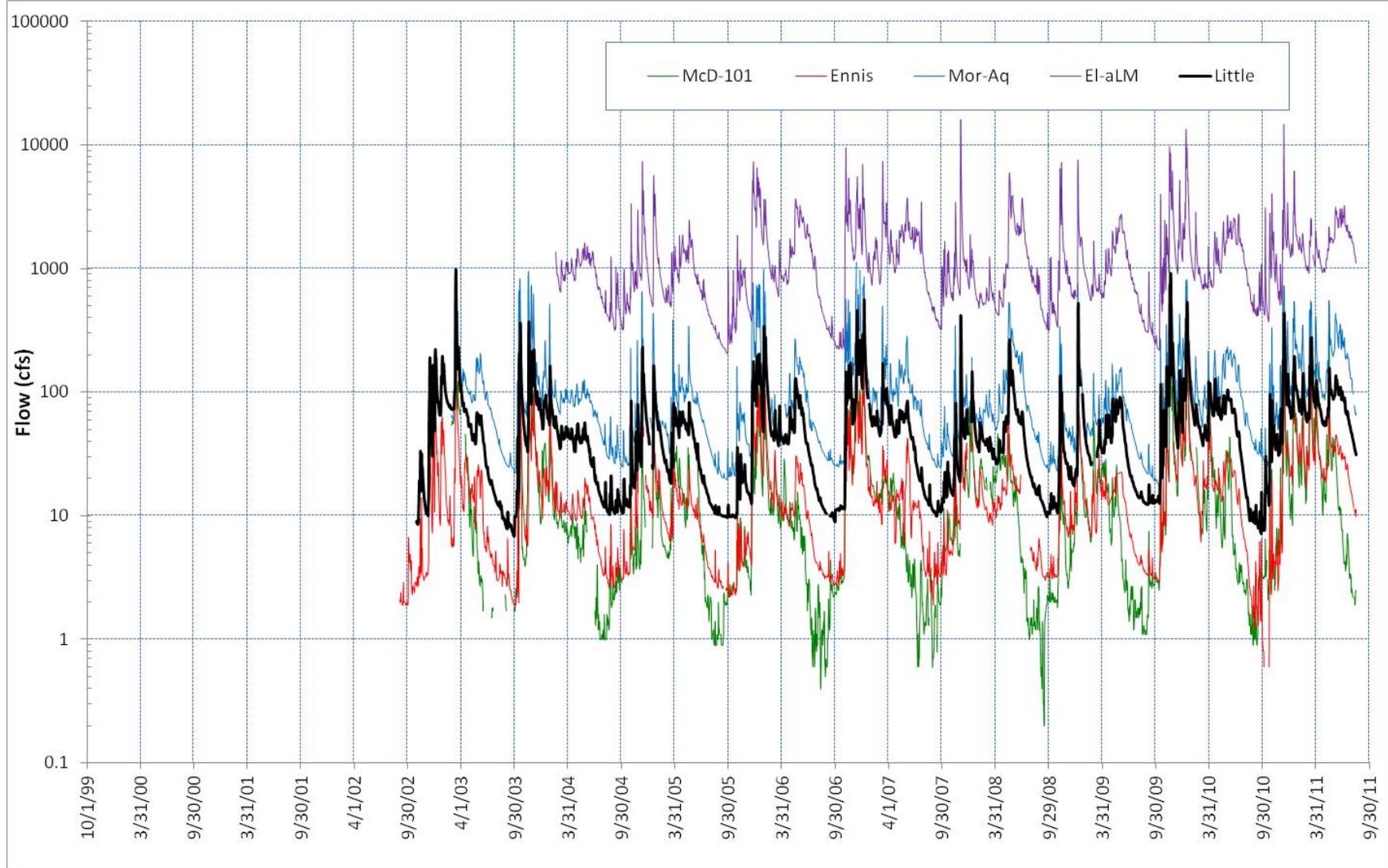
Figure 3. Measured flows at the Ecology "Little River near Mouth" gaging station, with flows from other selected gages.
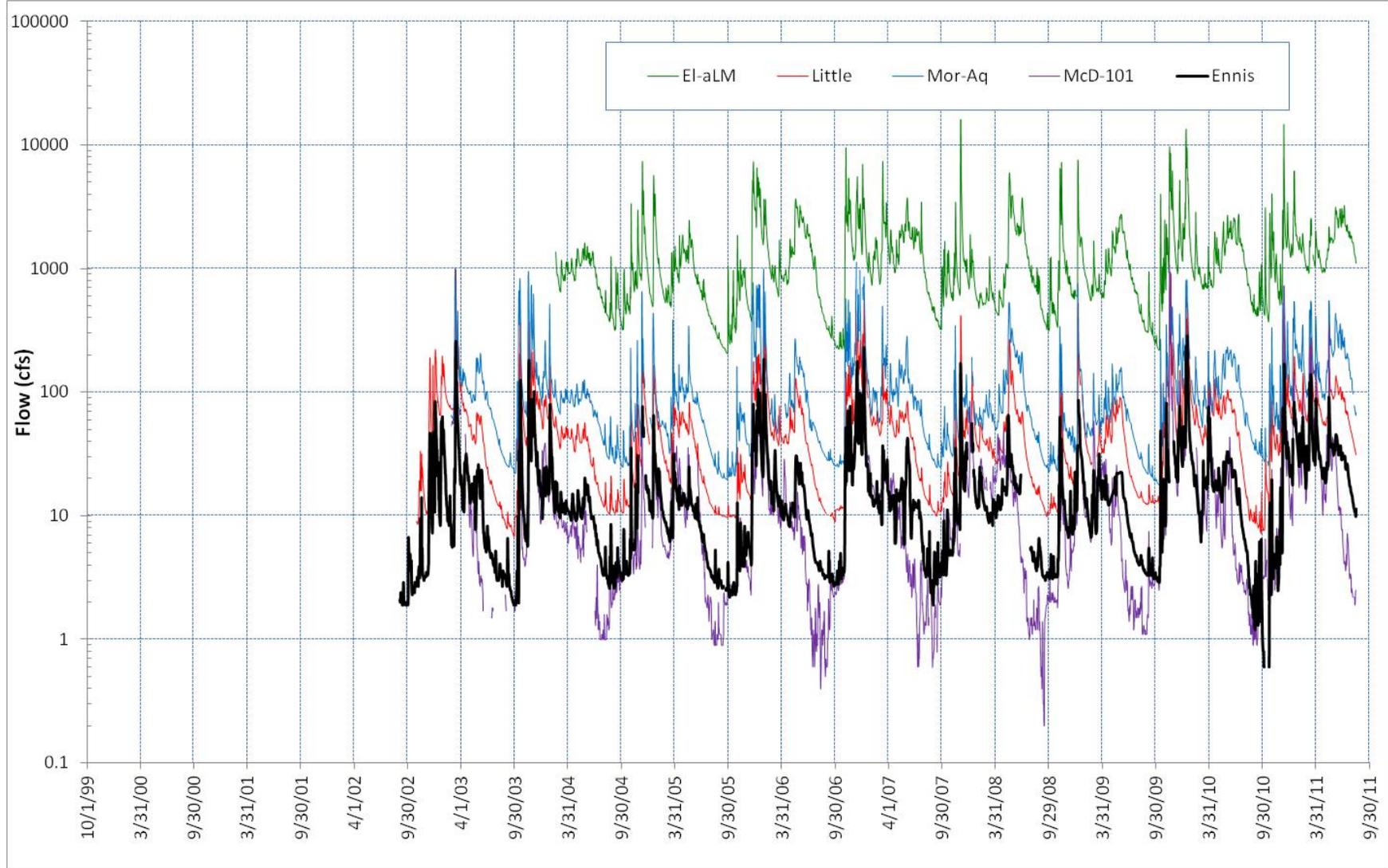
Figure 4. Measured flows at the Ecology "Ennis Creek near Mouth" gaging station, with flows from other selected gages.
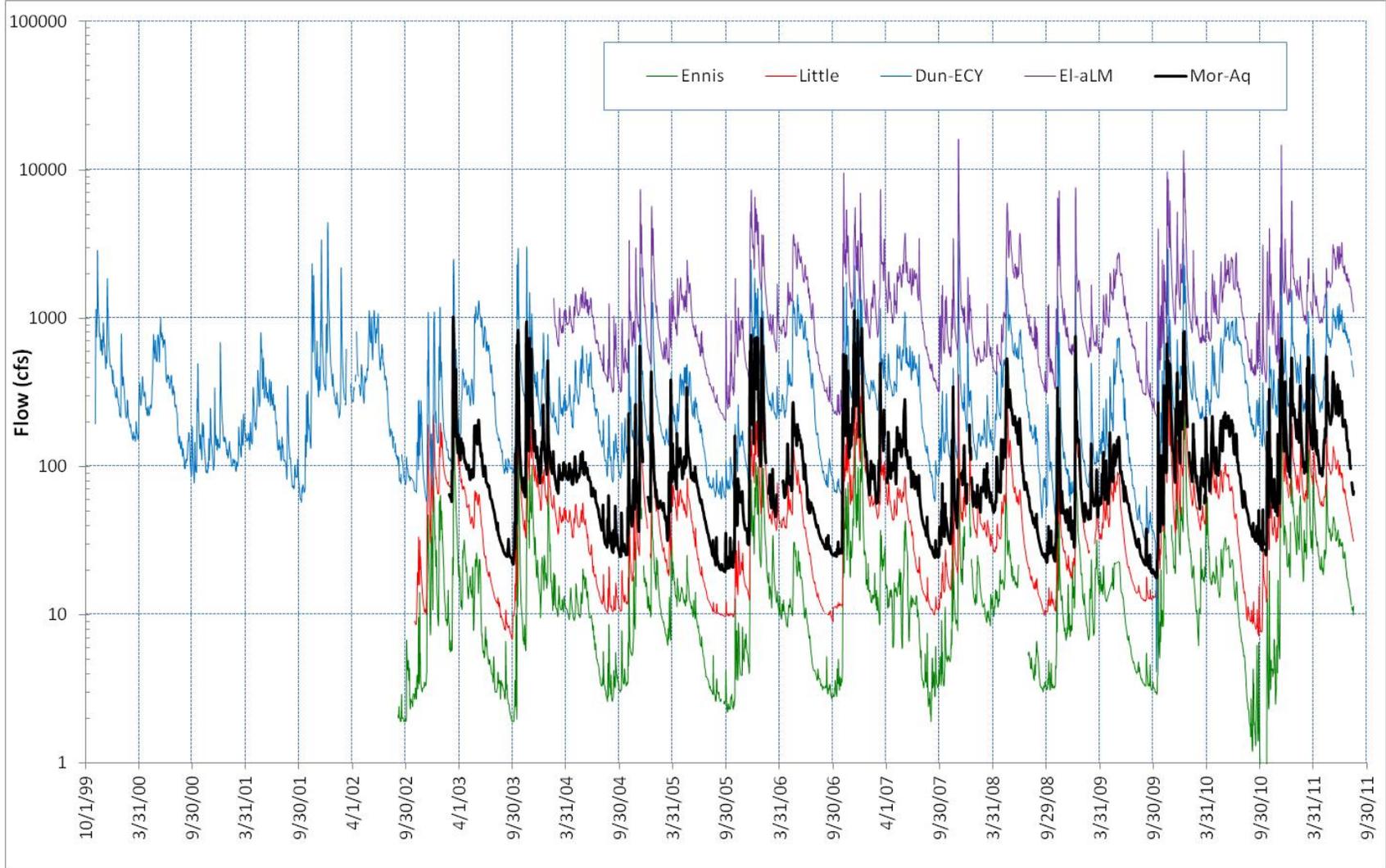
Figure 5. Measured flows at the Ecology "Morse Creek below Aqueduct" gaging station, with flows from other selected gages.
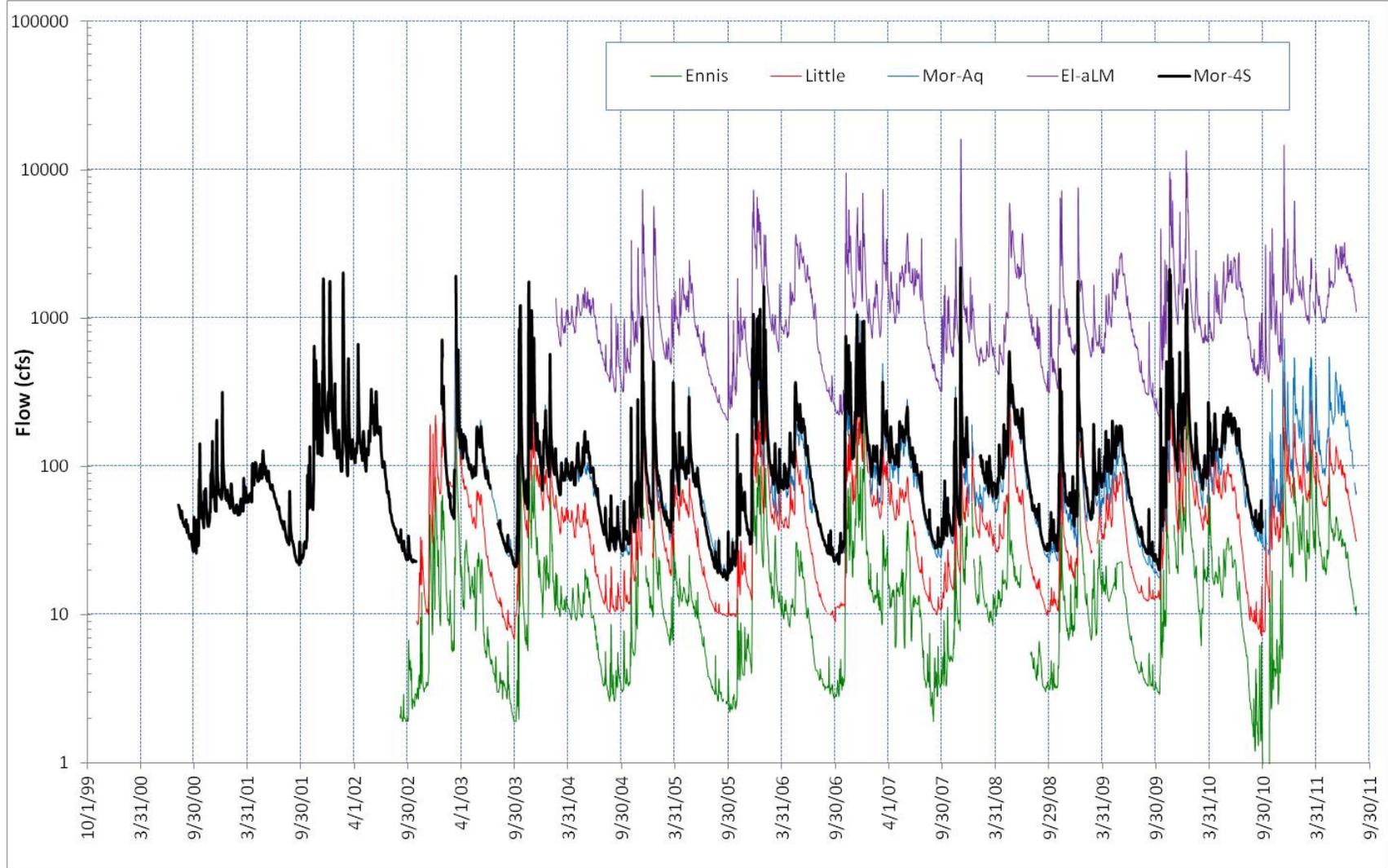
Figure 6. Measured flows at the Ecology "Morse Creek at Four Seasons Ranch" gaging station, with flows from other selected gages.
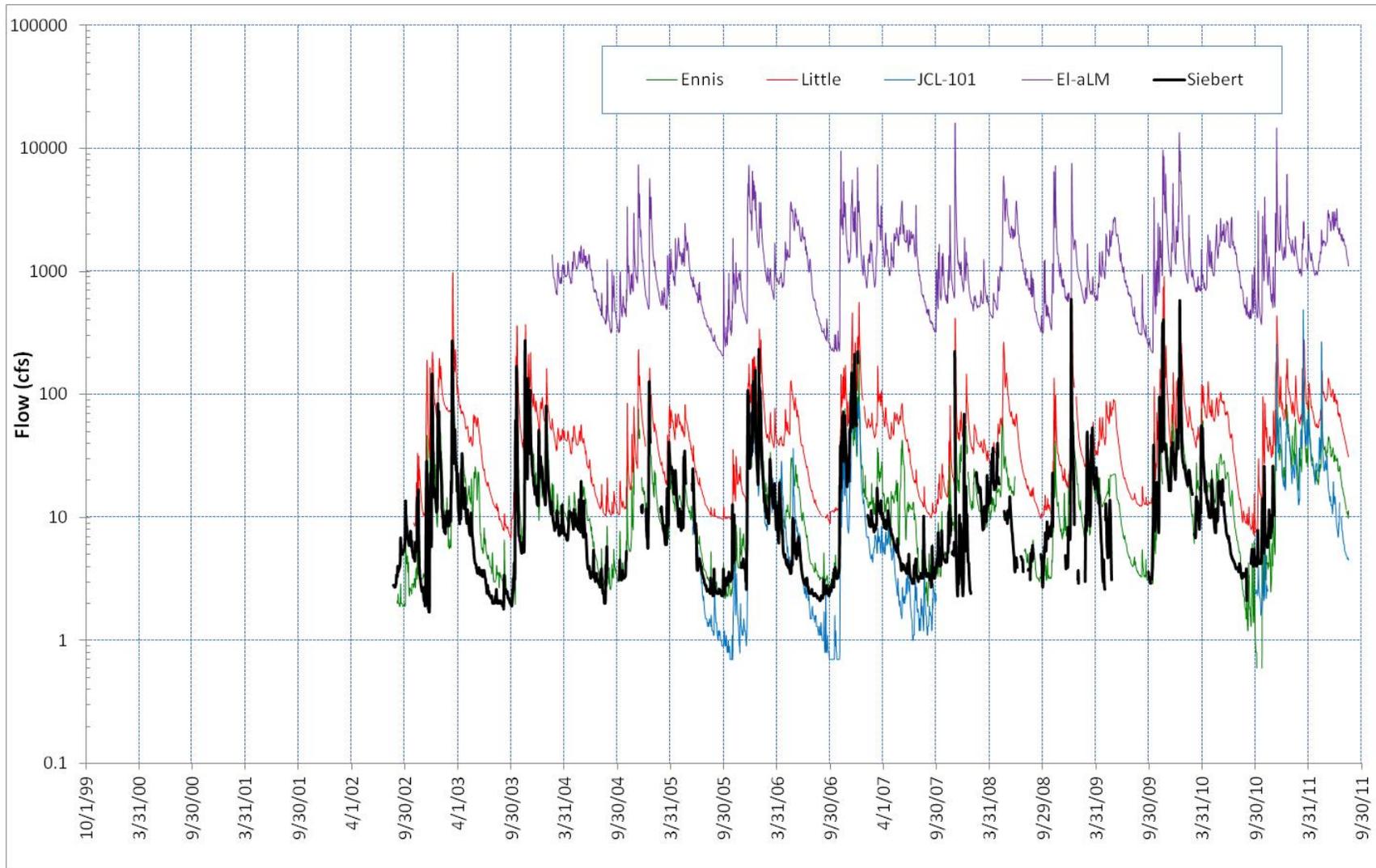
Figure 7. Measured flows at the Ecology "Siebert Creek at Old Olympic Highway" gaging station, with flows from other selected gages.
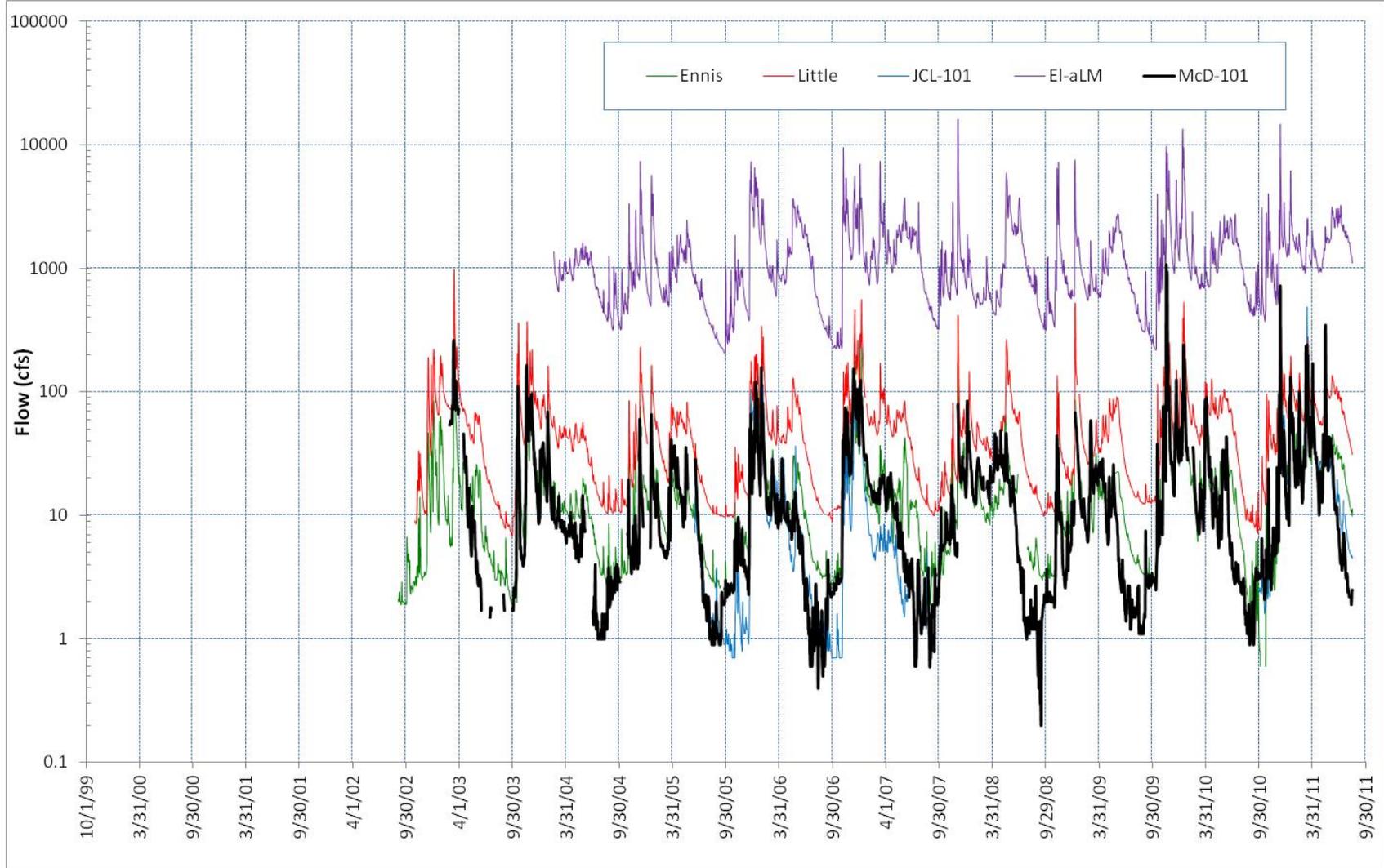
Figure 8. Measured flows at the Ecology "McDonald Creek at Highway 101" gaging station, with flows from other selected gages.
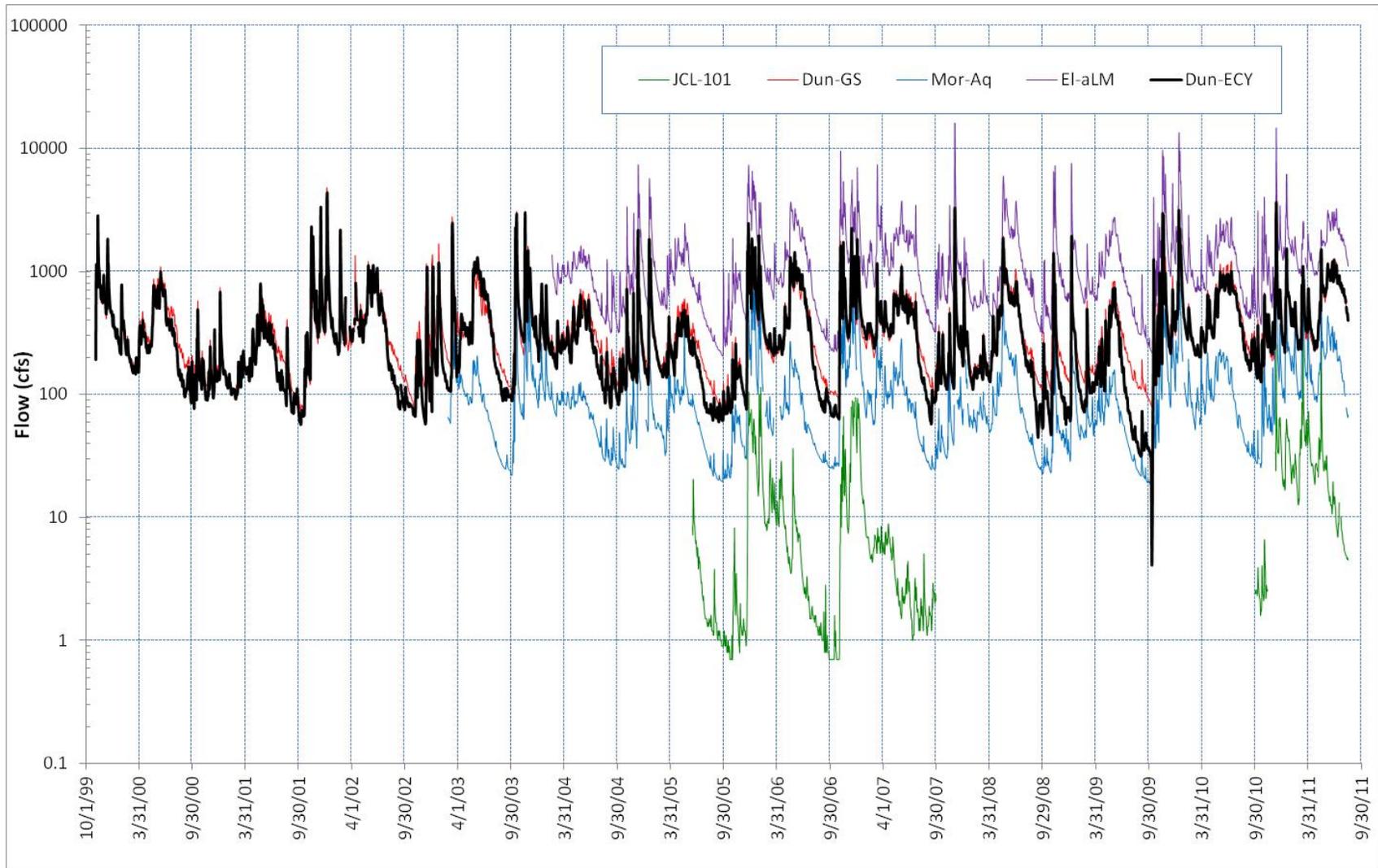
Figure 9. Measured flows at the Ecology "Dungeness River near Mouth" gaging station, with flows from other selected gages.
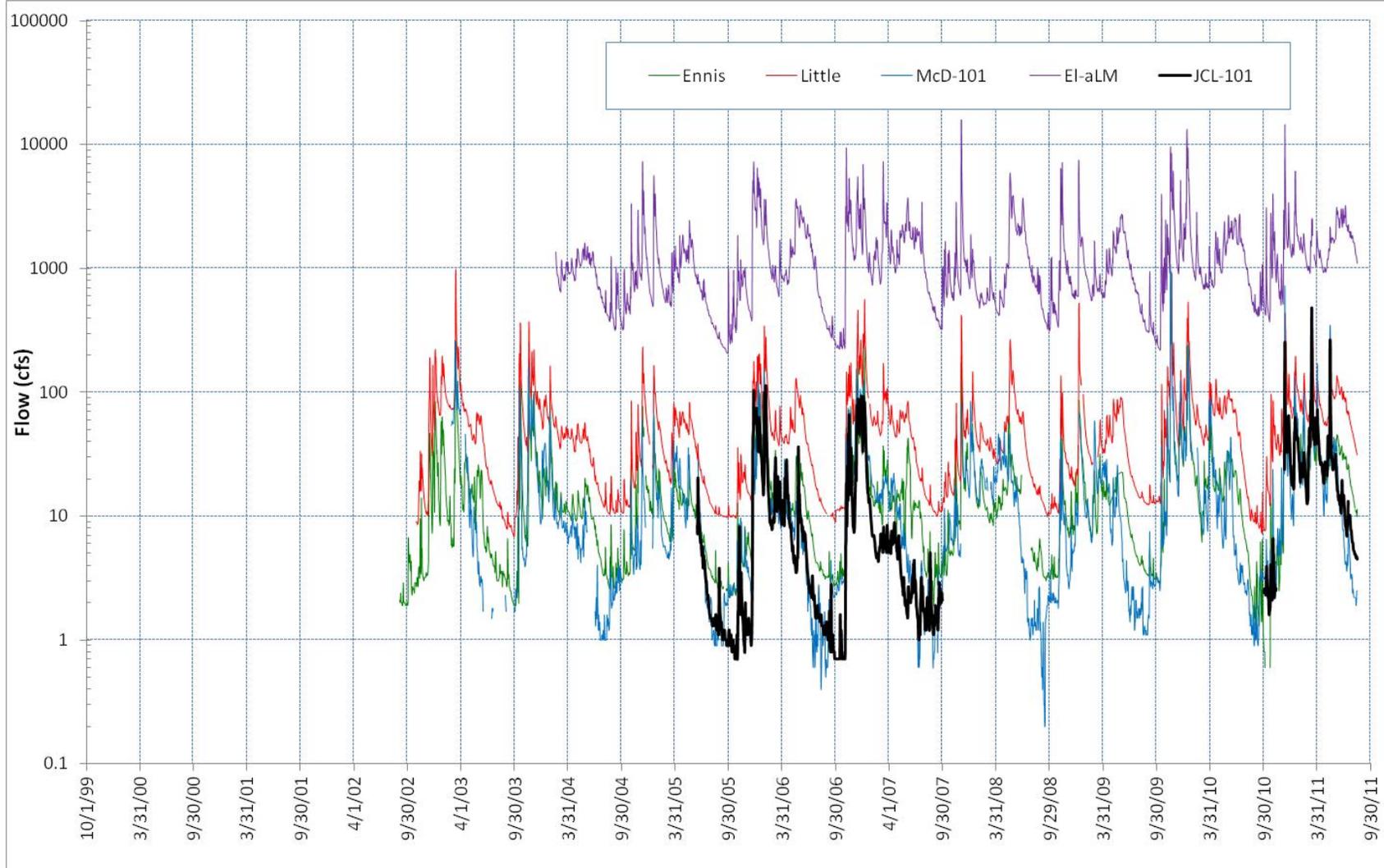
Figure 10. Measured flows at the Ecology "Jimmycomelately Creek at Highway 101" gaging station, with flows from other selected gages.
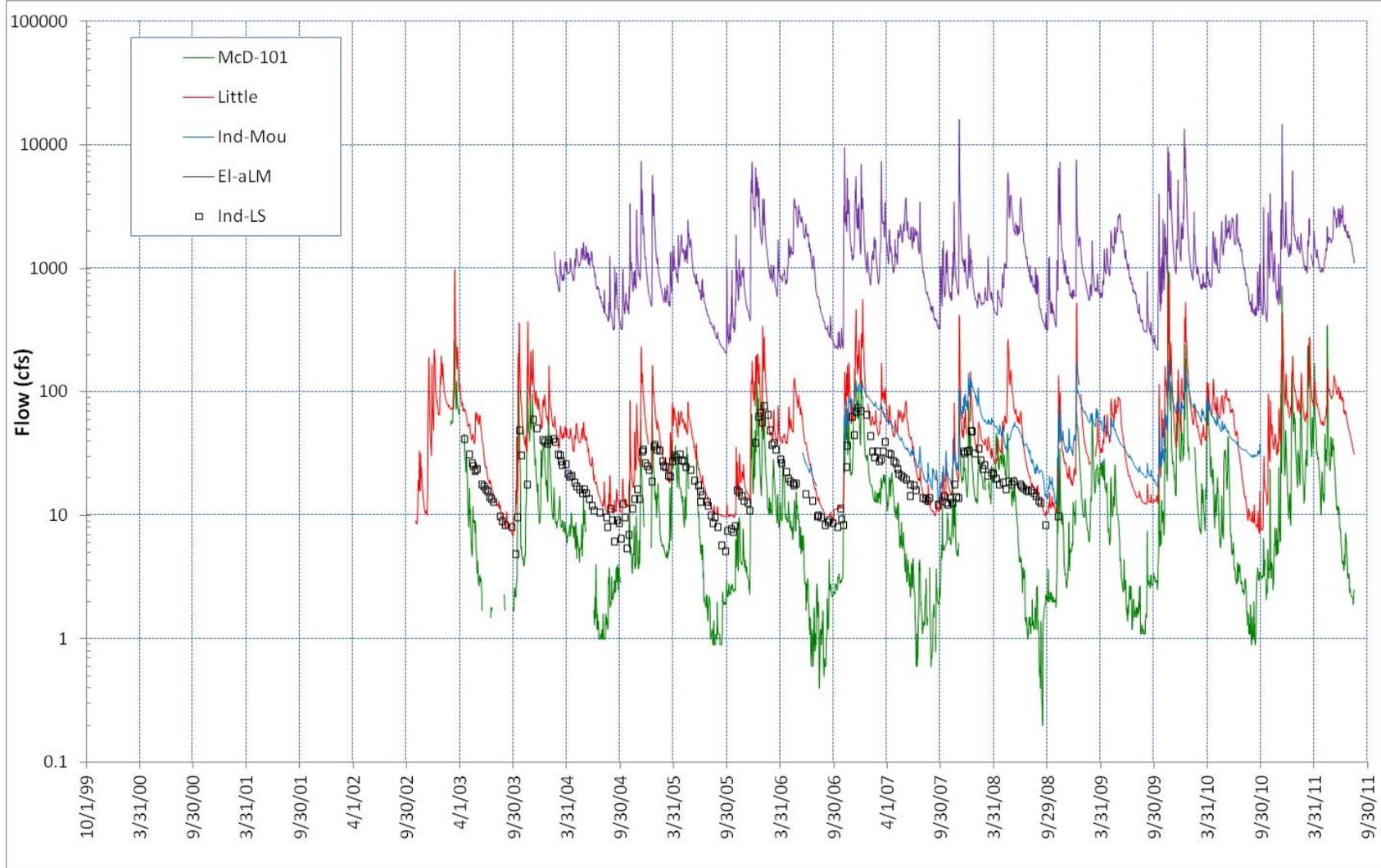
Figure 11. Measured flows at the Ecology "Indian Creek below Lake Sutherland" gaging station, with flows from other selected gages.
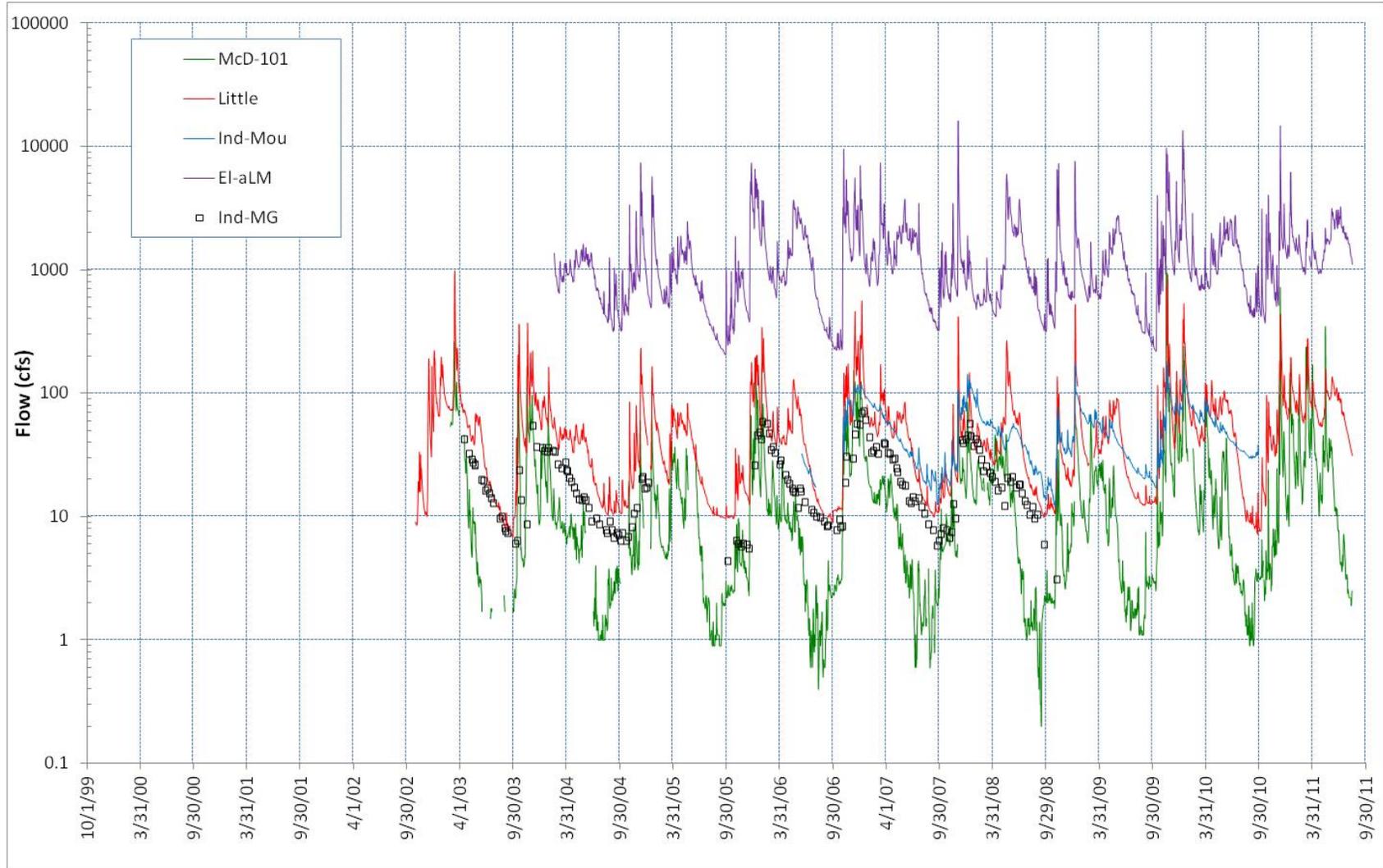
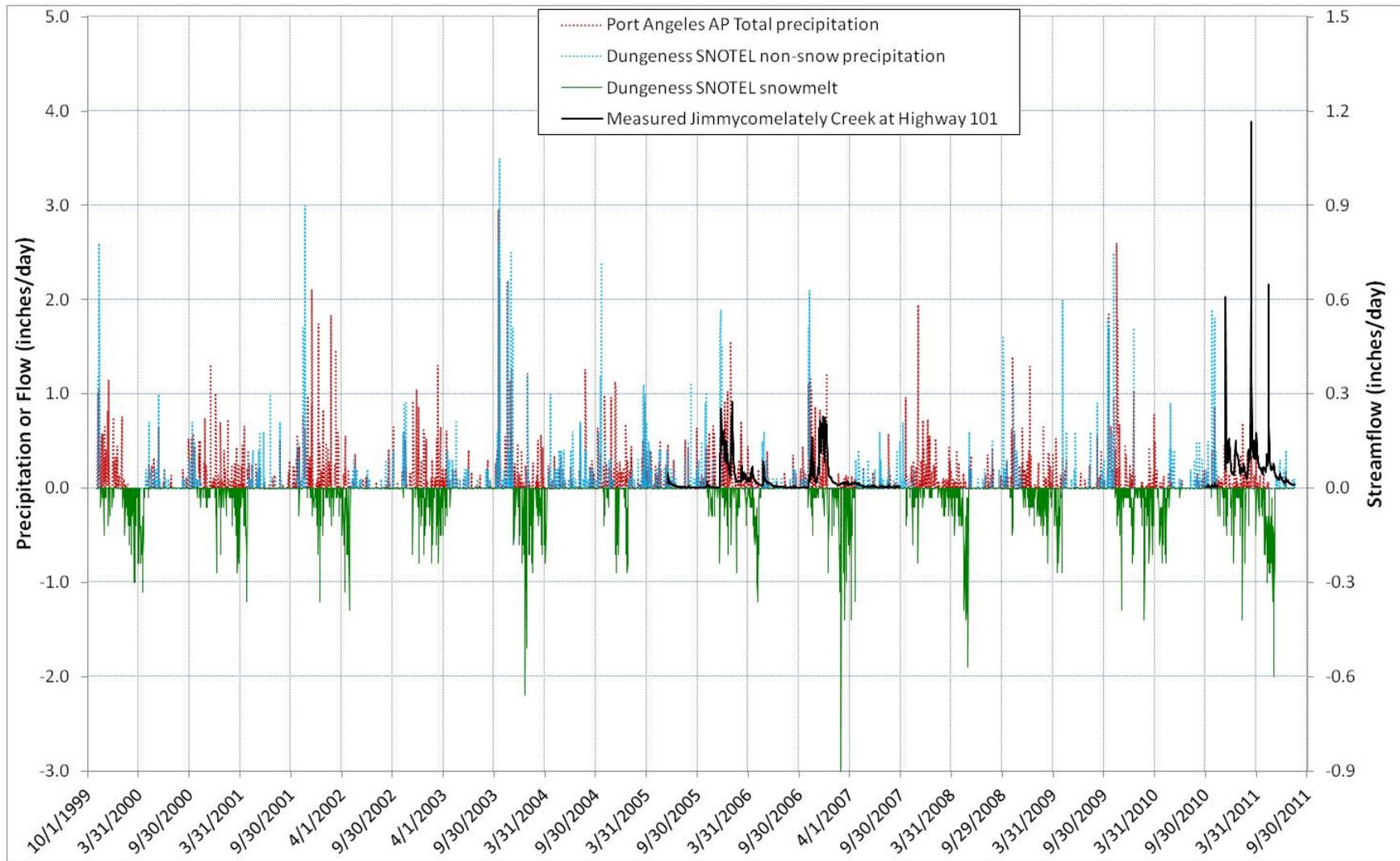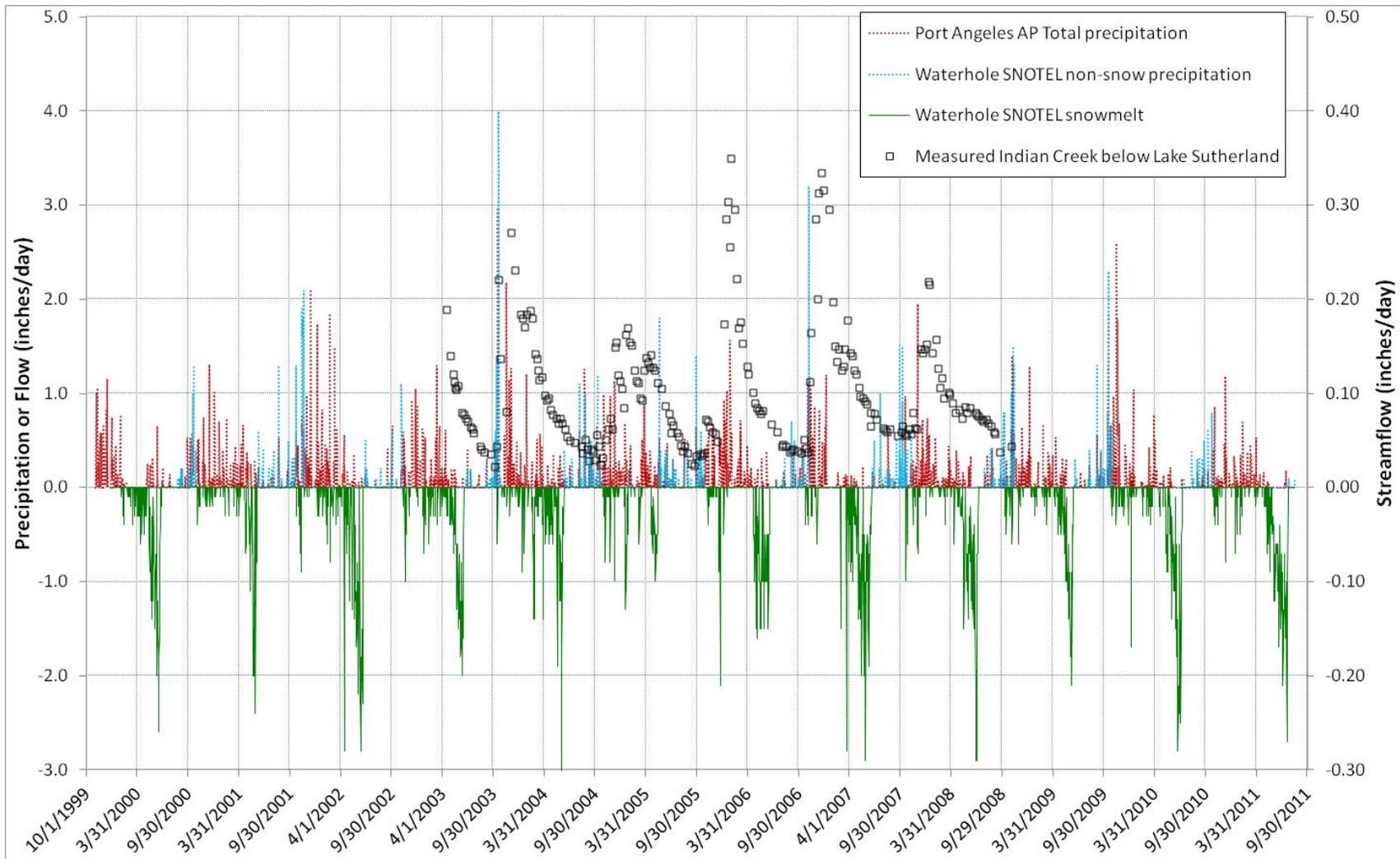Figure 12. Measured flows at the Ecology "Indian Creek near Maple Grove" gaging station, with flows from other selected gages.
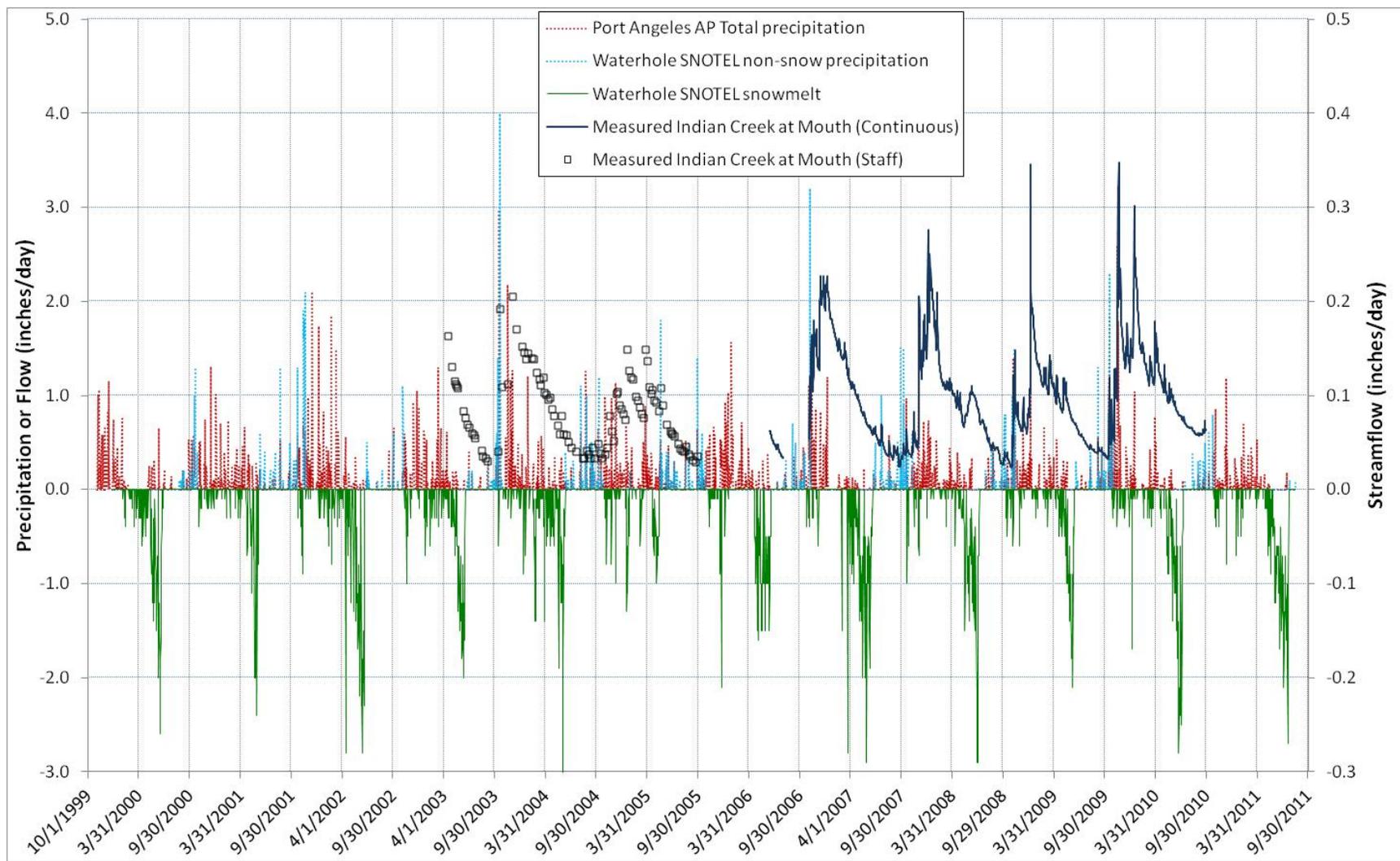
Figure 13. Measured areal flows at the Ecology "Indian Creek at Mouth" gaging station, with precipitation and snowmelt data.
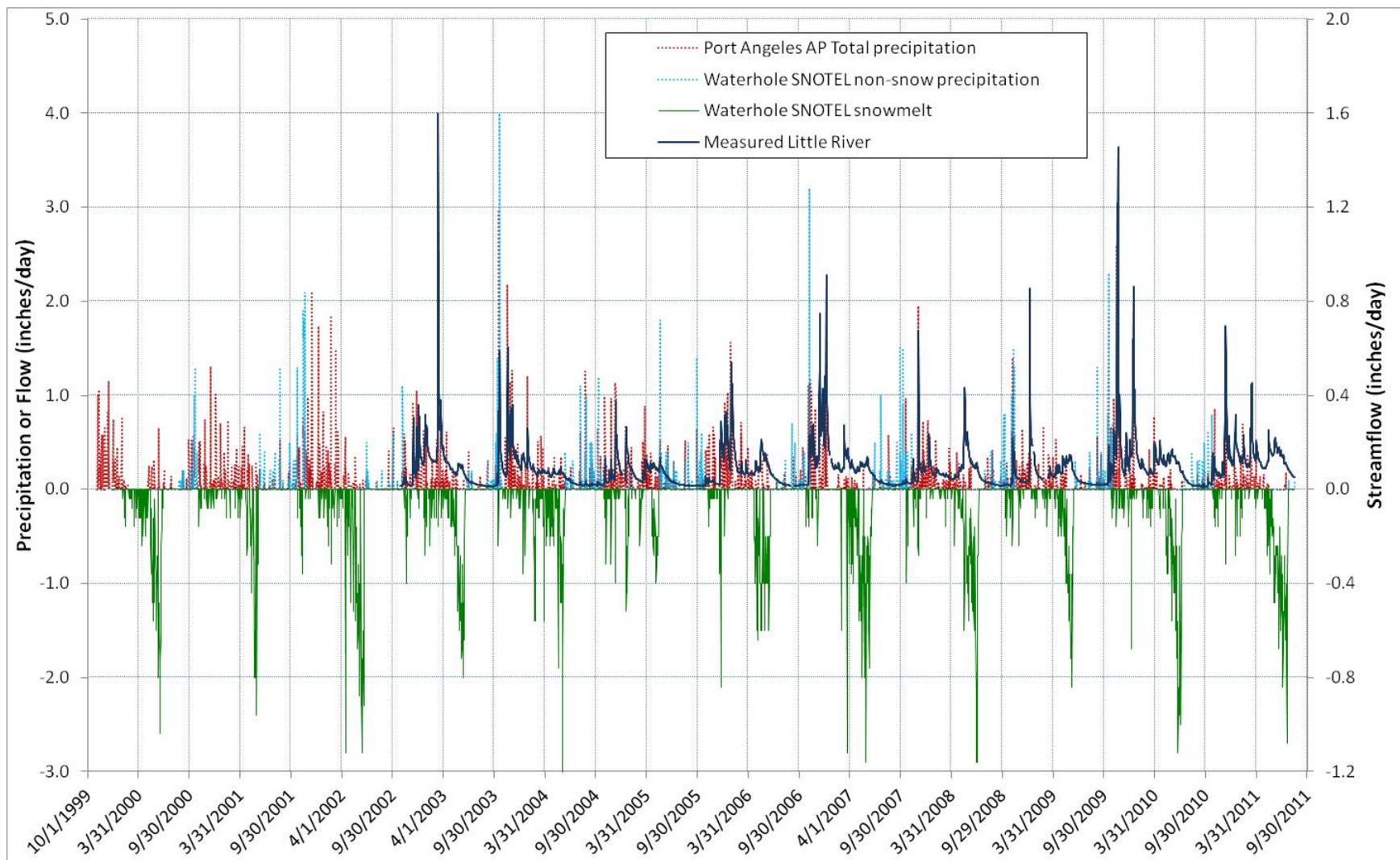
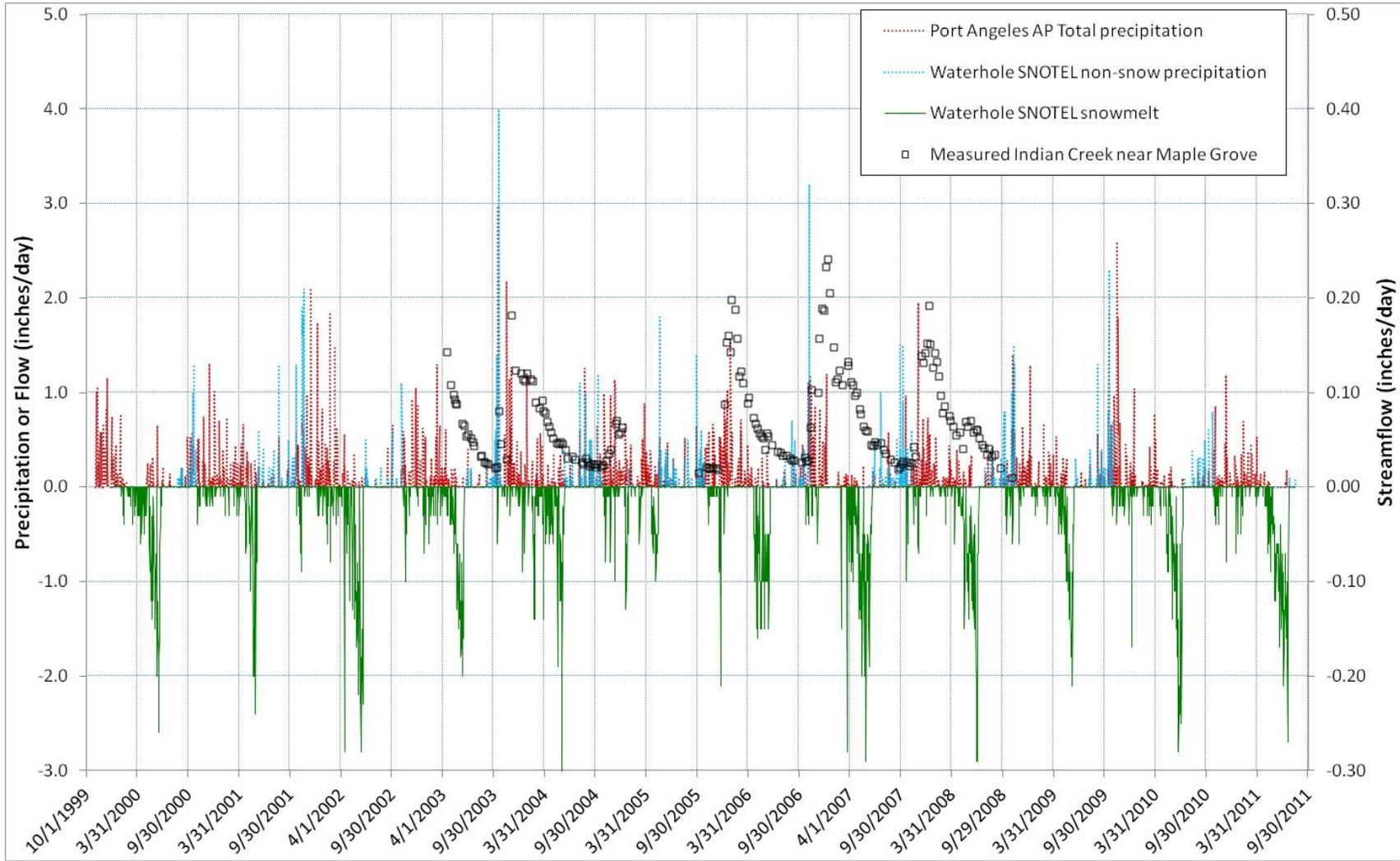Figure 14. Measured areal flows at the Ecology "Little River near Mouth" gaging station, with precipitation and snowmelt data.
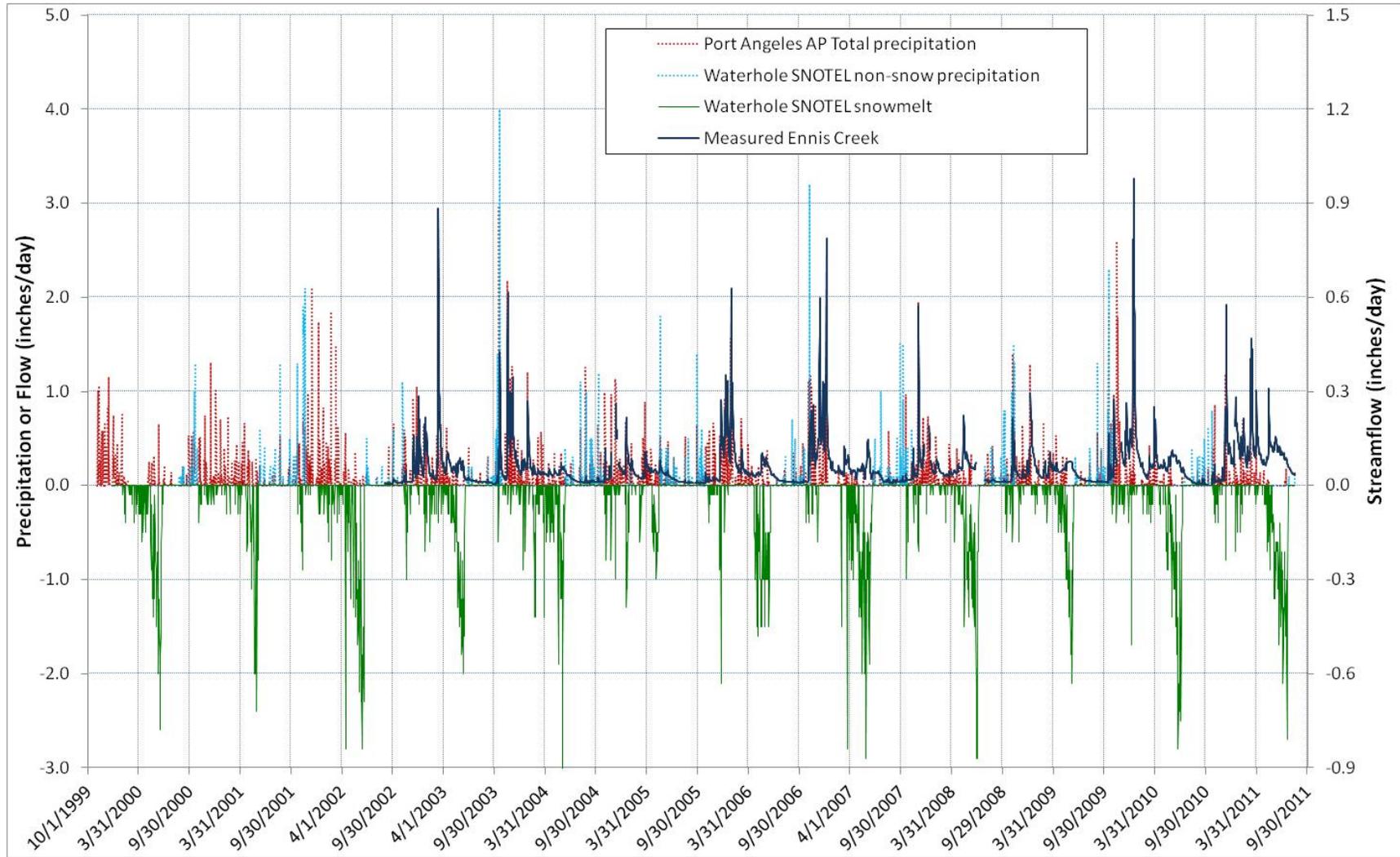
Figure 15. Measured areal flows at the Ecology "Ennis Creek near Mouth" gaging station, with precipitation and snowmelt data.
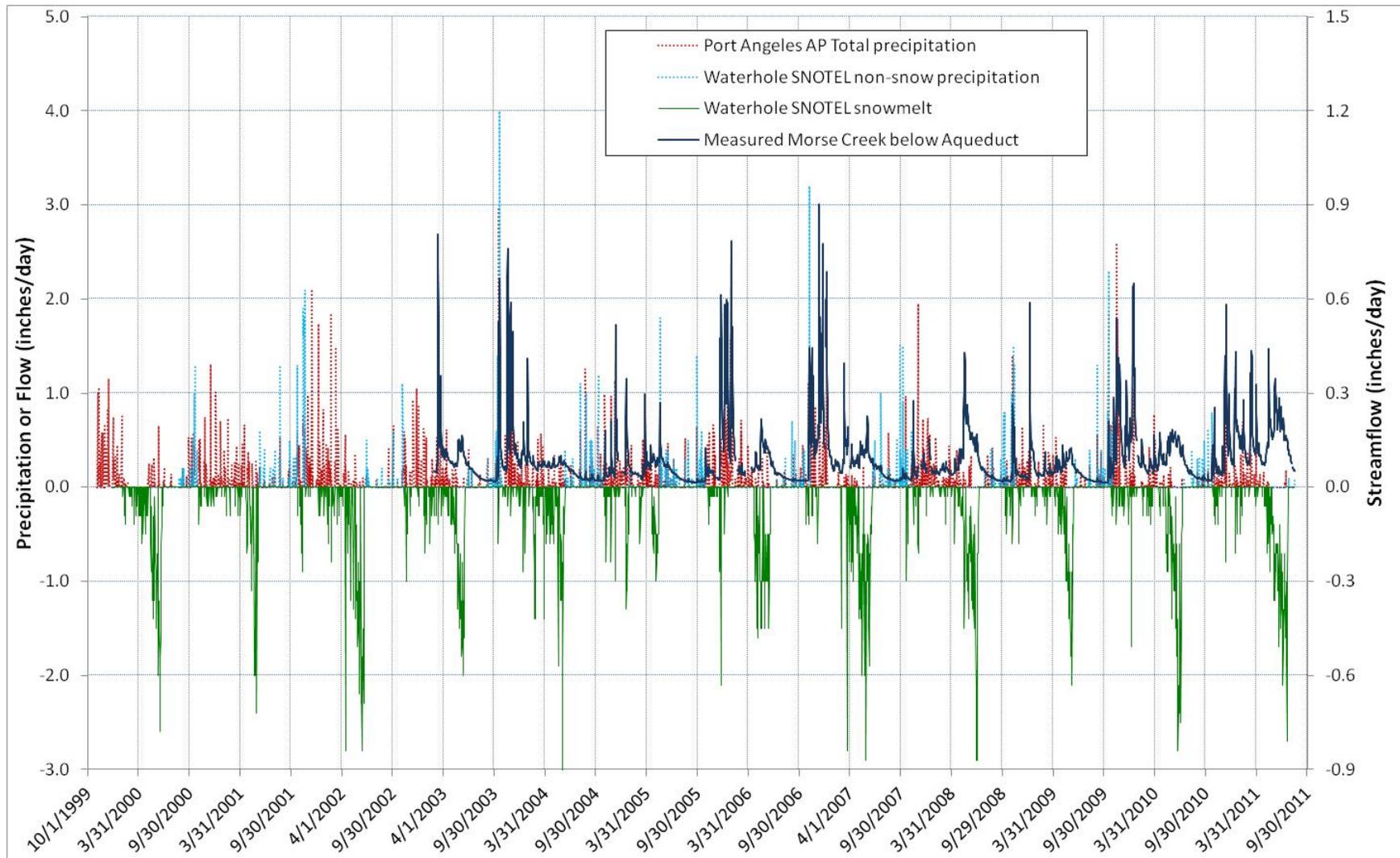
Figure 16. Measured areal flows at the Ecology "Morse Creek below Aqueduct" gaging station, with precipitation and snowmelt data.
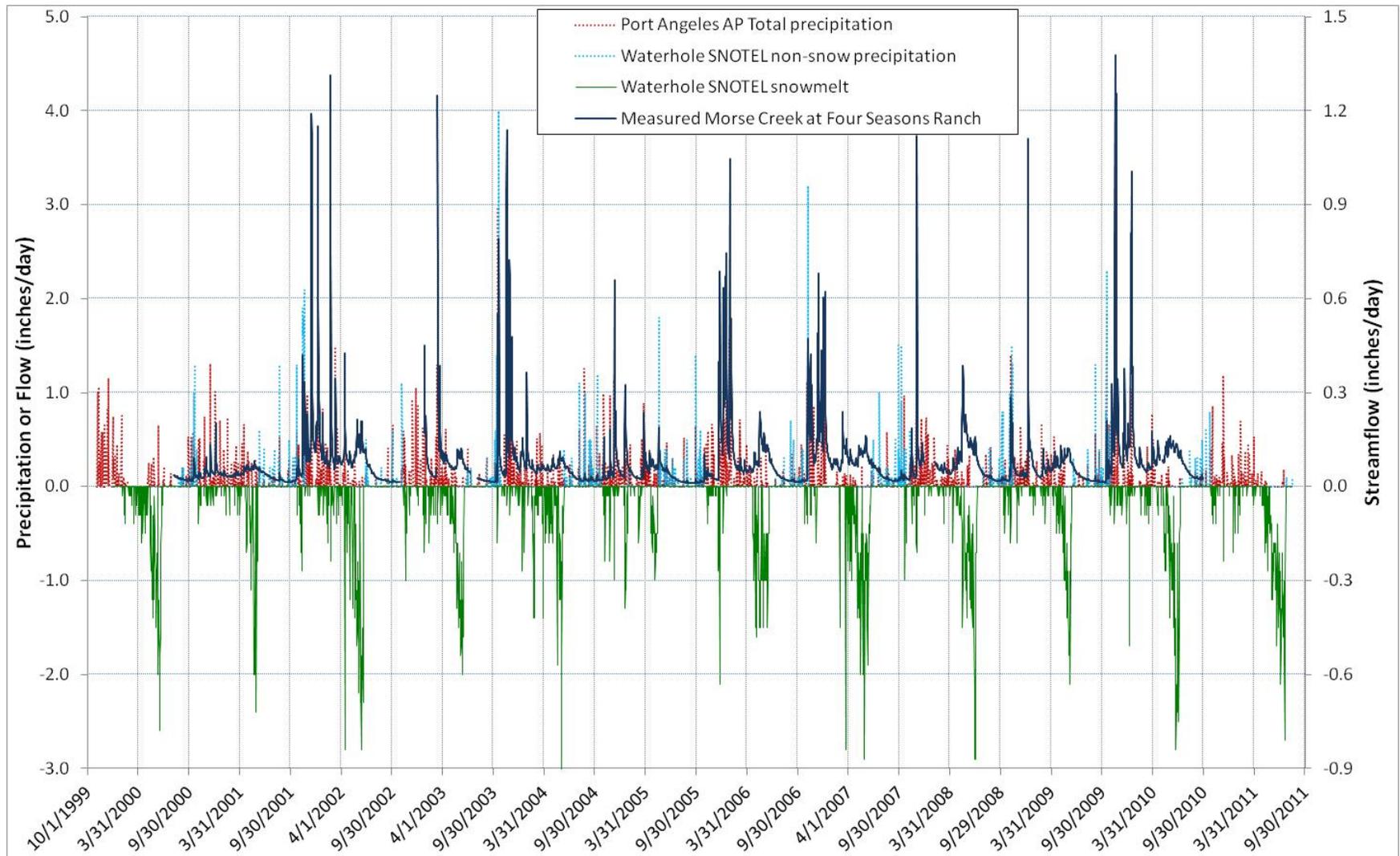
Figure 17. Measured areal flows at the Ecology "Morse Creek at Four Seasons Ranch" gaging station, with precipitation and snowmelt data.
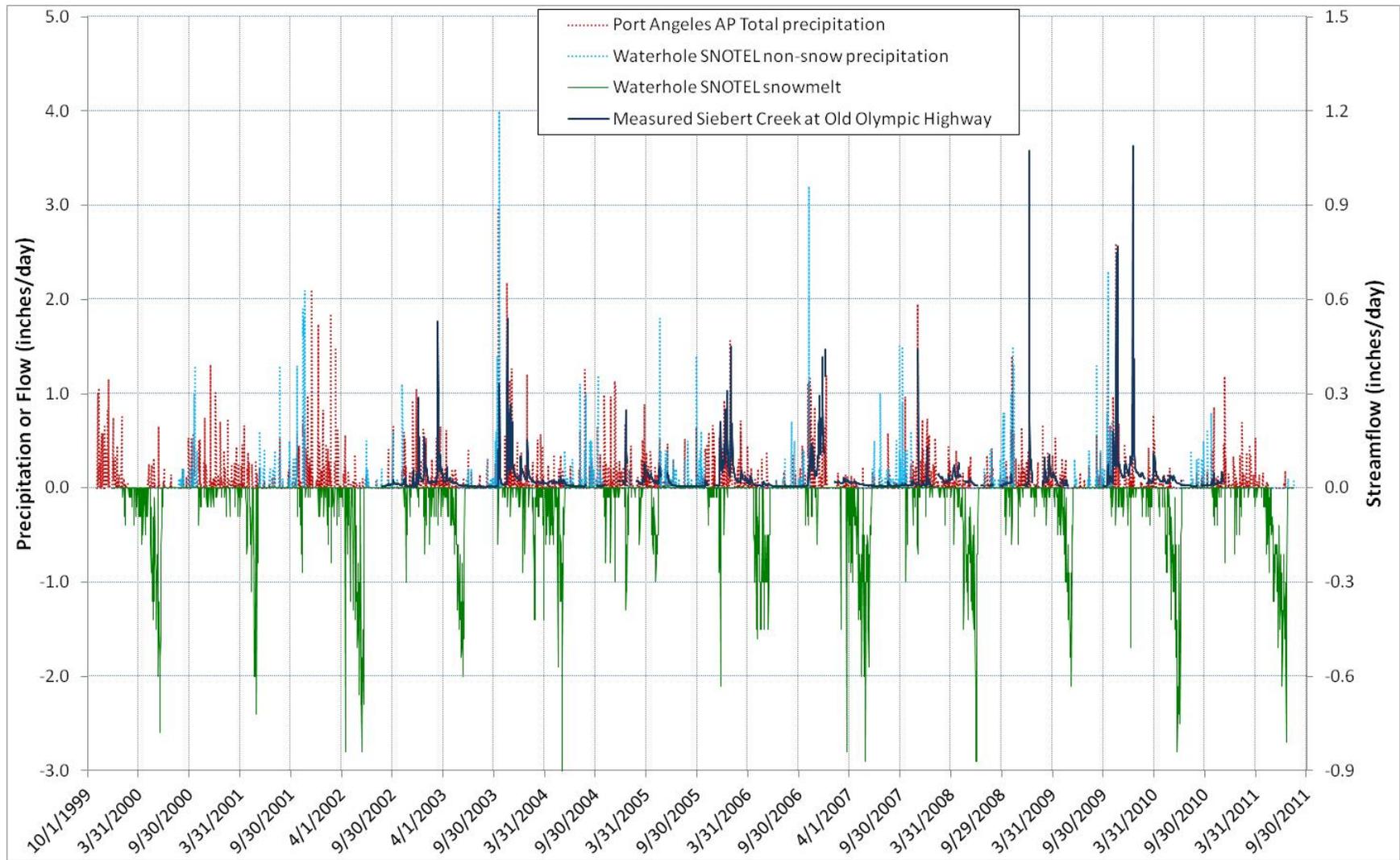
Figure 18. Measured areal flows at the Ecology "Siebert Creek at Old Olympic Highway" gaging station, with precipitation and snowmelt data.
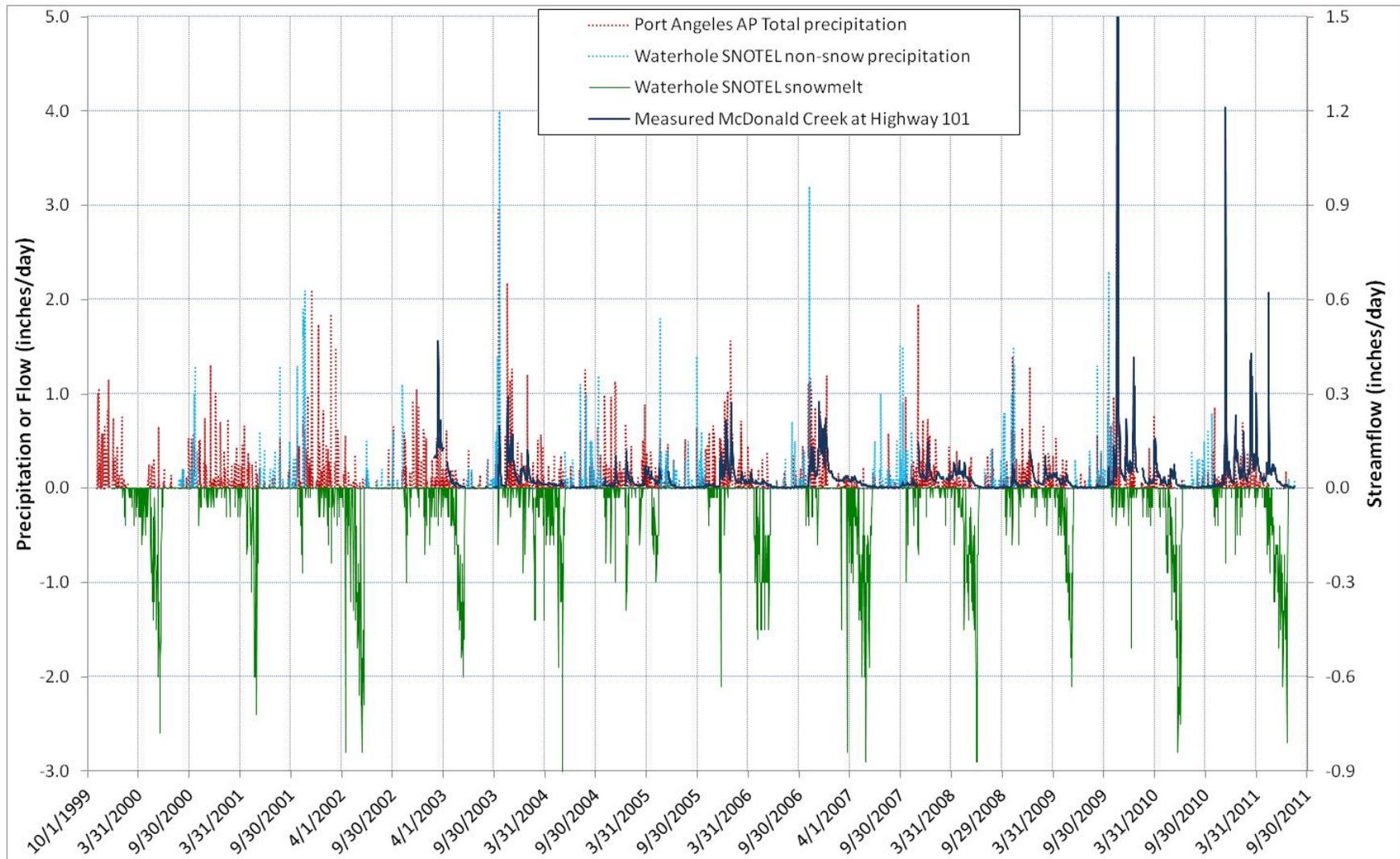
Figure 19. Measured areal flows at the Ecology "McDonald Creek at Highway 101" gaging station, with precipitation and snowmelt data.
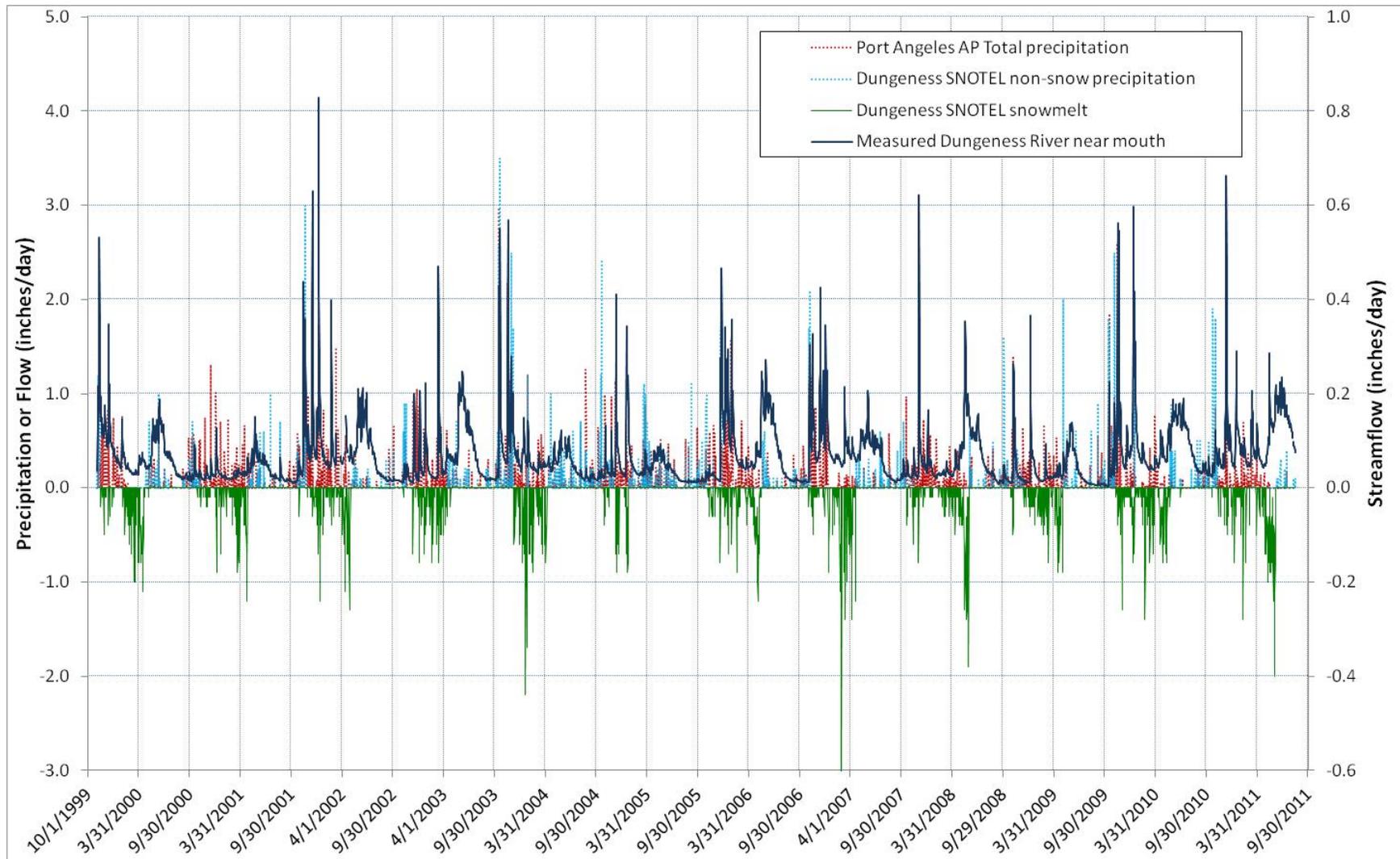
Figure 20. Measured areal flows at the Ecology "Dungeness River near Mouth" gaging station, with precipitation and snowmelt data.
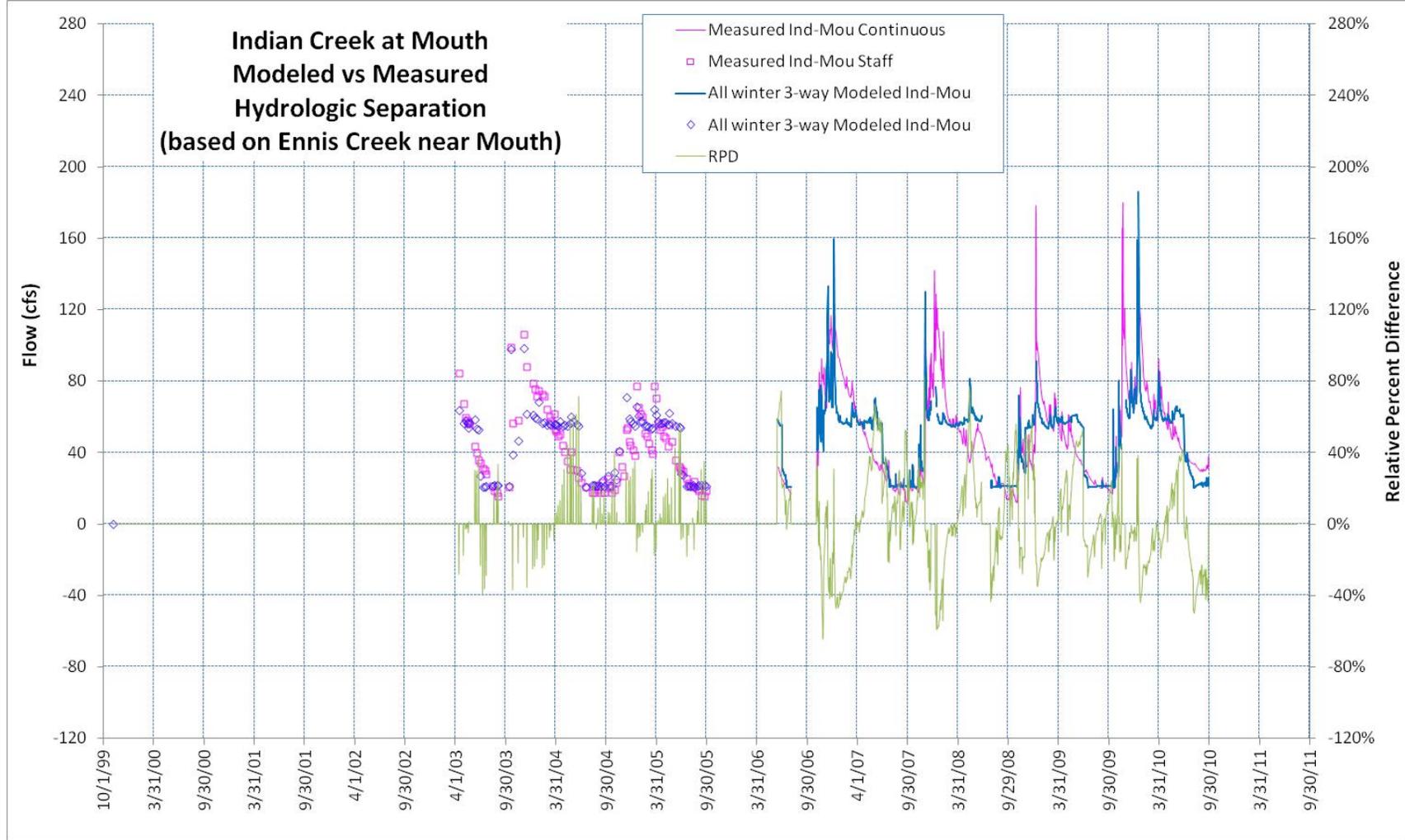
Figure 21. Measured areal flows at the Ecology "Jimmycomelately Creek at Highway 101" gaging station, with precipitation and snowmelt data.

Figure 22. Measured areal flows at the Ecology "Indian Creek below Lake Sutherland" gaging station, with precipitation and snowmelt data.

Figure 23. Measured areal flows at the Ecology "Indian Creek near Maple Grove" gaging station, with precipitation and snowmelt data.

Figure 24. Measured flows at the Ecology "Indian Creek at Mouth" gaging station, and modeled flows based on the Ecology "Ennis Creek near Mouth" station, with relative percent difference of paired values.
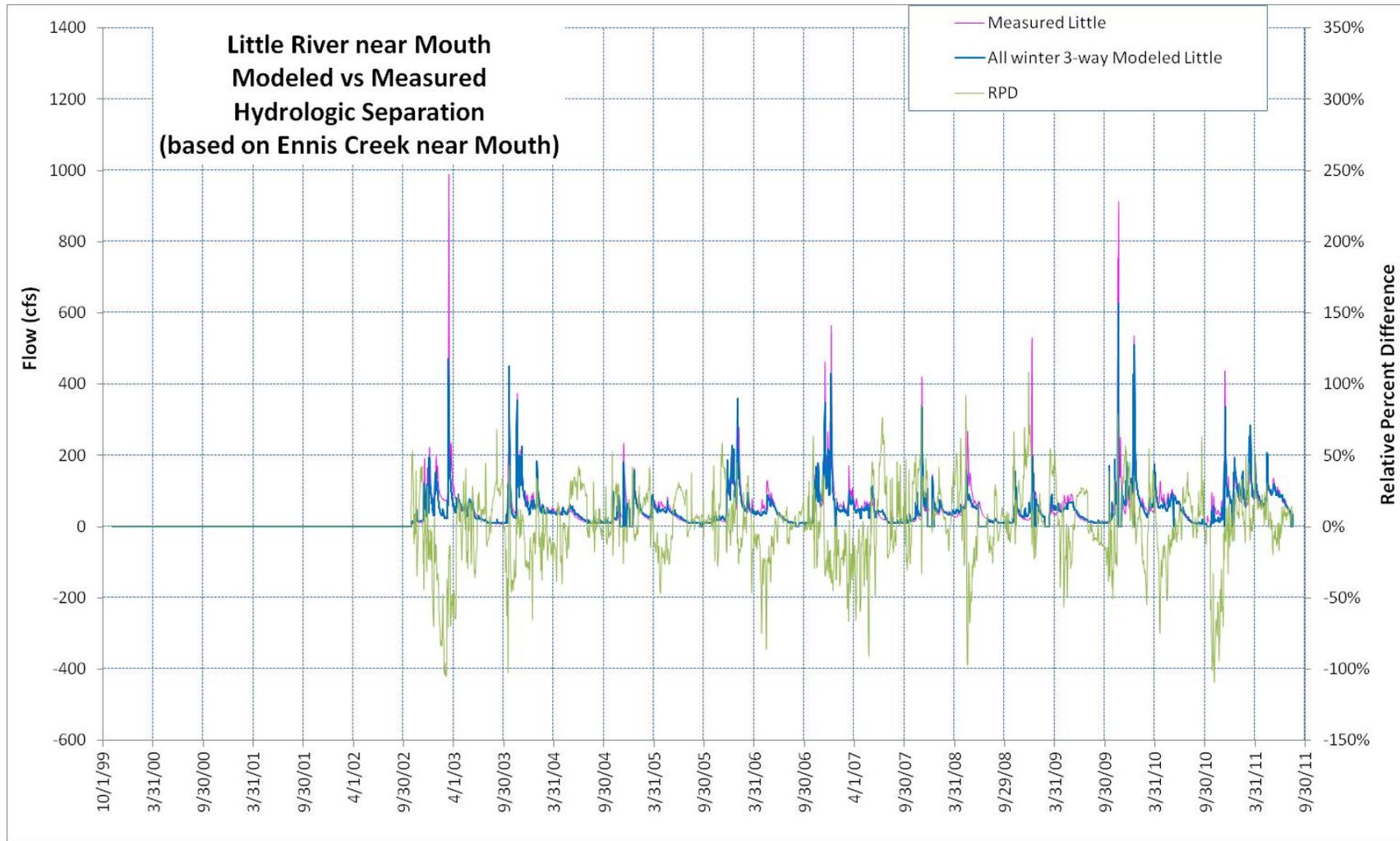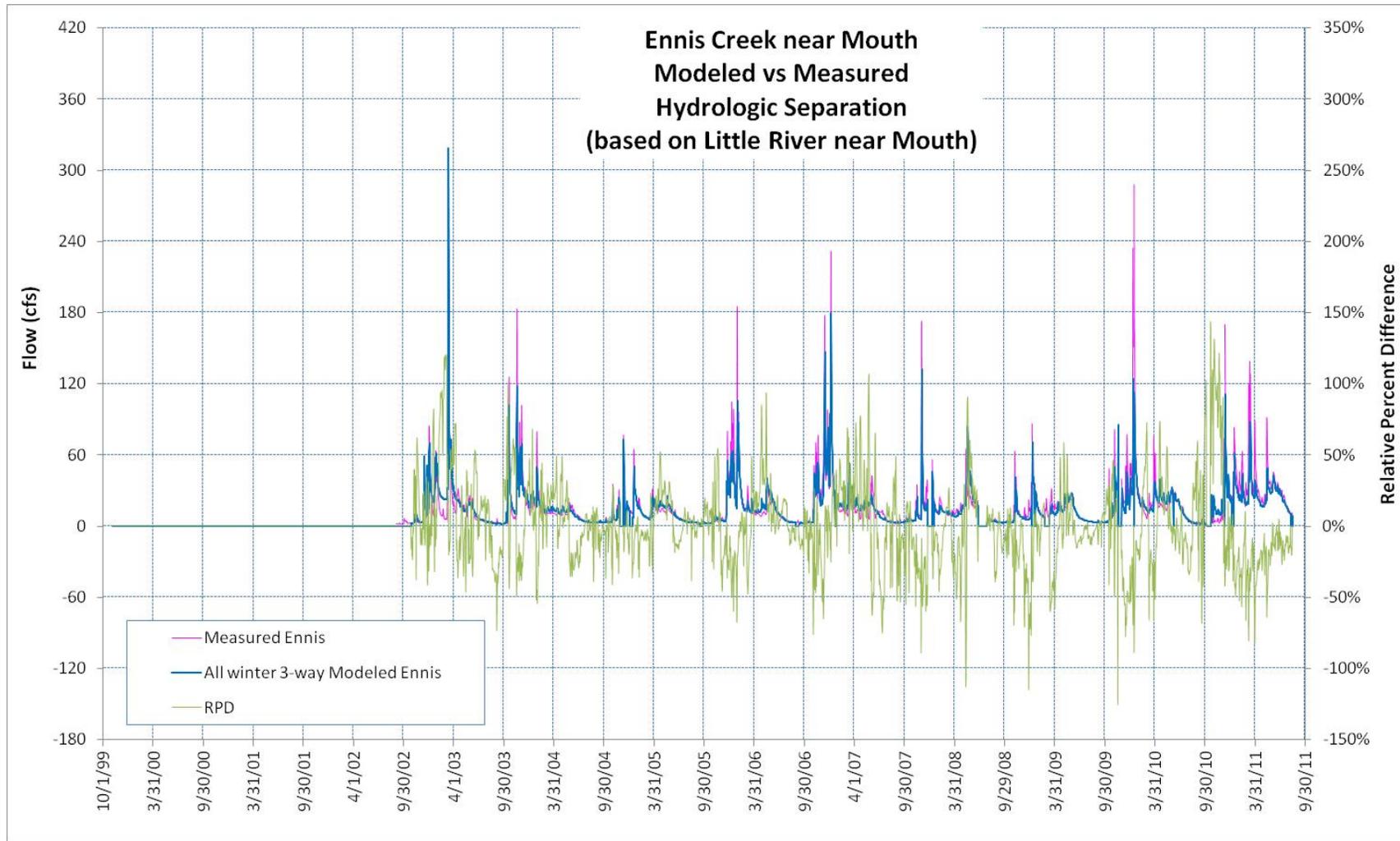
Figure 25. Measured flows at the Ecology "Little River near Mouth" gaging station, and modeled flows based on the Ecology "Ennis Creek near Mouth" station, with relative percent difference of paired values.

Figure 26. Measured flows at the Ecology "Ennis Creek near Mouth" gaging station, and modeled flows based on the Ecology "Little River near Mouth" station, with relative percent difference of paired values.
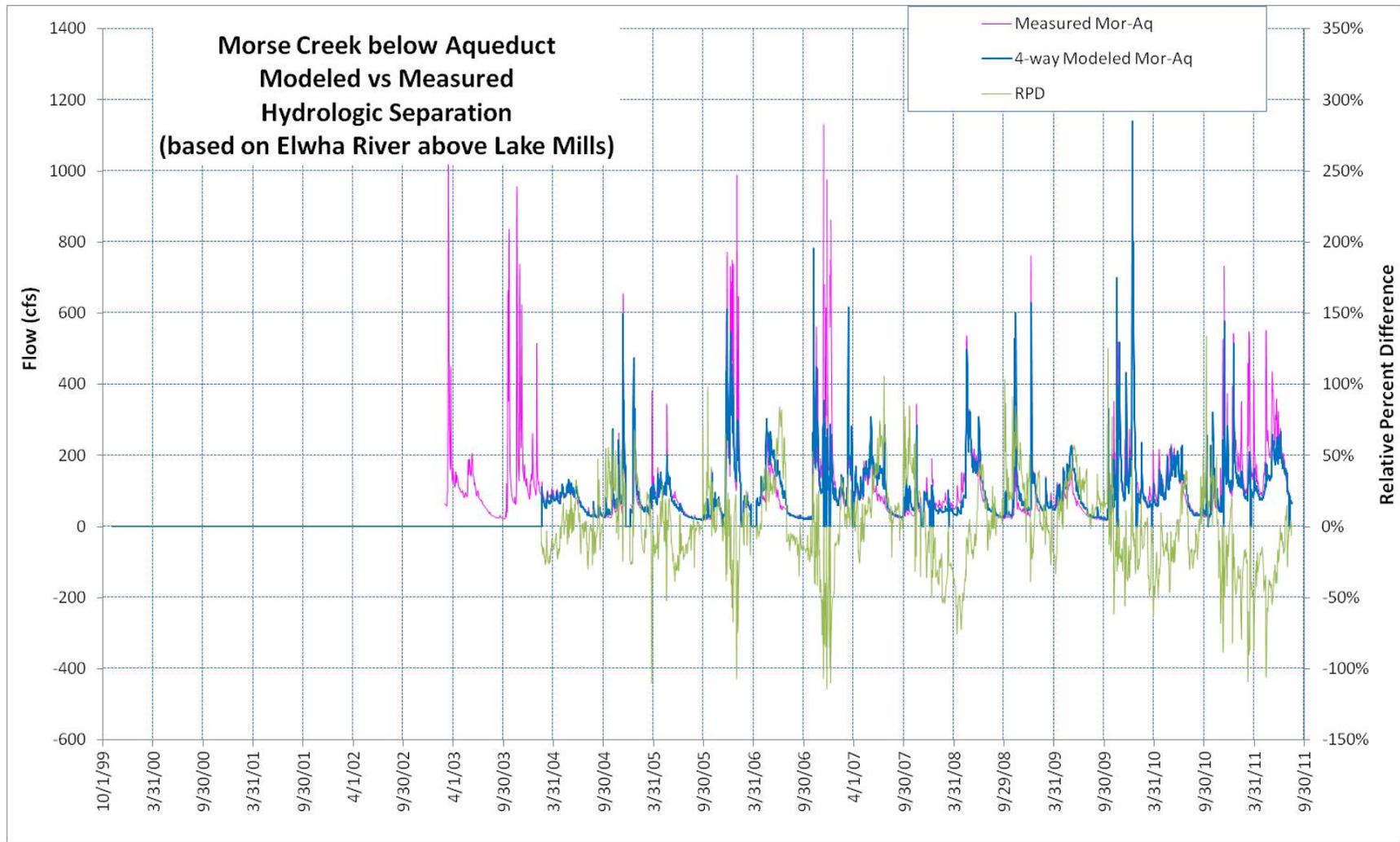
Figure 27. Measured flows at the Ecology "Morse Creek below Aqueduct" gaging station, and modeled flows based on the USGS "Elwha River above Lake Mills near Port Angeles" station, with relative percent difference of paired values.
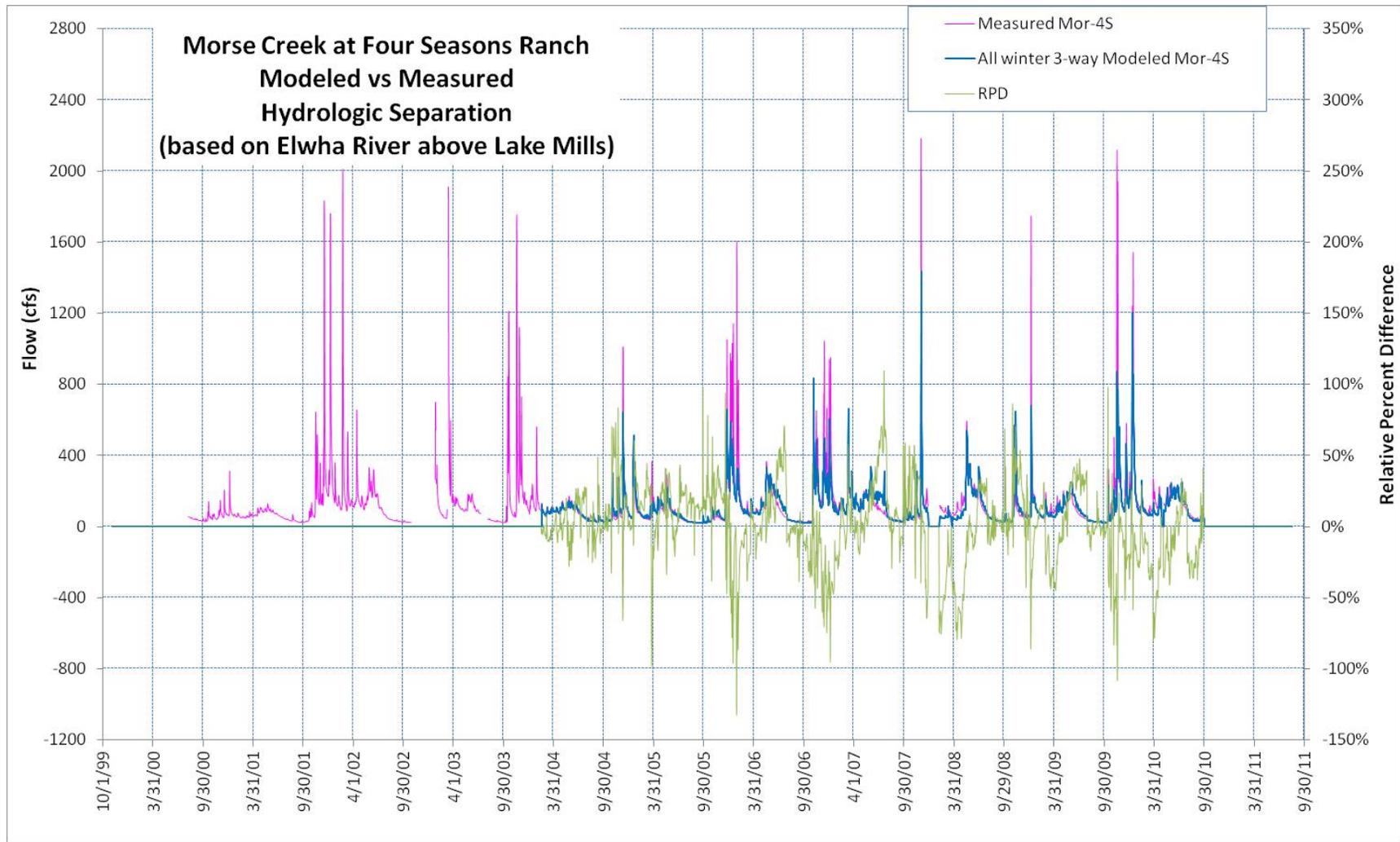
Figure 28. Measured flows at the Ecology "Morse Creek at Four Seasons Ranch" gaging station, and modeled flows based on the USGS "Elwha River above Lake Mills near Port Angeles" station, with relative percent difference of paired values.
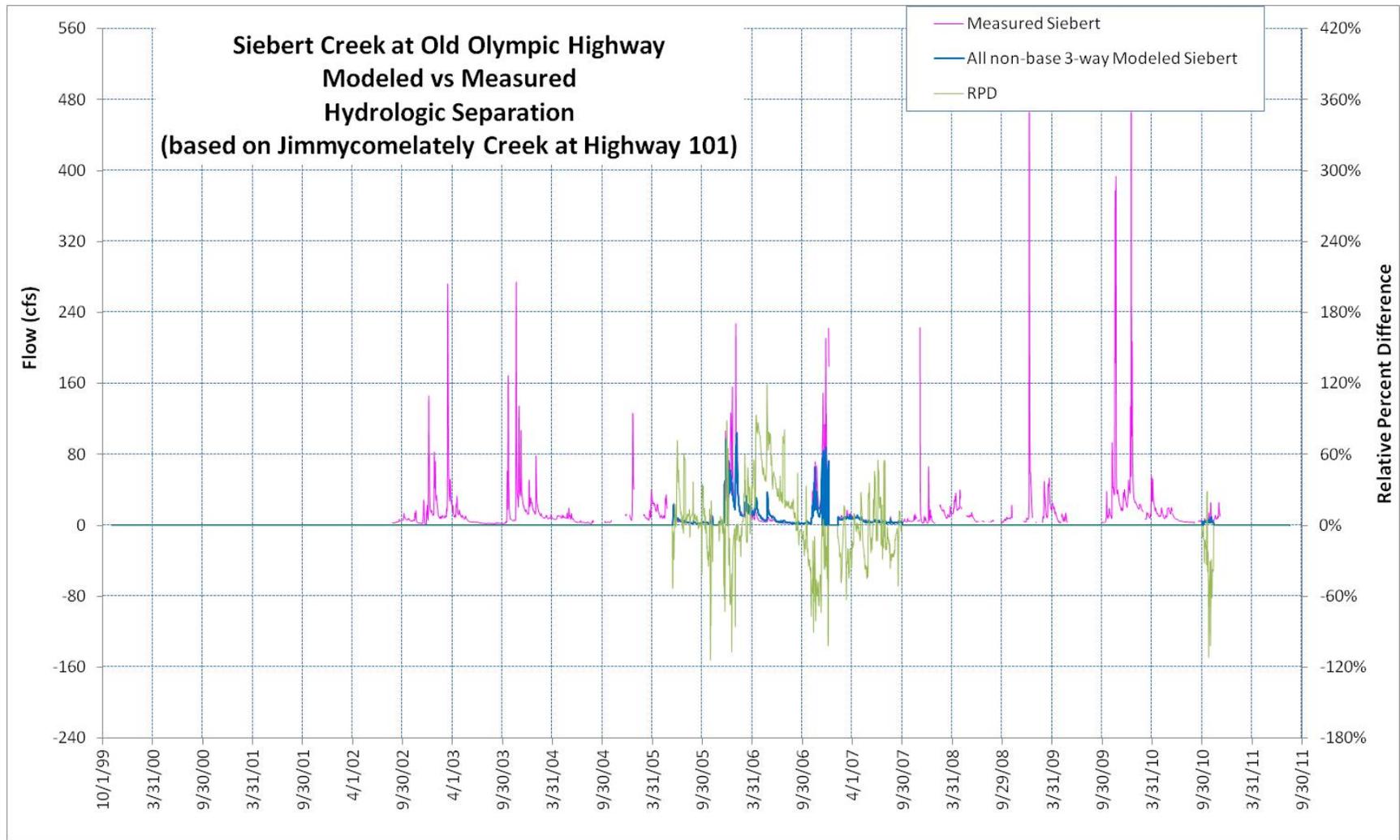
Figure 29. Measured flows at the Ecology "Siebert Creek at Old Olympic Highway" gaging station, and modeled flows based on the Ecology "Jimmycomelately Creek at Highway 101" station, with relative percent difference of paired values.
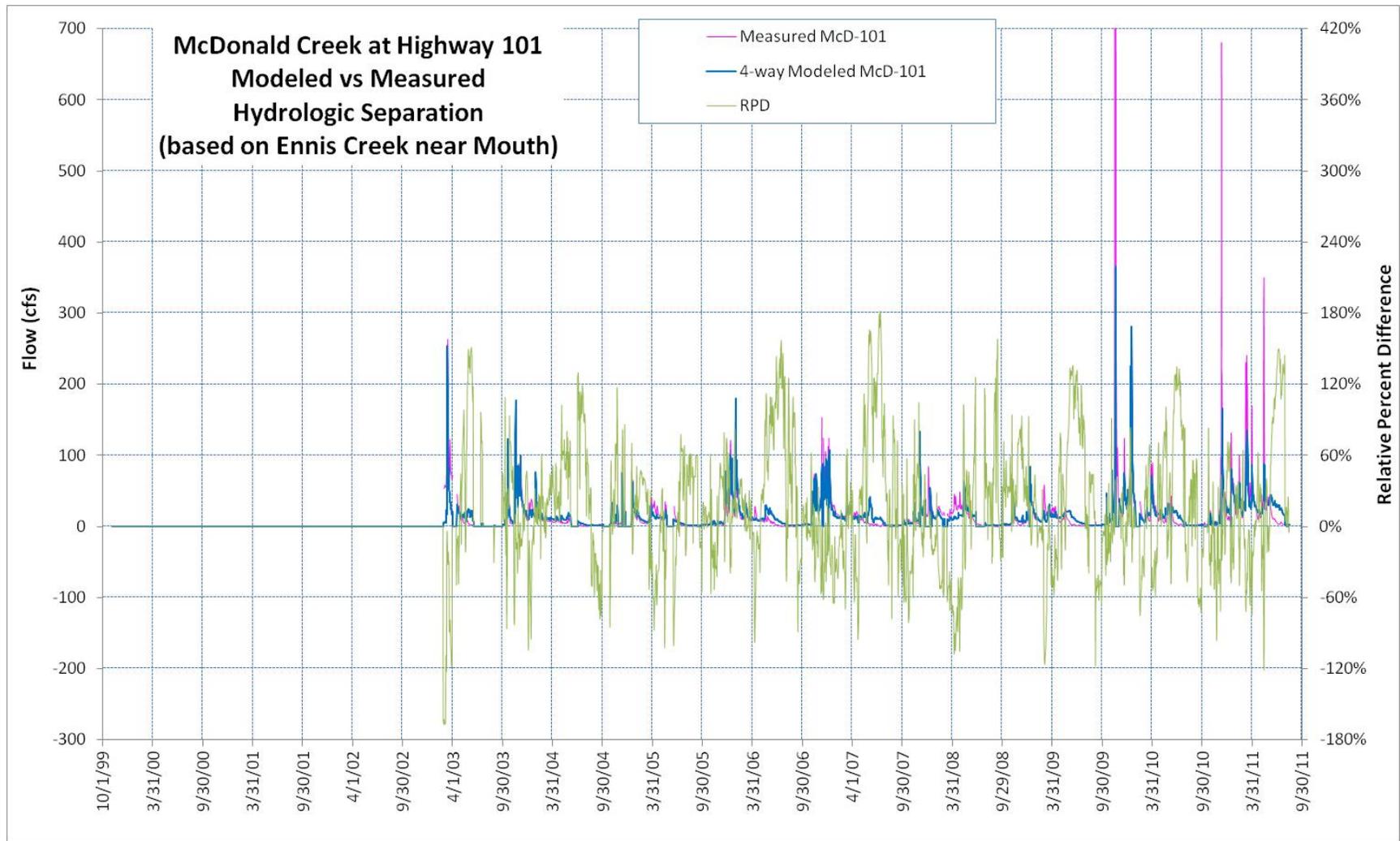
Figure 30. Measured flows at the Ecology "McDonald Creek at Highway 101" gaging station, and modeled flows based on the Ecology "Ennis Creek near Mouth" station, with relative percent difference of paired values.
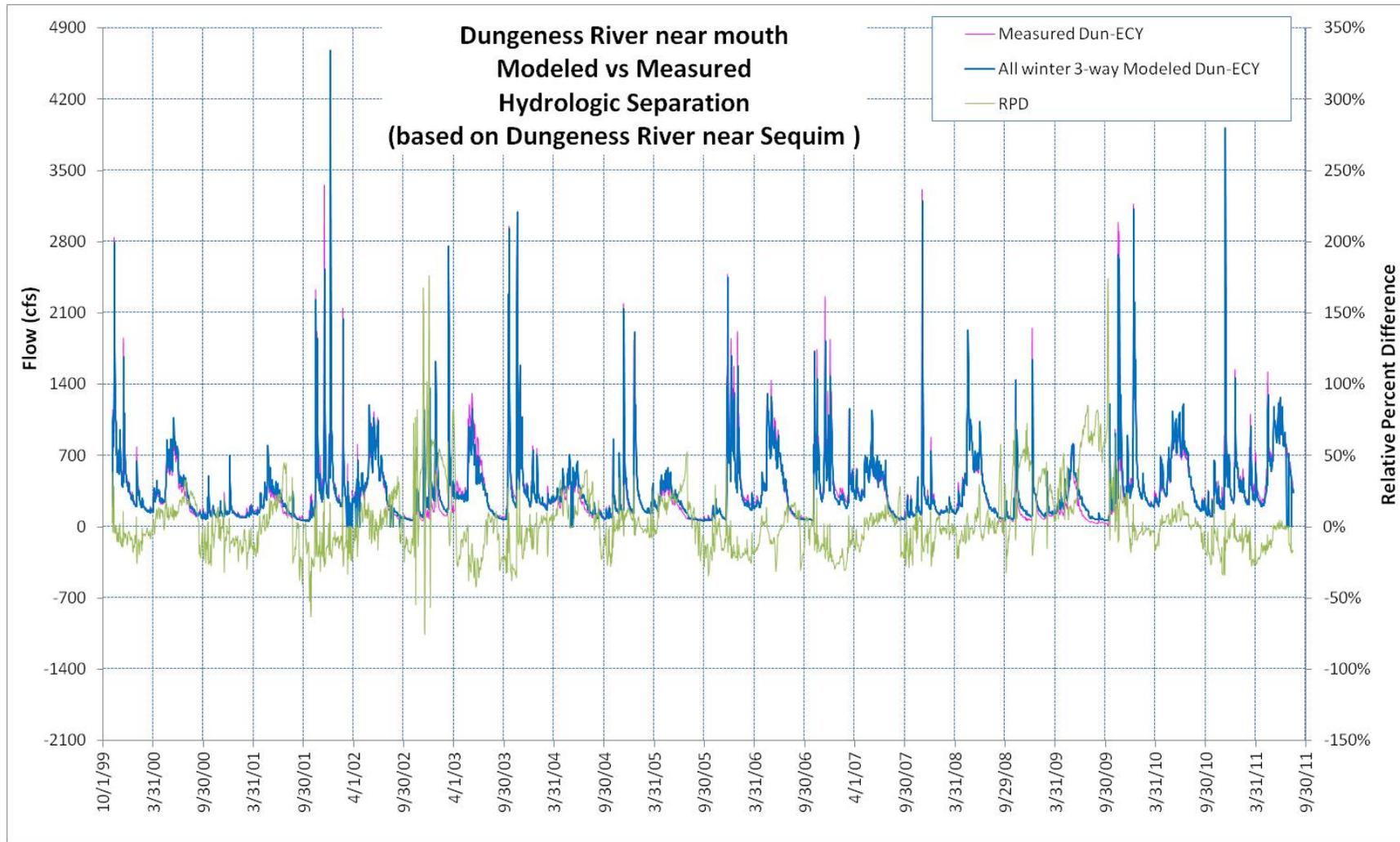
Figure 31. Measured flows at the Ecology "Dungeness River near Mouth" gaging station, and modeled flows based on the USGS "Dungeness River near Sequim" station, with relative percent difference of paired values.
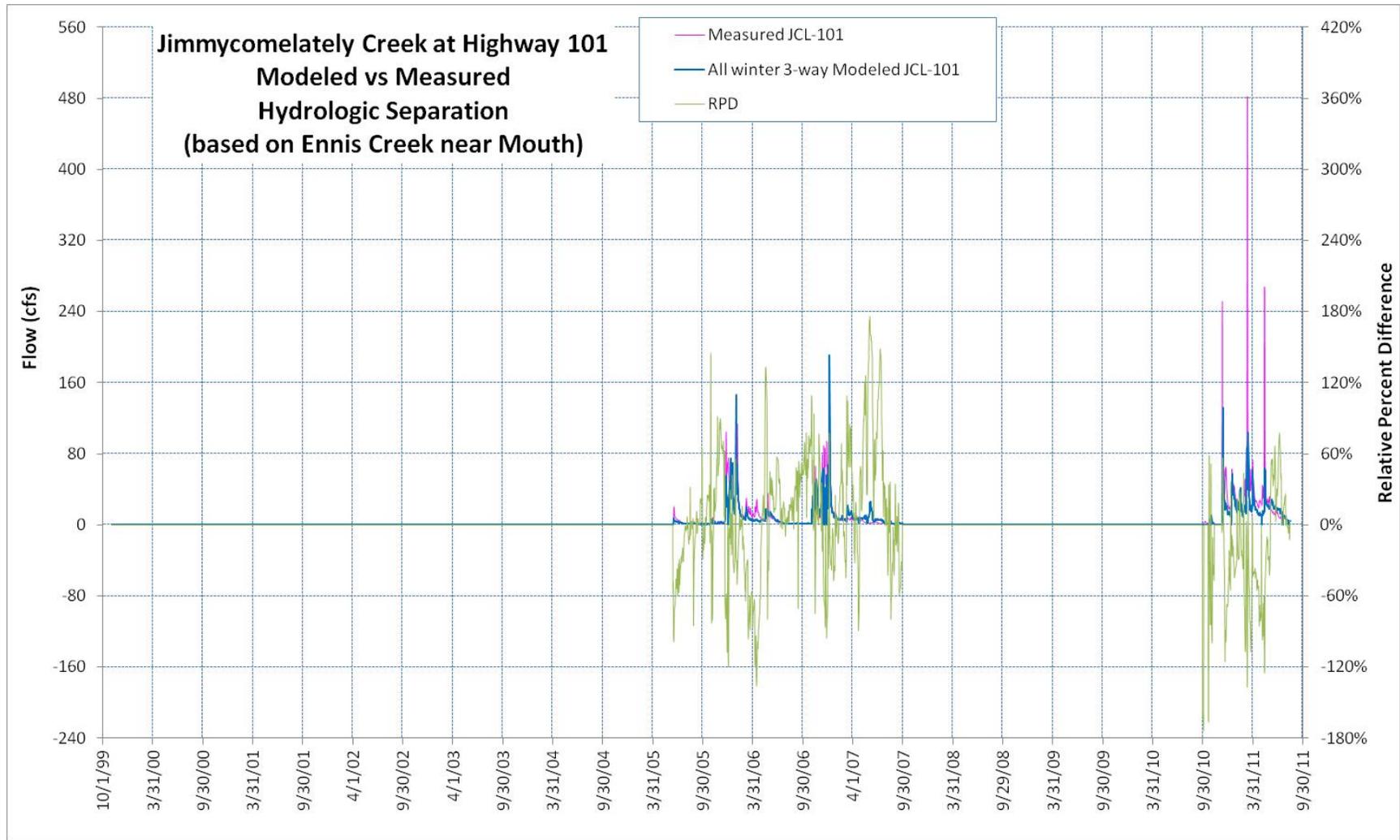
Figure 32. Measured flows at the Ecology "Jimmycomelately Creek at Highway 101" gaging station, and modeled flows based on the Ecology "Ennis Creek near Mouth" station, with relative percent difference of paired values.
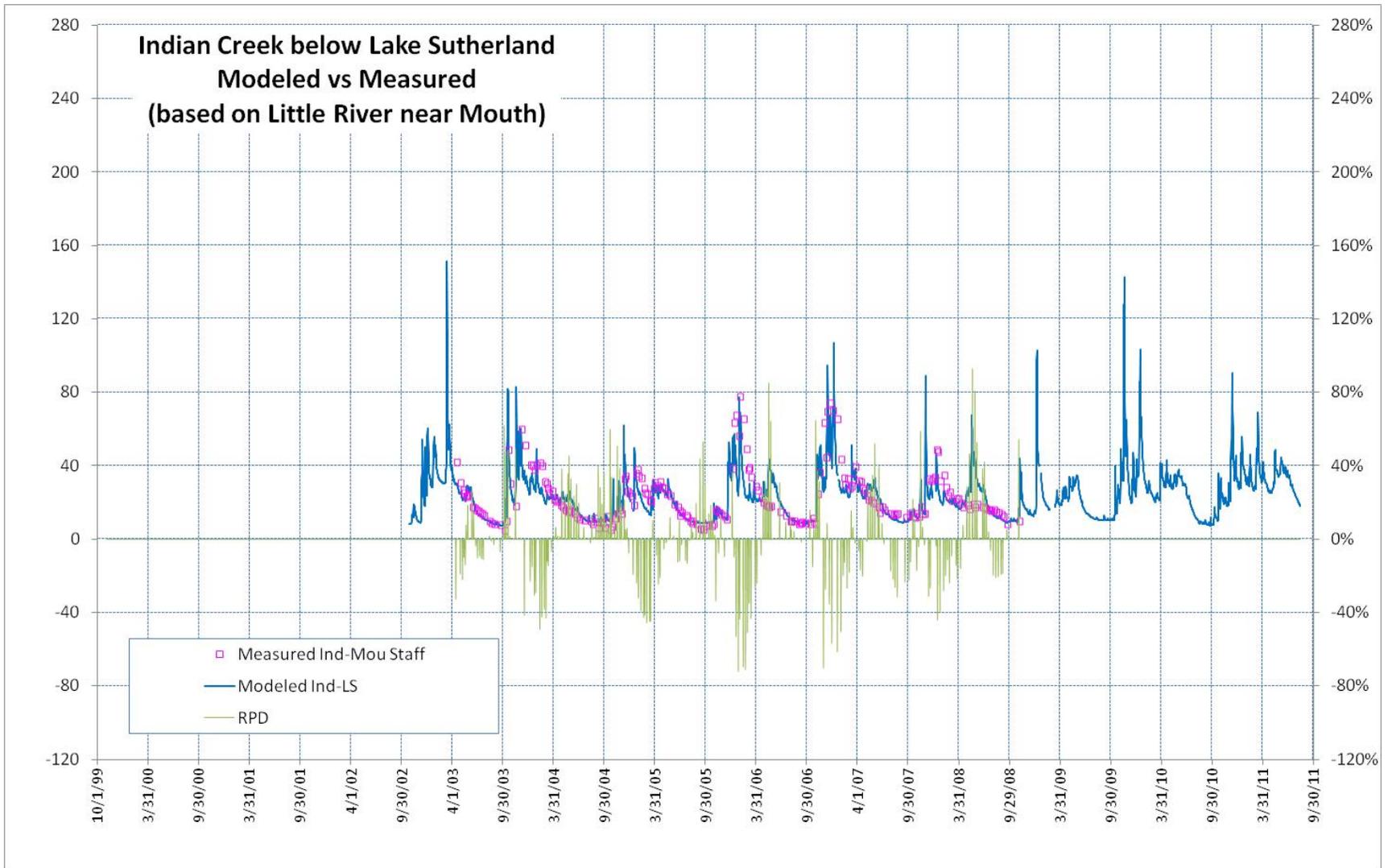
Figure 33. Measured flows at the Ecology "Indian Creek below Lake Sutherland" gaging station, and modeled flows based on the Ecology "Little River near Mouth" station, with relative percent difference of paired values.
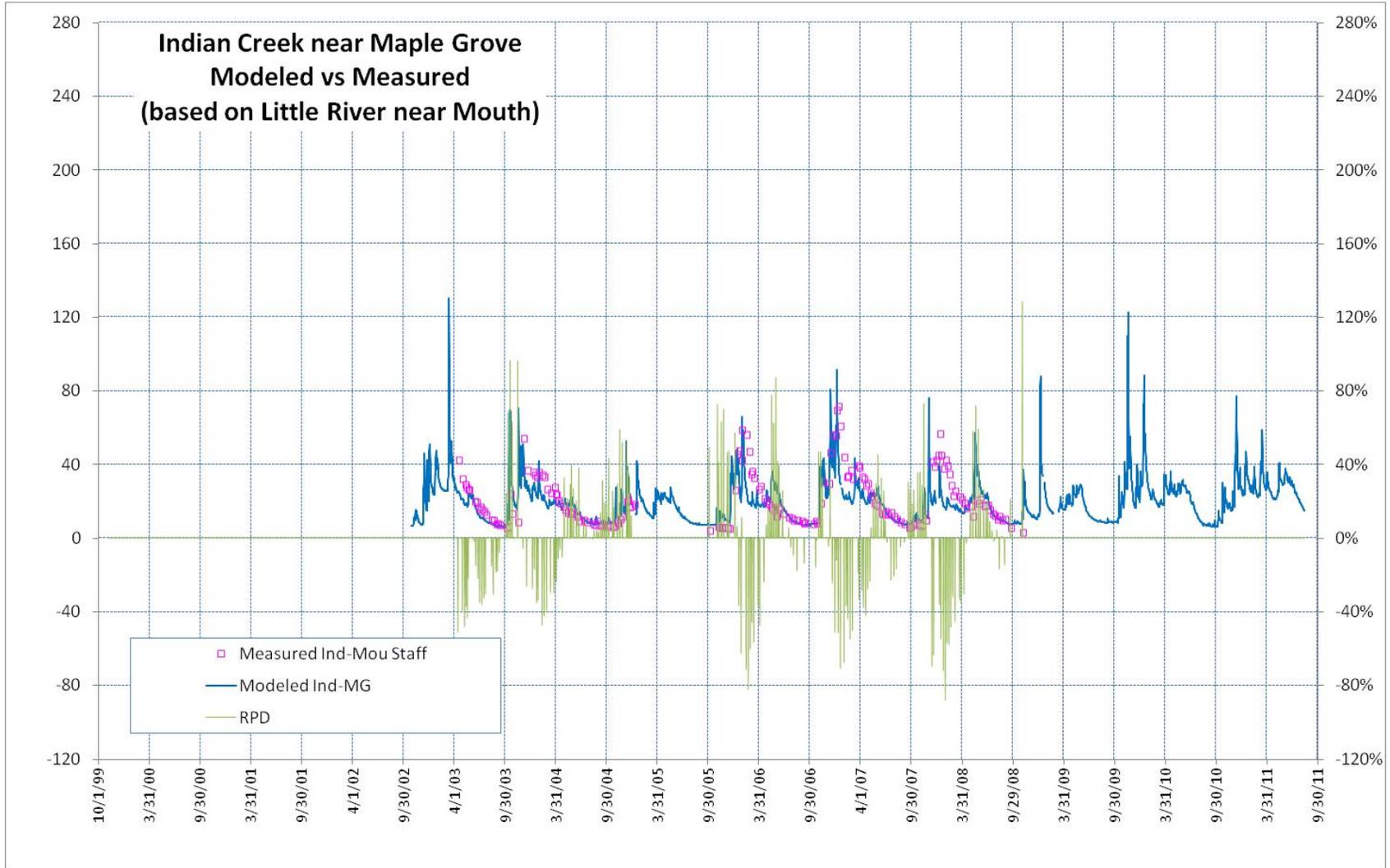
Figure 34. Measured flows at the Ecology "Indian Creek near Maple Grove" gaging station, and modeled flows based on the Ecology "Little River near Mouth" station, with relative percent difference of paired values.

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.

Basin: A geographic area corresponding to a watershed in which all land and water areas drain or flow toward the lower elevation outlet of a central collector such as a stream, river, or lake.

Elwha-Dungeness watershed planning area: The combined areas of WRIA 18 and the Sequim Bay watershed in WRIA 17

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.

Reach: A specific portion or segment of a stream.

Stage height: Water-surface elevation above a gage datum, sometimes referred to as gage height.

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

Study area: The study area for this project is the Elwha-Dungeness watershed planning area.

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

Watershed: The geographic area from which all land and water areas drain or flow toward the lower elevation outlet of a central collector such as a stream, river, or lake. Sometimes referred to as the drainage basin.

WRIA 17: Water Resource Inventory Area 17, which includes the Sequim Bay and Discovery Bay watersheds and other tributaries to the Strait of Juan de Fuca, Admiralty Inlet, and northern Hood Canal.

WRIA 18: Water Resource Inventory Area 18, which includes the Elwha River and Dungeness River watersheds (basin) and other neighboring tributaries to the Strait of Juan de Fuca.

Acronyms and Abbreviations

%RSD	Percent relative standard deviation
AP	Airport
cfs	Cubic feet per second
Deg	Degrees
DRMT	Dungeness River Management Team
Ecology	Washington State Department of Ecology
EMMT	Elwha-Morse Management Team
F	Fahrenheit, a unit of temperature
ID	Identification Code
Min	Minutes
n	Number of values
NF	National Forest
No.	Number
r^2	Coefficient of determination
RCW	Revised Code of Washington
RPD	Relative percent difference
RSD	Relative standard deviation
Sec	Seconds
SNOTEL	Snowpack Telemetry system, U.S. Department of Agriculture
SWE	Snow water equivalent
U.S.	United States
USFS	United States Forest Service
USGS	United States Geological Survey
W	West
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WY	(See Glossary above)